Grid Impacts of Variable Generation at High Penetration Levels

Dr. Lawrence Jones
Vice President
Regulatory Affairs, Policy & Industry Relations
Alstom Grid, North America

ESMAP Training Program
The World Bank Group
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Outline

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Introduction to Grid Integration Issues

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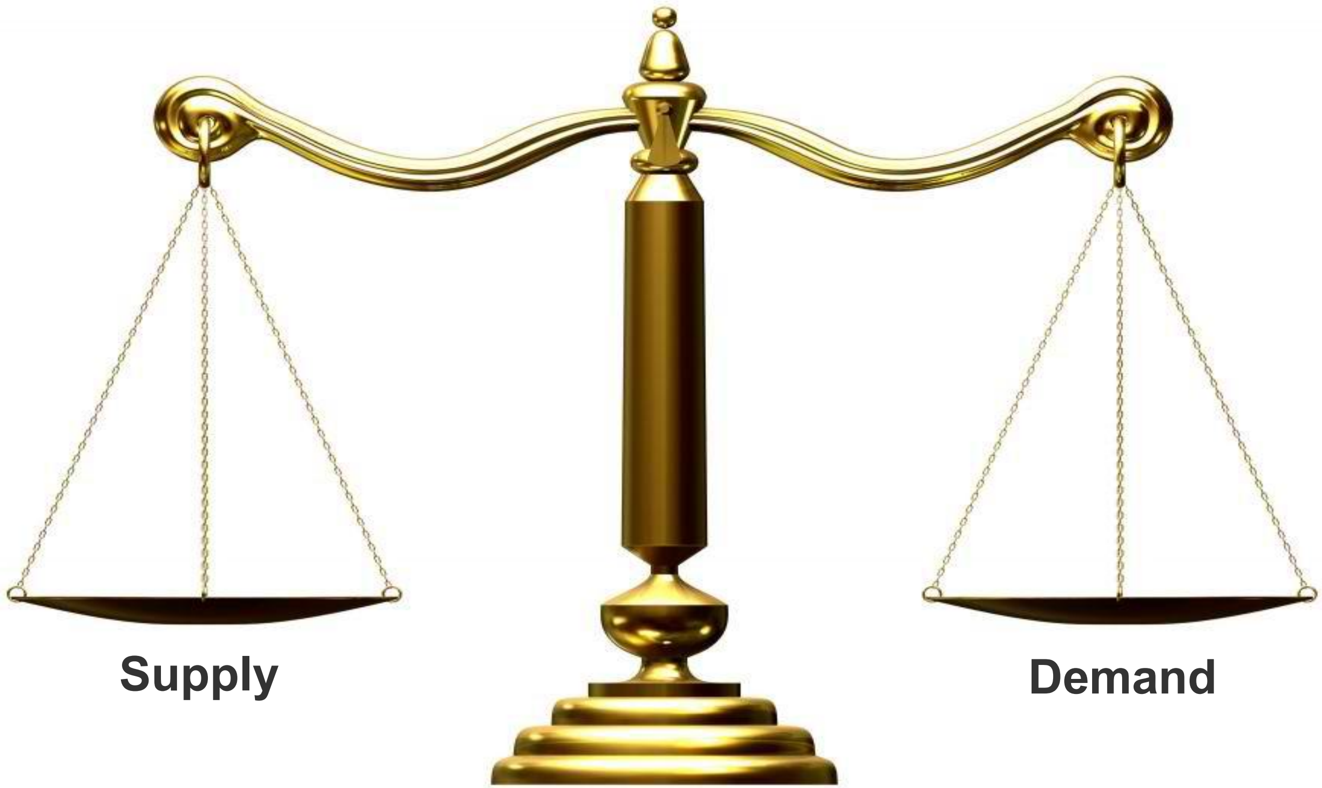
Power System Operation



*Maintaining the **Balance** between Supply and Demand*

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Key Grid Operation Issues

Stability	Variability
Balancing	Uncertainty
Adequacy	Net Load

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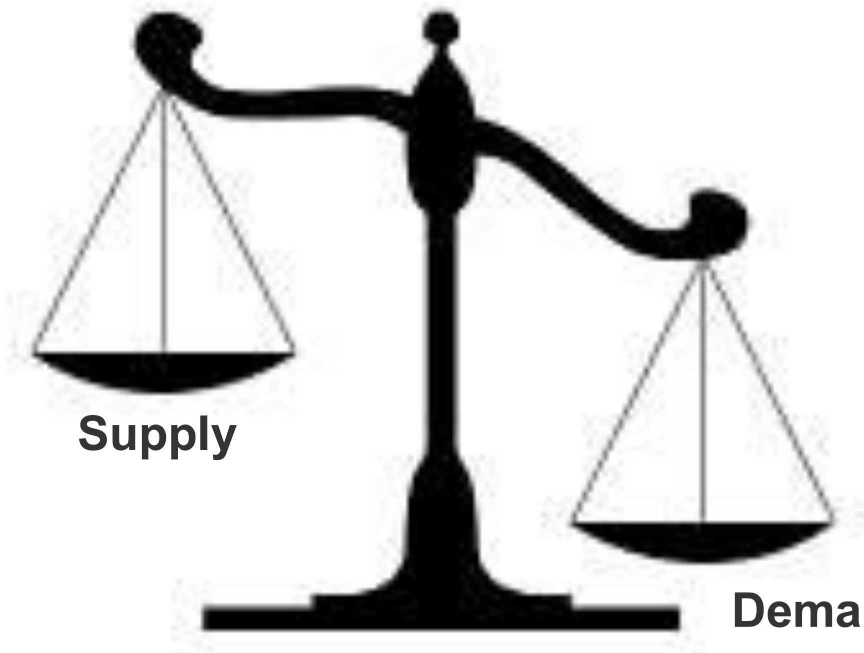
Two Common Characteristics of all Power Systems: ***Variability and Uncertainty***



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Balancing Challenge - Simultaneous Variation of Generation and Load, Subject to Uncertainty

Variability

- Load varies by seconds, minutes, hours, by day, weather etc
- Variable generation vary based on fuel availability
- Dispatchable generation may not be available

Uncertainty

- System operational decision is made by using the best available forecasts (load, generation, etc)
- Forecast error is common – there is no perfect forecast
- Dispatchable resources may deviate from scheduled set points

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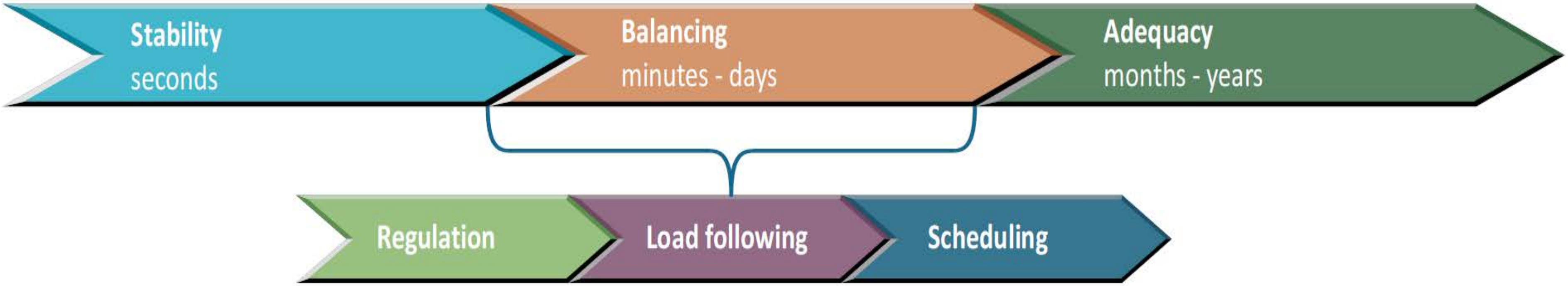
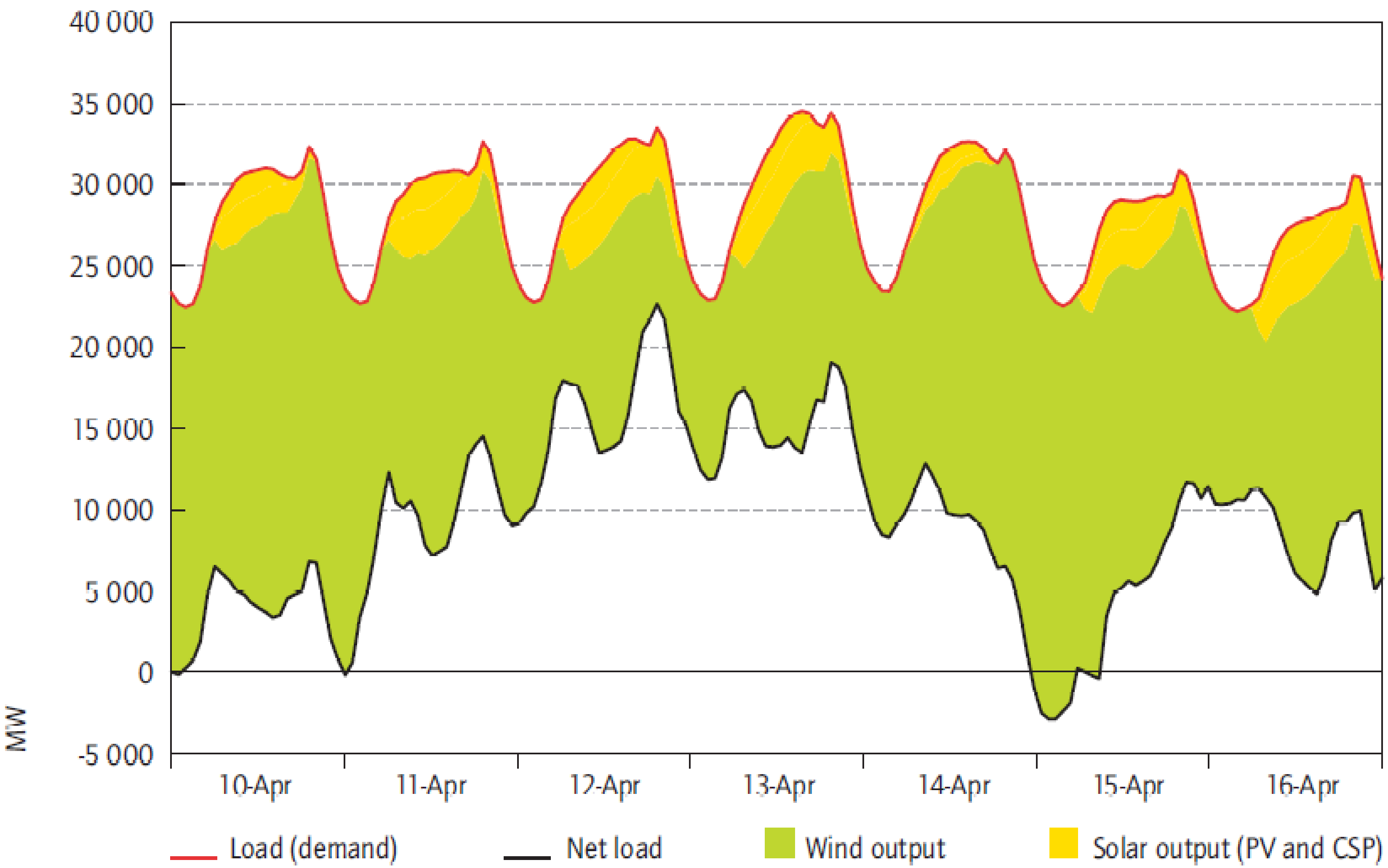
Power System Operations – Time Frames Matter



	Response time	Duration
Regulation	~ 1 minute	10 minutes
Load-following	~10 to 30 minute	1 hr
Scheduling	~ 1 day	6 hrs

Source: Ref. 1

Variability in Demand and ***Net Load***



Source: WWIS, NREL, 2010

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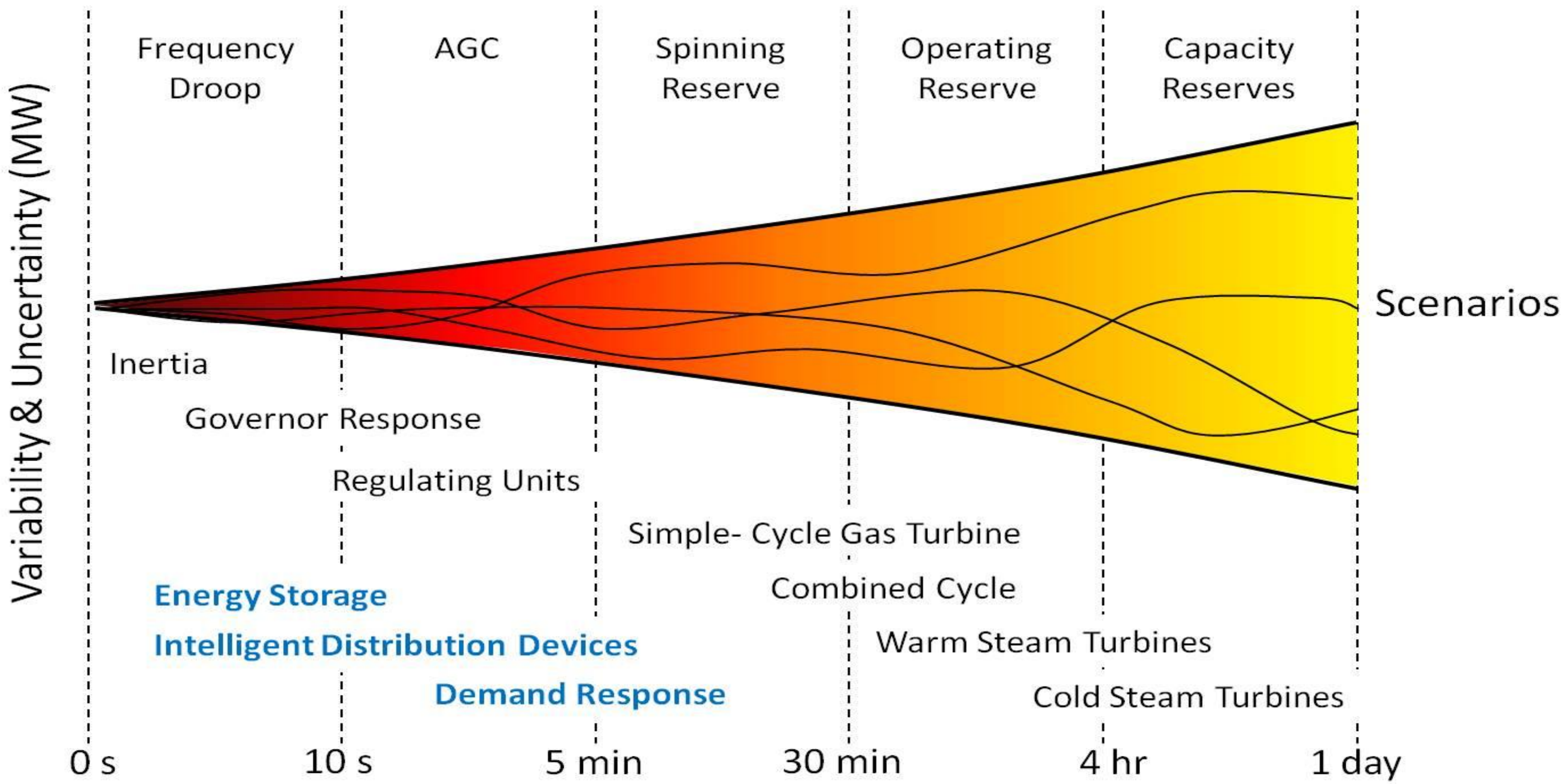
Interaction of Variable Generation with Power Grid Operations - Time Scales Matter



Graphic Illustration – Courtesy of Russ Philbrick . See Ref. 2

Impacts of Variable Generation on Grid Operations

- Procuring the flexible resources necessary to cope with increased system variability
- Managing congestion
- Forecasting to cope with ramp events.
- Efficient electricity markets
- Determining adequate operating reserves and transmission capacity
- Unit commitment and economic dispatch that takes into account the transmission network
- Managing new operational constraints, e.g., inertia, fault currents, unusual power flow limit
- Controlling system voltages
- Maintaining dynamic performance – Transient and Small signal stability (voltage, frequency and rotor angle)

Four Coupled Dimensions of Integrating Variable Generation

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Four Dimensions of Integration

Physics

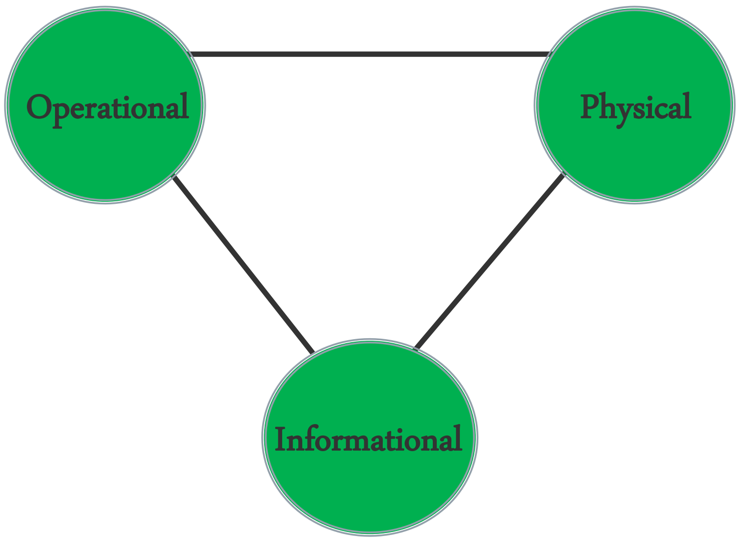
Operation

Variable Generation Integration

Economics

Information

Physical, Operational, and Informational



- Physical
  - How wind and solar plants are connected to the T&D grids
- Operational
  - Considers the system conditions and performance goals, and also operational requirements and guidelines for the physical grid and electricity markets
- Informational
  - How information is managed and used by assets and human operators

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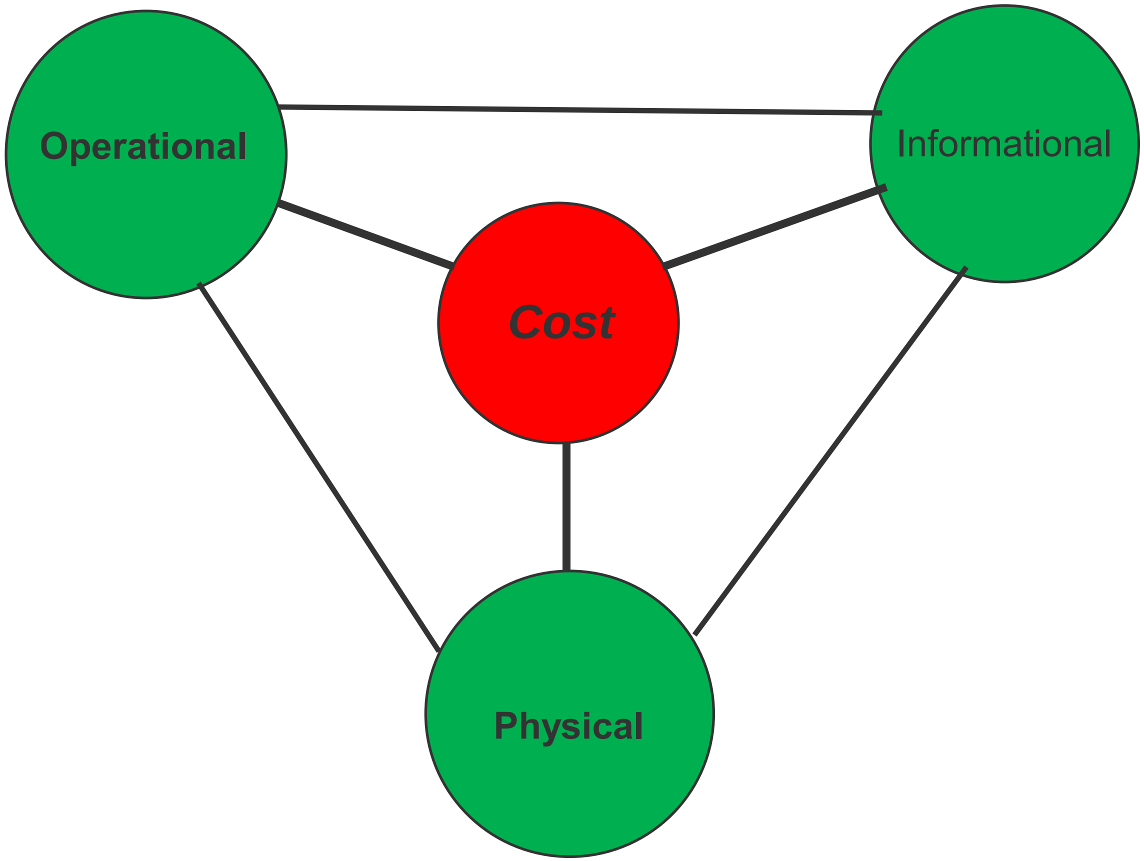
What is the cost of balancing power systems with high penetration of variable generation?



Perform operational impact studies accounting for various costs factors

Highlights from Global Study of Variable Generation Integration

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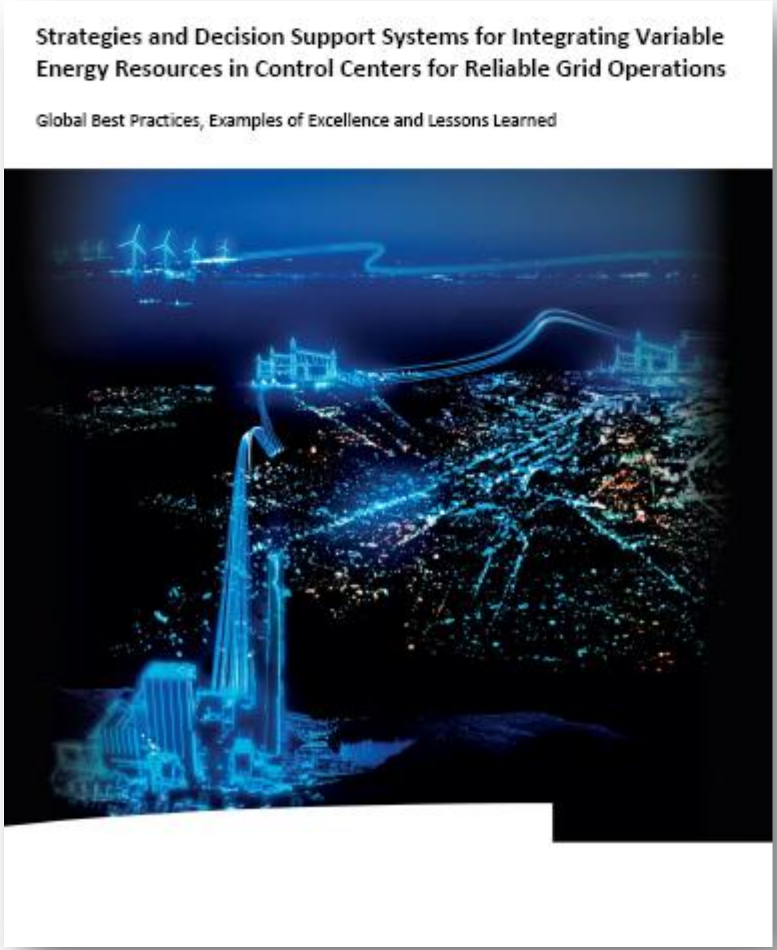
Global Survey on Variable Generation Integration

- DoE‟s goals for this ground-breaking global research project were to establish a central source for information on:
  - Wind integration trends
  - Global best practices
  - Examples of excellence
  - Lessons learned
  - Recommendations for tomorrow



Available at: http://energy.gov/articles/new-report-integrating-variable-wind-energy-grid.

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Three Complimentary Research Methods

Questionnaire for Grid Operators

6 In-Depth Control Center Visits

Survey of Existing Literature

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Unprecedented Gathering of Global Data

Power Grids represented in this survey account for ***72% of worldwide wind capacity***

- **33** grid operators
- **18** countries
- Combined wind generation of **141 GW**

Source: Ref. 2

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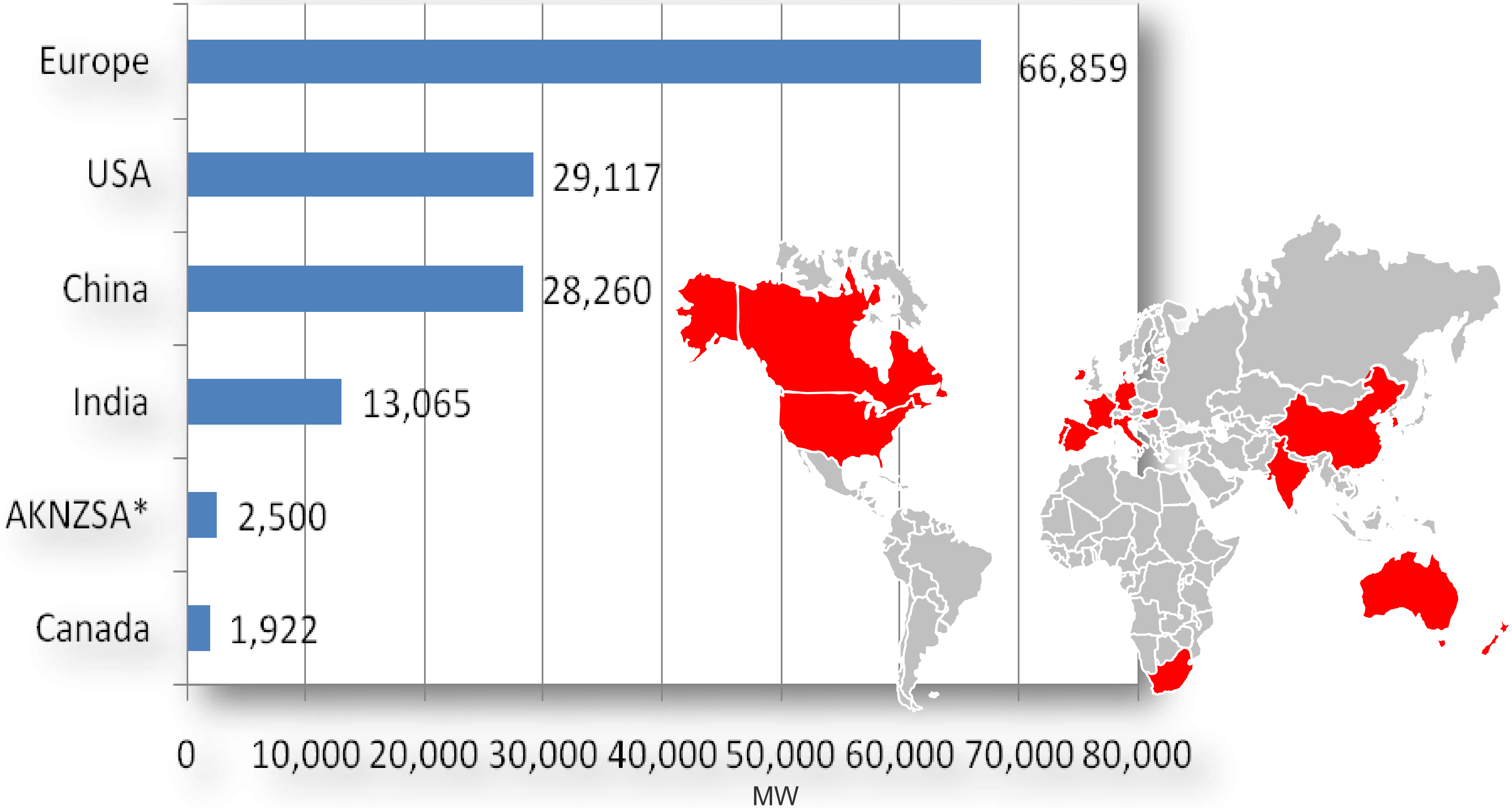
Wind Generation Capacity Distribution by Country & Region



**AKNZSA: Australia, Korea, New Zealand, South Africa*

Source: Ref. 2

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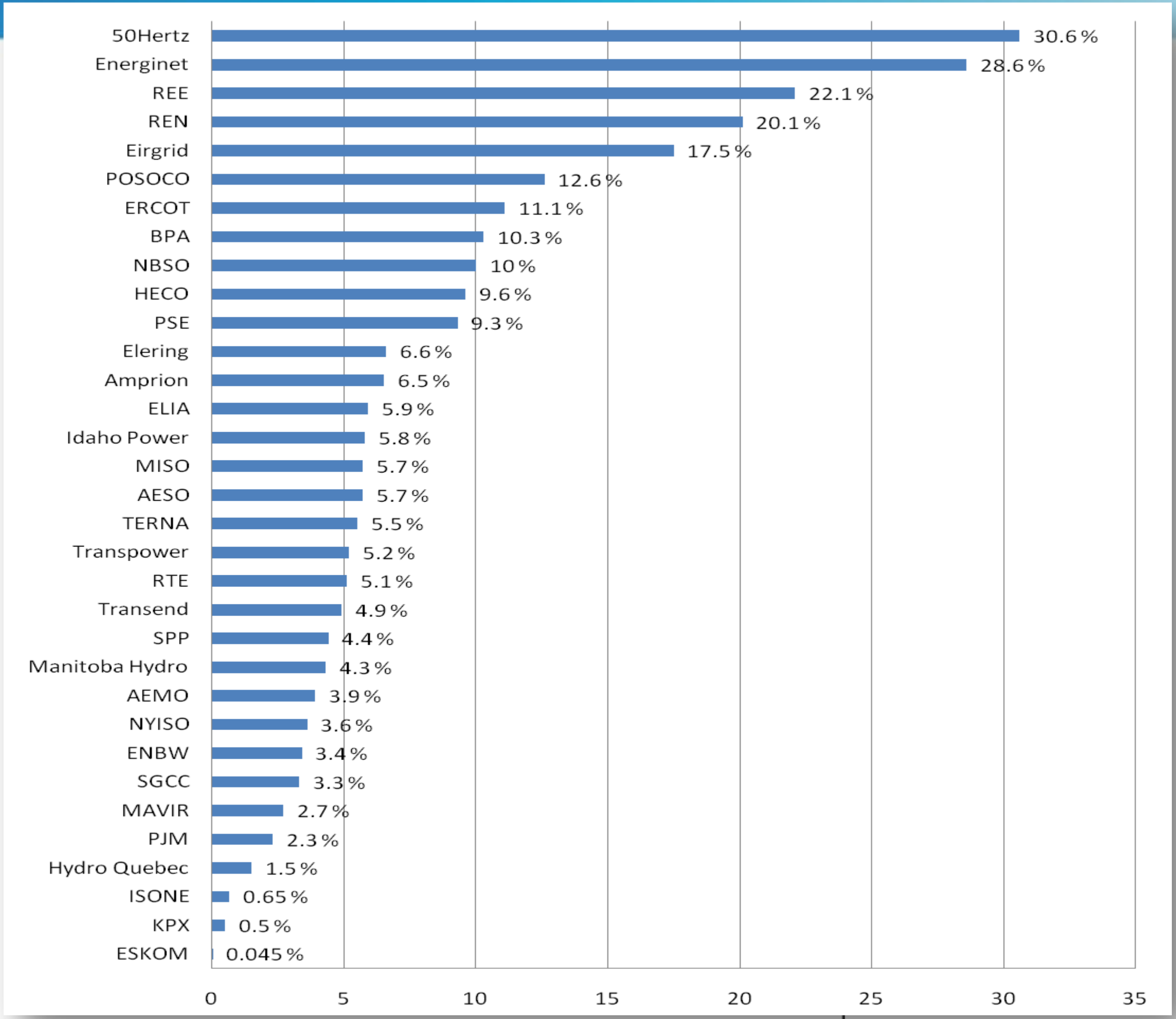
Wind Generation Capacity Penetration Level

- Large operators do not necessarily have the most experience with wind
- Smaller operators with higher penetration have valuable insights



Source: Ref. 2

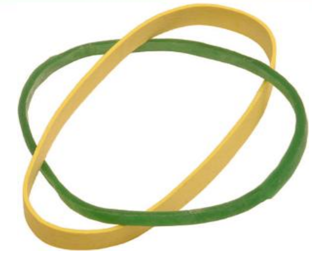
Five Elements for Successful Variable Generation Integration

1. **Accurate Forecasting**

2. **Decision Support**

3. **Policy/Regulation**

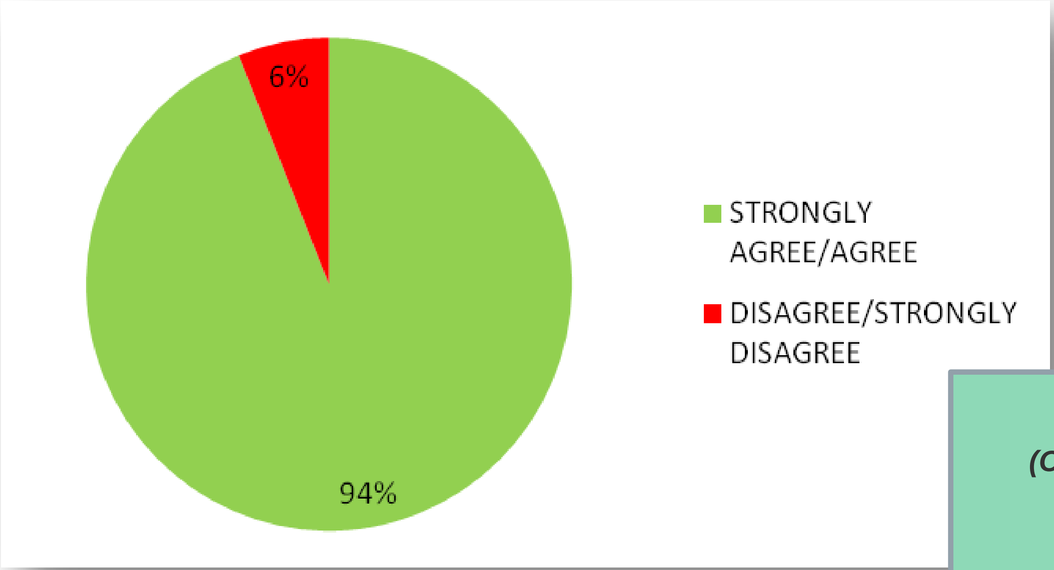
4. **Flexibility**



5. **Workforce**

Source: Ref. 2

Forecasting is Vital to Successful Integration



Key Forecasting Tools

(Cited by at Least 40% of Respondents)

Next-Hour Forecast
Ramp Forecasting
Ensemble Forecast
Weather Situational Awareness
Ramp Risk Forecast
Short-Term Forecast

The need for short-term forecast (5-10 minutes) will be increasingly important as wind penetration increases

Source: Ref. 2

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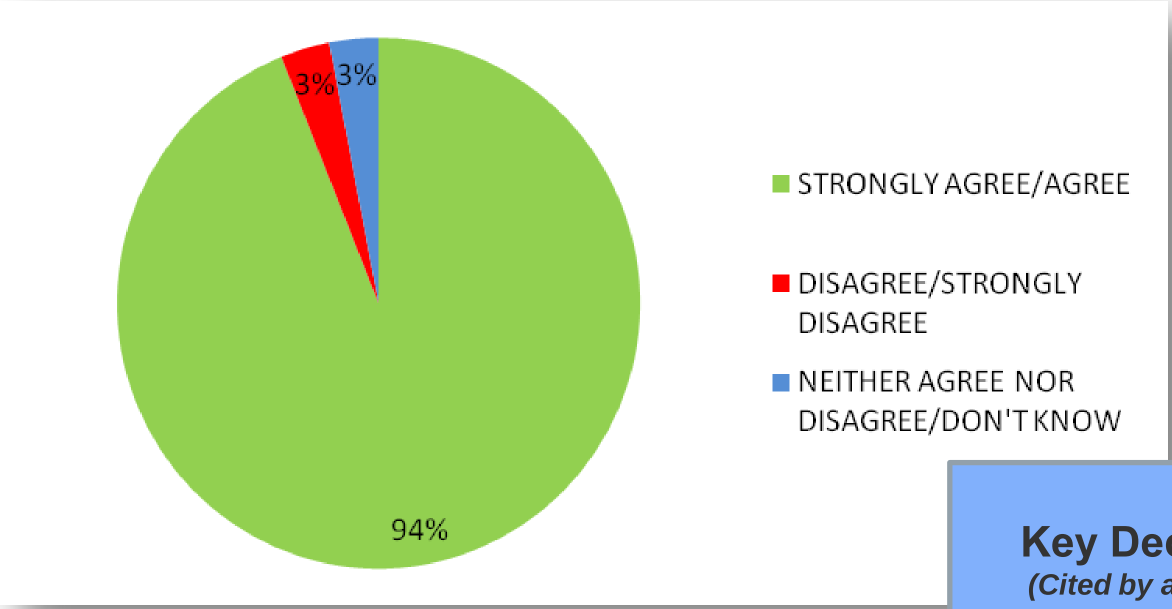
Decision Support Systems Are Essential



Key Decision Support Tools

(Cited by at Least 50% of Respondents)

Voltage Stability Analysis
Optimal Power Flow with Wind Forecast
Transients Stability Analysis
Optimization-Based Transmission Planning

Forecast and uncertainty information must be incorporated into real-time decision support systems and planning tools

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Strategies, Solutions and Decision Support Systems

- The role of system flexibility
- Advanced transmission and distribution systems applications
- Market design and mechanisms
- Demand response

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System Flexibility

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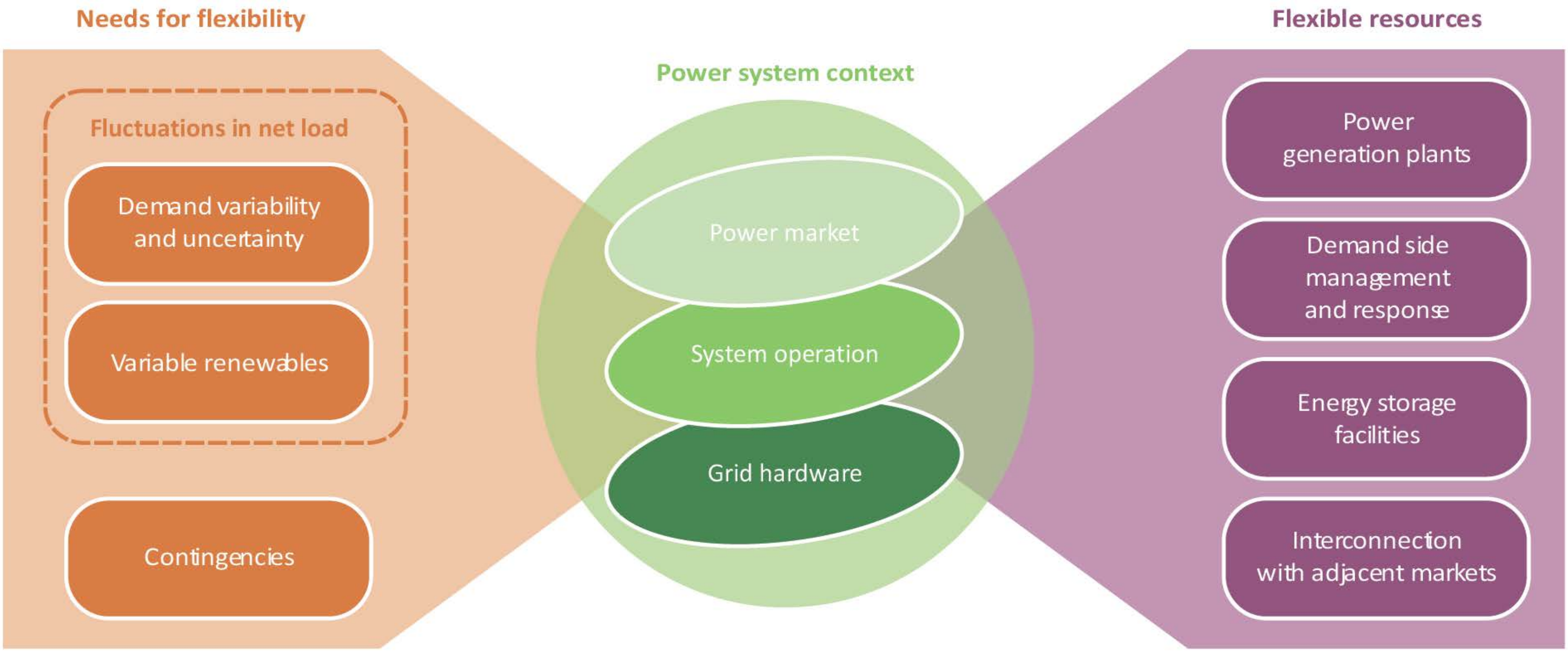
Power System Flexibility

Power system flexibility expresses the extent to which a power system can increase/decrease electricity production or consumption in response to variability, expected or otherwise.

Flexibility Needs and Resources



Existing and new flexibility needs can be met by a range of resources in the electricity system – facilitated by power system markets, operation and hardware.

Source: Ref. 1

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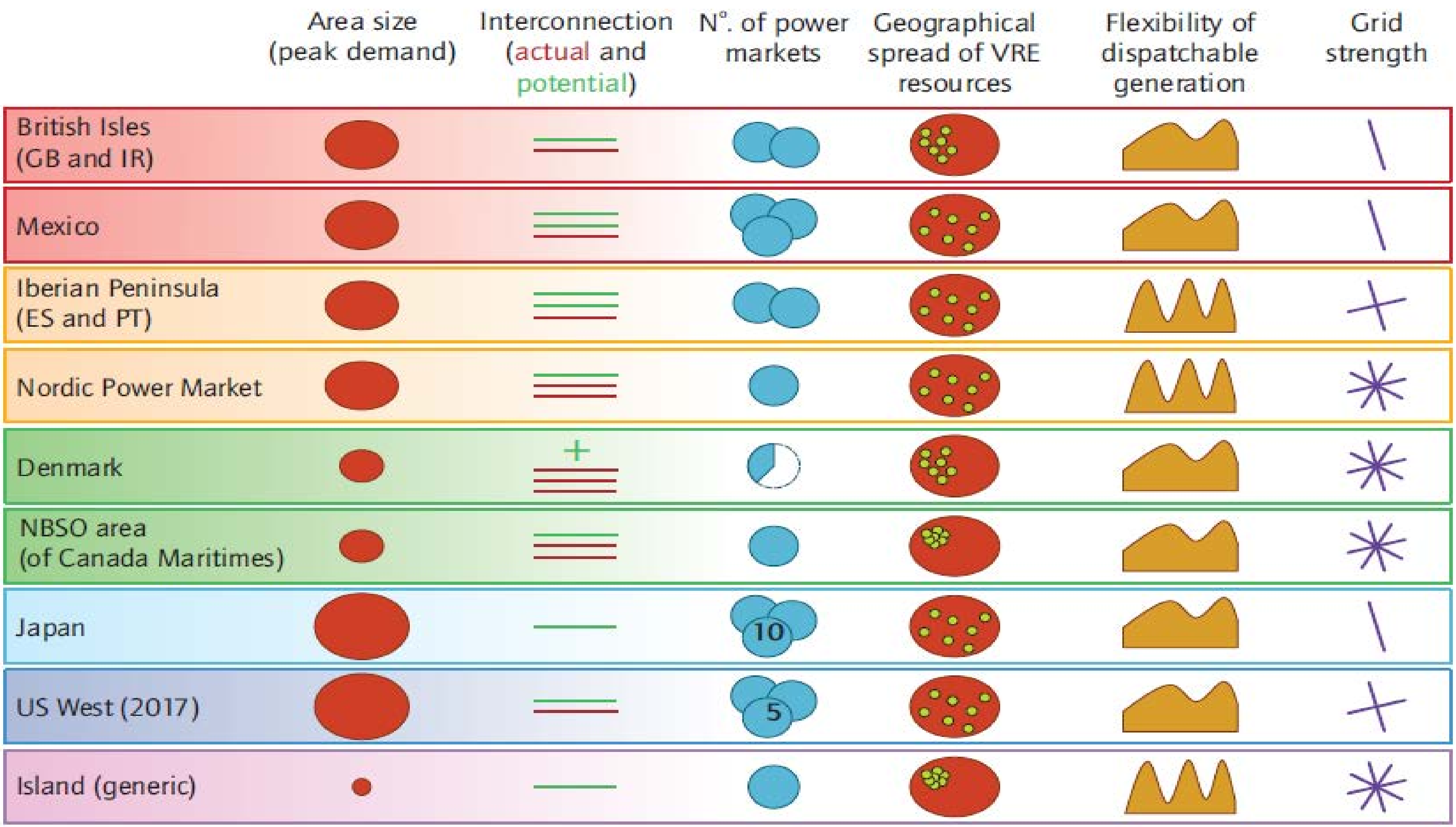
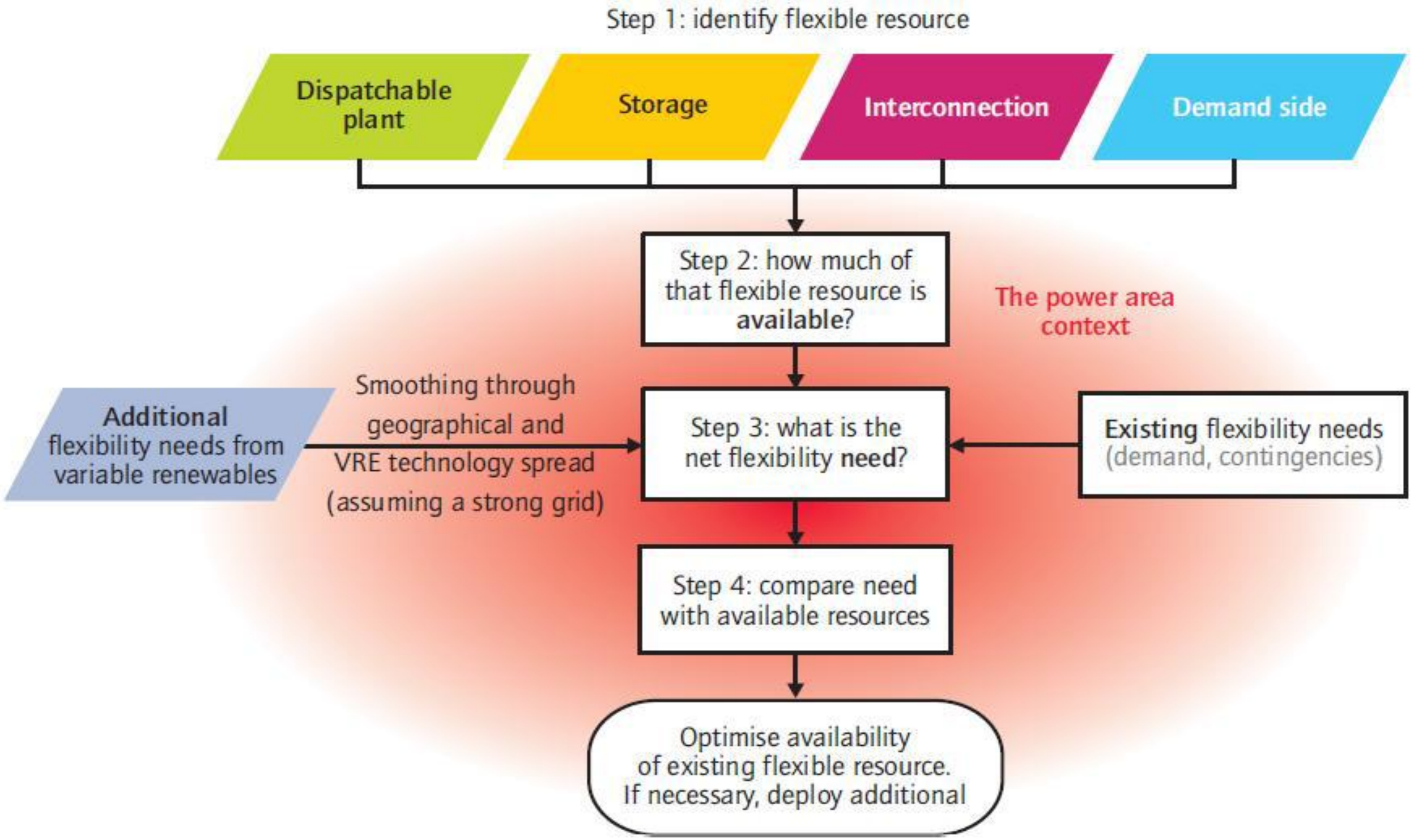
Understanding the Unique System Attributes that Affect Flexibility



Source: Ref. 1, Case Studies

Flexibility Assessment Method (FAST) – IEA Method to Identify a Power System‟s Balancing Capacity



Source: Ref.1

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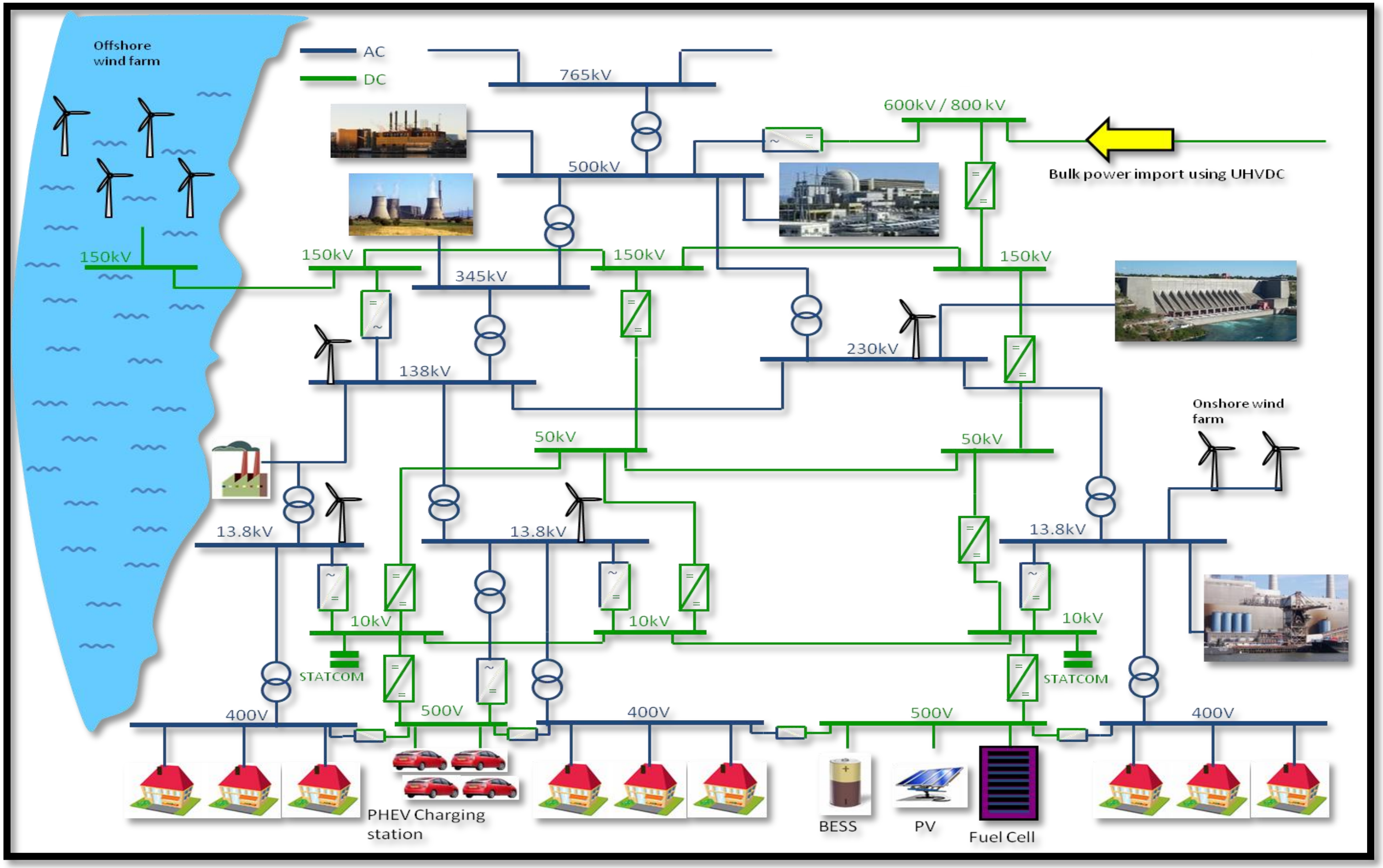
Smarter T&D Electricity Grids Increase Flexibility



Source: Ref. 2

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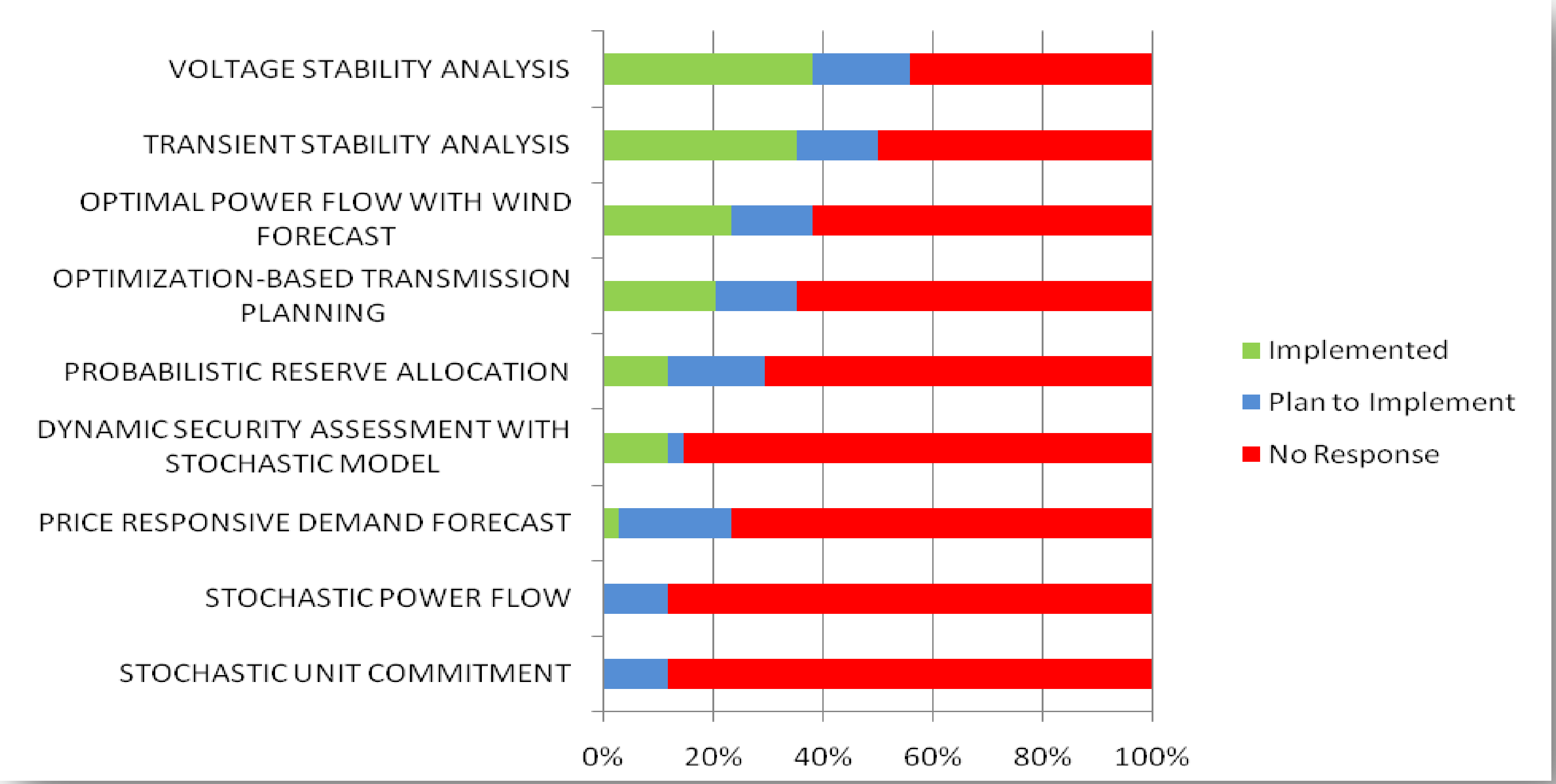
Advanced Transmission and Distribution Systems Applications

Implement Advanced Decision Support Systems to Support Wind Integration



Grid operators are at different stages of deploying advanced decision support tools in control center

Source: Ref. 2

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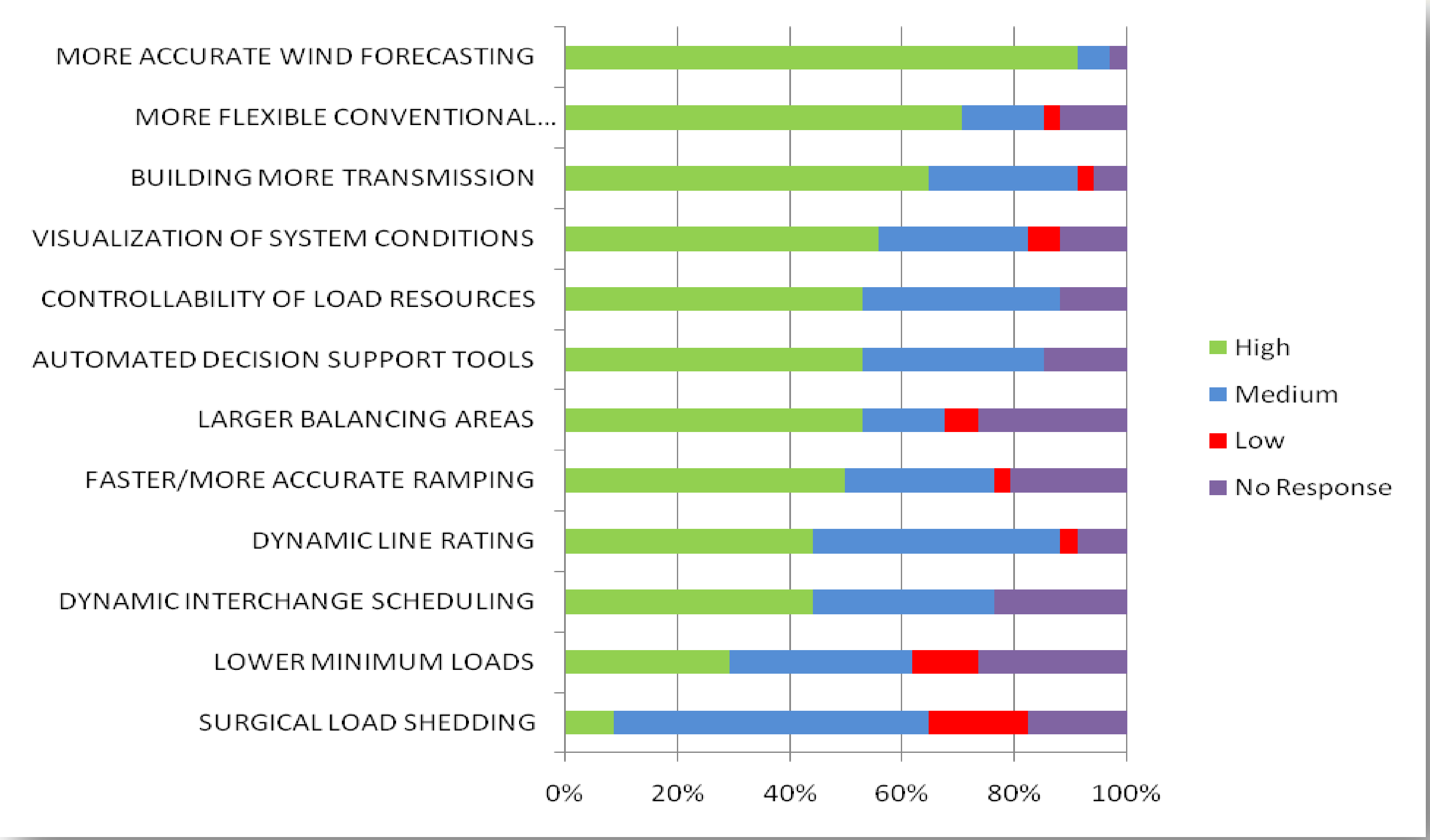
Importance of Processes, Policies, and Procedures



Source: Ref. 2

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Managing and Mitigating Operational Uncertainty

Inputs:
- Numerical Weather Prediction
- Wind / Solar Description & Location
- Historical Met & Power Data
- Future Availability & Outages
- Load Forecast

Renewable Forecast Management

Real Time Control
- Network security (current and look ahead)
- Load-following power balancing
- Wind Generation Monitoring and control
- Reserve Monitoring
- Real time curtailment
- Archiving

Day Ahead UC & Dispatch
- Market or Regulated env
- Wind Integration Policies
- Reserve Adequacy

Studies & Outage Evaluation
- Steady State
- Dynamic Stability
- Look-ahead
- What-if scenarios
- Transmission Planning
- Generation Adequacy

Simulation
- Operator Training
- Realistic wind simulation
- Scenario creation
- Event replay

Performance Analysis & Reporting
- Centralized forecast
- Public publishing
- Market participants
- Wind plant operators
- Researchers

Bridging the gap between Forecast and Operations

Source: Alstom Grid

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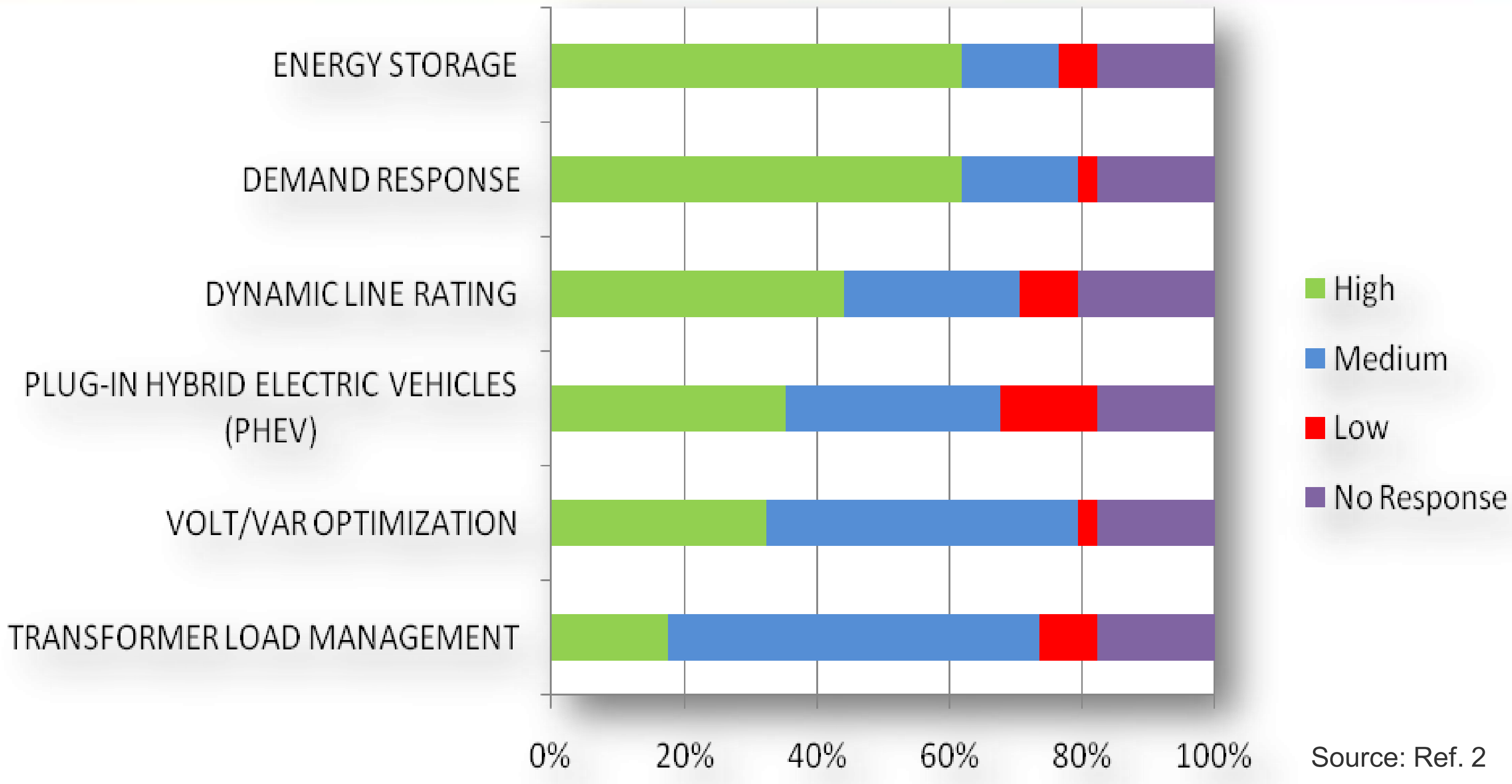
Deploy Smarter Technologies and Applications



Source: Ref. 2

Integration of smart applications with wind power forecast improves real-time operations, but some smart technologies must become more efficient and cost competitive for benefits to be fully-realized.

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Market Design and Mechanisms

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Market Design and Mechanisms

- Market should be designed to support the frequent scheduling (e.g., sub-hourly) and dispatching of generation and transmission resources.
- Ancillary services markets (e.g., efficient procurement of more flexible resources).
- Greater coupling and harmonization between national and regional electricity markets (e.g., reserve sharing and transmission scheduling).
- Congestion management
- Regulatory policies should be designed and implemented to support the development of multi-regional markets for ancillary services and reserves..

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Demand Response

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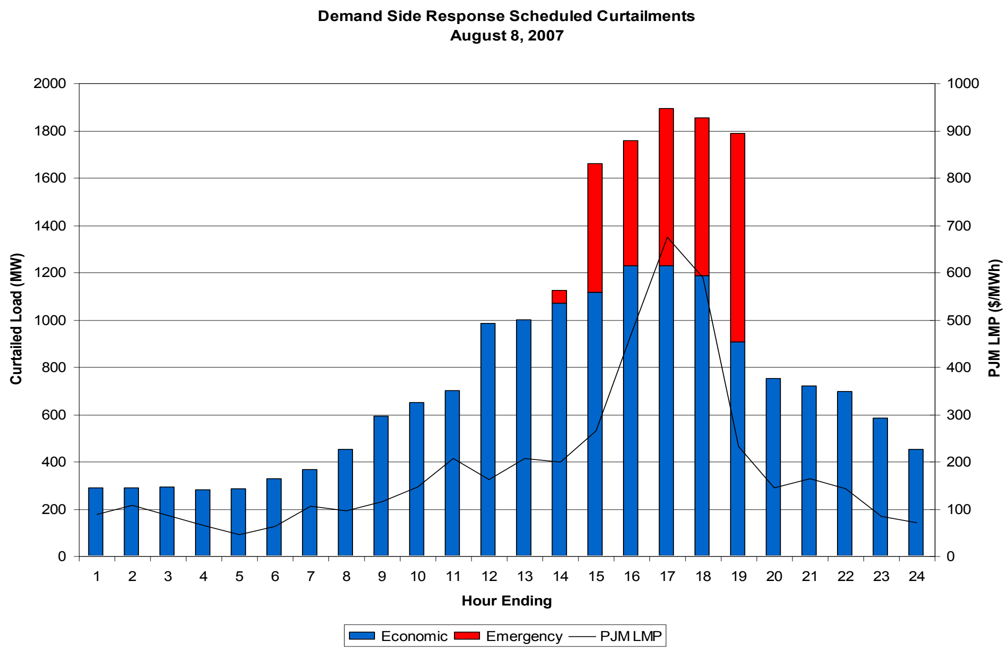
Demand Response (DR): A Smart Grid Technology

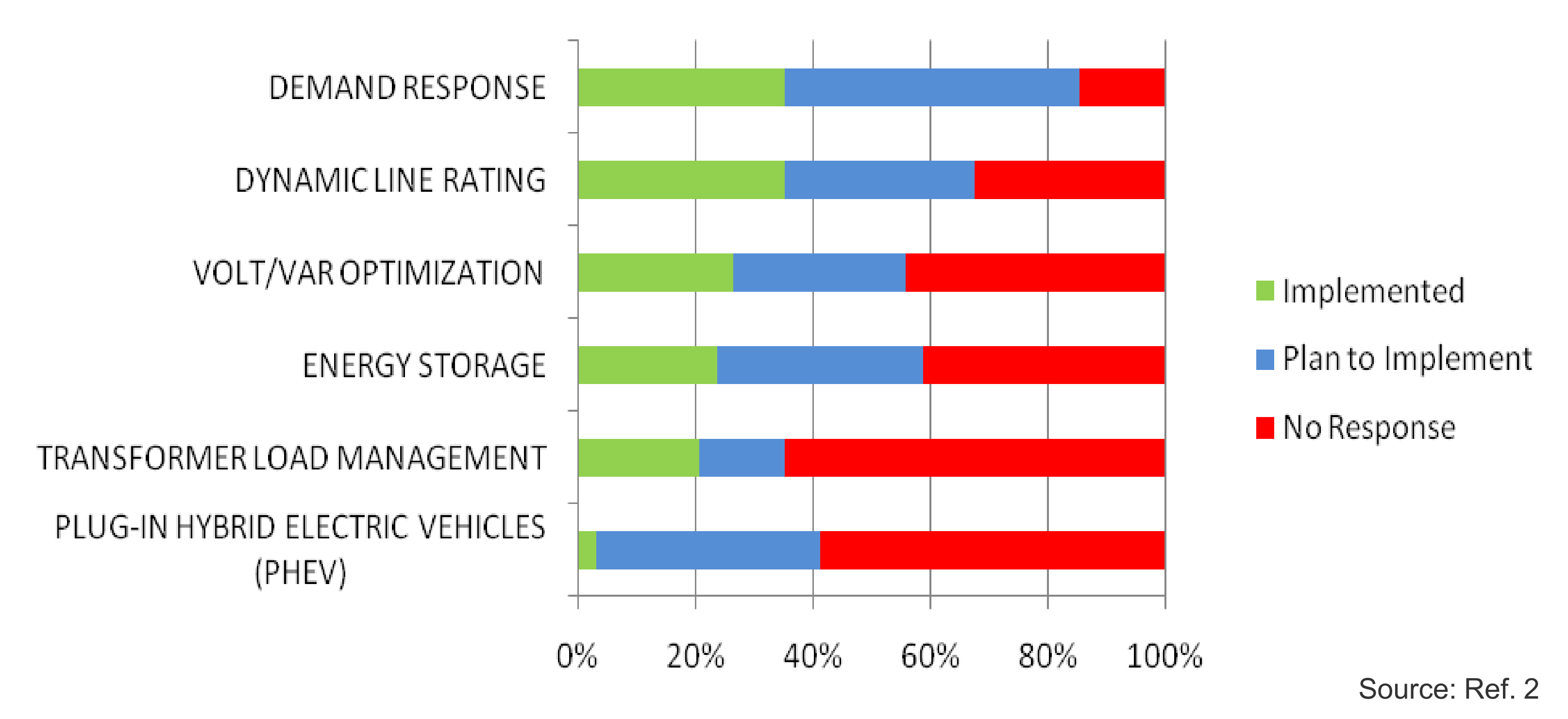
A basic concept – utilities provide incentives to electricity customers to reduce their consumption during periods of peak demand.

- To address the challenge of peak demand, utilities typically bring new generation assets online, known as "peaker plants."
- Demand response offers a faster and cheaper alternative to peak generation.
- Utilities, grid operators, and end users all have incentives to adopt demand response.



Demand Response Event → **Notify** → **Curtail** → **Verify** → **Restore**

Smart Applications Currently Implemented or Will be Implemented



Respondents who have implemented DR programs are in systems with competitive electricity markets, and Storage has huge growth potential

Source: Ref. 2

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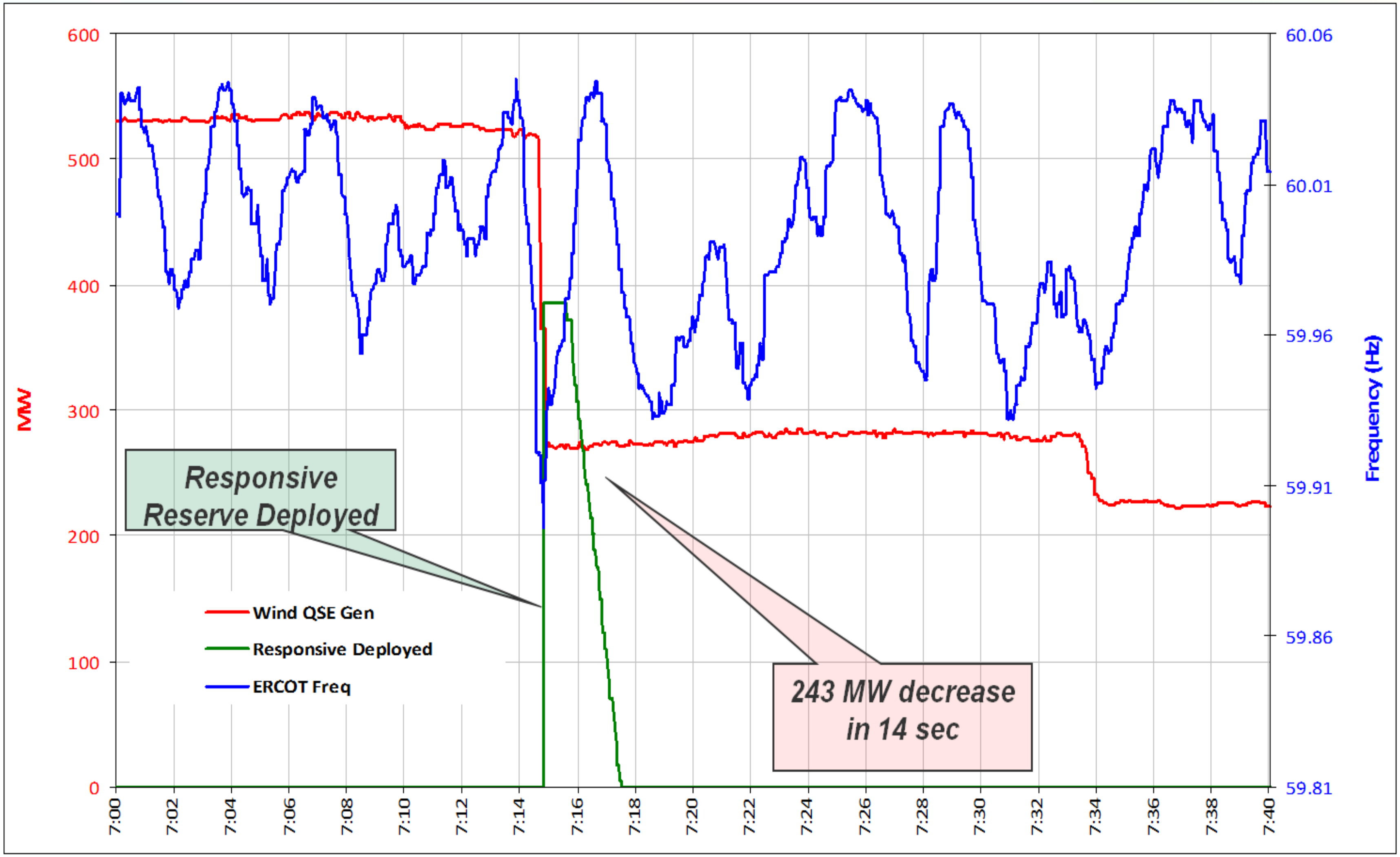
Instantaneous Wind Ramp in ERCOT on February 28, 2008



Source: Presentation by John Dumas, ERCOT

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Conclusions

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Conclusion (1)

More and more grid operators are interested in applying industry best practices and examples of excellence as the starting point for deploying their own decision support systems built specifically to address wind energy integration at the control center level.

Conclusion (2)

Efficient integration of wind and solar energy requires grid operators to have access to a proper mix of flexible resources ranging on the supply-side, delivery-side and demand-side.

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References

1. International Energy Agency. *Harnessing Variable Renewables: A Guide to the Balancing Challenging*, 2011. www.iea.org/publications

2. Lawrence E. Jones, *Strategies and Decision Support Systems for Integrating Variable Energy Resources in Control Centers for Reliable Grid Operations.* 2011. Download at: http://energy.gov/articles/new-report-integrating-variable-wind-energy-grid.

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Thank You

Dr. Lawrence Jones
Alstom Grid
+1 (425) 241 0649
lawrence.jones@alstom.com

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