Reliability and Flexibility for Carbon Neutral Central, West and East Asia – Sub-session - Dialogue with Champions:

07 June 2024 | 16:00 to 17:20 (GMT+8)
Agenda

- **Smart Grids at a Glance**
  - How Smart Grids Help Grid Reliability and Resiliency
  - Selected Use Cases – Country Examples
  - Recommendations for Central Asia Power System
  - Extra Slides for Smart Grid Components’ Contributions to Power System Flexibility
Smart Grids Mega Trends

Current Energy System

- Centralized Generation
- Centralized Control (TSO)
- Generation Follows Demand
- Well Established Demand Forecasts
- Well Defined Communication

Worldwide Megatrends

- More Technologies, More Constraints
- Increased Data Volume and Faster – Security?
- Demand-Supply Balancing in Realtime
- Complex Projections + flexible Optimization
- New Techniques (Cloud, In-Memory, SaaS)

- Multi-Purpose Energy Infrastructure
- Demand Follows Generation
- Digitalization of all Living Areas
- Decentralised Smartness
- Volatile Generation + Stochast. Demands
Smart Grids Definition

Integration of theoretically infinite number of generators, transmission and distribution grids, storage systems and prosumers over information and communication technology (Definition Smart Grids as a combination of all energy carriers)

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\text{ICT} \\
\text{Smart Grids} = \int \left( \text{Conventional Generation} + \text{Transmission} + \text{Distribution} + \text{Power Storage} + \text{Renewable Generation} + \text{Prosumers} + \text{New Load Types} \right)
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Why Smart Grids?

The smart grid solutions to be developed are aimed at achieving the following objectives:

• Development of the electricity infrastructure as the basis for meeting the political targets in terms of **sustainability**

• Best possible **integration of renewable energy** and distributed generation

• Increase the energy system’s **efficiency** and improve the infrastructure

• Greater **flexibility** and supply-orientation

• Enable **new services** to be provided – metering, smart services, electric mobility, ...

• Development of energy regions of the future that are themselves responsible to a great extent for a sustainable energy supply (**cellular energy structures**)

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A model set up of a smart grid network. (Source: Smart Grid and Renewable Energy)
Smart Grid Technologies are pivotal to System Flexibility and Reliability

- Advanced Network Monitoring, Control, and Management Systems, Advanced Controllers
- SCADA (Supervisory Control and Data Acquisition)
- EMS (Energy Management System) and ADMS (Advanced Distribution Management Systems)
- WAMS/WACS/PMUs
- Dynamic Equipment Rating
- Forecasting Systems and AI
- Asset Management and GIS
- Advanced Metering Infrastructure (AMI)
- Enterprise Information Technology and Integration
- FACTS (STATCOM, SVCs, etc.)
- DERMS/DRMS/VPP Management
- Other Modern Technologies
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Real-time Monitoring and Remote Control of the Power Grid

- Modern energy landscapes require integration of real-time monitoring and remote-control systems in power grids for reliability and resilience.
- Data processed includes grid sensor, IED data, and meteorological conditions.
- Systems like SCADA, ADMS, and WAMS convert raw data into actionable insights.
- Benefits include early anomaly detection, improved situational awareness, and proactive grid management.
- Real-time data helps manage grid resources efficiently during adverse events and maintain uninterrupted power supply.
- Condition-based monitoring aids in optimized asset management, cost reductions, and extended asset lifespan.

Outage Management Practices

- Outage management is crucial for consistent and reliable power supply, integrating OMS with SCADA/EMS/DMS for effective detection, analysis, and restoration.
- Automated systems with real-time data from smart meters and sensors enable immediate outage detection.
- Integration with AMI offers detailed data from end-users, enhancing the accuracy of outage analysis.
- OMS optimizes resource allocation and supports the entire outage lifecycle, improving restoration efficiency.
- Performance monitoring and reporting by OMS ensure compliance with regulatory standards and quality of service indices.
Enhancing Reliability and Resilience (2/4)

- AMI is crucial in improving grid stability, reliability, and operational efficiency, featuring smart meters, communication networks, and data management systems.
- AMI allows for detailed real-time grid performance monitoring, aiding in identifying non-technical losses and facilitating rapid response to grid disruptions.
- The system’s extensive reach across the grid ensures granular visibility for thorough performance analysis and strategic improvements.
- AMI supports demand response programs, enabling effective demand-side management and grid reliability.
- Real-time outage detection capabilities minimize downtime and improve customer satisfaction.
- Continuous voltage level monitoring at various network points detects anomalies, aiding in maintaining grid stability.

Automated Fault Identification and Grid Reconfiguration

- Automated Fault Identification and Grid Reconfiguration technologies are crucial for modern electric power systems, with self-healing networks enhancing resilience and efficiency.
- SCADA systems provide centralized monitoring and immediate fault detection.
- EMS/ADMS optimizes grid operations with advanced algorithms for load flow analysis and fault localization.
- PMUs and WAMS offer precise grid stability analysis, improving decision-making and grid recovery capabilities.
- Self-healing power networks automatically detect, isolate, and resolve faults, reducing downtime and enhancing service reliability.
Enhancing Reliability and Resilience (3/4)

Root-Cause Analysis of Faults

- Root-cause analysis of faults is essential for enhancing grid reliability through advanced analytical functions.
- Time-series analysis of historical fault data and PMU data utilization provide trend analysis and anomaly detection.
- Integration with asset management systems correlates faults with specific equipment, aiding in comprehensive fault analysis.
- Machine learning algorithms recognize fault patterns, enhancing predictive capabilities.
- GIS-based visualization aids in identifying geographical fault hotspots.
- Network topology and load flow analysis assess grid impact during faults, informing reconfiguration strategies.

Disaster Preparedness and Grid Resilience

- Smart Grids transformation is vital for power system resilience, especially in disaster scenarios.
- Advanced analytics predict extreme weather events, enabling proactive grid management.
- Real-time monitoring, anomaly detection, and automated response maintain grid stability during critical conditions.
- Advanced decision making in dispatch room via digital tools helps a fast and optimized disaster response via adequate resource allocation and speeds up recovery.
Enhancing Reliability and Resilience (4/4)

Predictive Asset Management

- Predictive maintenance ensures critical infrastructure readiness for adverse conditions.
- Predictive maintenance uses insights from operating conditions for efficient equipment maintenance.
- Smart grids systems (e.g., APMS) generate precise predictions about asset and potential failures.
- This approach balances maintenance needs, improving reliability and reducing costs.
- Analysis of customer and consumption patterns aids in prioritizing high-impact assets for maintenance.

Cyber Resilience

- Cyber resilience is critical due to increasing cyber-attacks on power systems.
- The convergence of IT and OT systems in power grids expands the horizon of cyber threats.
- Smart Grid applications address cybersecurity issues, detecting and preventing fraud and threats.
- AI-driven tools analyze network traffic and user behavior, enhancing cybersecurity measures.
Smart Grids and Flexibility – Needs for Flexibility

1. **Flexibility for Power:** Achieving short-term balance between power supply and demand to maintain frequency stability. Timeframe: From fractions of a second up to one hour.

2. **Flexibility for Energy:** Managing medium to long-term balance between energy supply and demand. Timeframe: From hours to several years.

3. **Flexibility for Transfer Capacity:** Enhancing the ability to transfer power between regions to address local or regional bottlenecks, reducing congestion costs. Timeframe: From minutes to several hours.

4. **Flexibility for Voltage:** Maintaining bus voltages within specified limits to handle local and regional demands. Timeframe: From seconds to tens of minutes.
To enable a secure transition towards carbon neutrality, the deployment of both short and long duration flexibility resources will need to be coordinated with the integration of weather-dependent renewable generation sources and the phase-out of fossil-fuel generation. These resources will be located at transmission and distribution, onshore and offshore, and in other energy sectors.
Smart Grid’s Contribution to Enhancing System Flexibility

- FACTS and Advanced Controllers as Enabler for Optimal Grid Use (3, 4)
- Real Time Monitoring and Control for Optimal Grid Management (1, 3, 4)
- Power Plant Testing and Modernization for Proper Ancillary Services (1, 4)
- Energy Forecasting for Improved Flexibility (1, 2, 4)
- Dynamic Equipment Rating (3)
Smart Grid’s Contribution to Enhancing System Flexibility

- Sector Coupling and Multi-Purpose Energy Infrastructure (1, 2)
- Power Storage Potential (1, 2, 3, 4)
- Coordinated RES/DER Management as a Source of Flexibility (1, 2, 4)
- Virtual Power Plants and Smart Mini Grids (1, 2, 4)
- Demand Response Potential (1, 2)
Long Term Planning as the Assurance of Flexibility (1/2)

- **Implementing Advanced Flexibility Metrics**: Metrics such as Residual Load Analysis and Expected Energy Not Served (EENS) which provide insights into the flexibility needs arising from increasing variability in the balance of generation, demand, and storage. These metrics help identify the critical periods where flexibility is most needed and assess the potential economic impact of energy not served, which is crucial for optimizing investments in flexibility resources.

- **Economic Evaluation through Probabilistic Simulations**: Implementation of chronological probabilistic simulations to assess resource adequacy and identify the economic implications of flexibility actions. These simulations help in understanding how different flexibility measures (like ramping capabilities and scarcity management) perform under various scenarios, providing a basis for cost-effective planning.
Long Term Planning as the Assurance of Flexibility (2/2)

✓ Focus on Ramping and Scarcity Period Flexibility: Addressing ramping flexibility needs by identifying large daily residual load gradients and utilizing metrics to understand the economic losses associated with load expectation failures during high ramp periods. Managing scarcity period flexibility by analyzing continuous periods during which renewable energy resources might not be available, using metrics like the maximum annual value of 100-hour residual load rolling averages to predict and prepare for extended scarcity conditions.

✓ Sector Integration and Interconnections: Initiating planning studies for sector coupling and exploiting the benefits of multi-purpose energy infrastructures to improve system resilience and flexibility. Leverage interconnections to balance loads across wider areas, reducing the risk of local scarcities and smoothing out variability in renewable generation.
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✓ Extra Slides for Smart Grid Components’ Contributions to Power System Flexibility
Denmark is a leader in integrating renewable energy sources into its power grid, with a strong emphasis on wind energy. To manage the variability and enhance grid reliability, Denmark has implemented several smart grid technologies focusing on ancillary services, forecasting, and automation.

**Key Smart Grid Technologies**

- **Technology for Enhanced Frequency Regulation and Balancing**: Denmark utilizes technological solutions for wind turbines and energy storage to offer ancillary services like frequency regulation. The Cell Controller Pilot Project in Bornholm showcases how decentralized energy resources (DERs) are coordinated to ensure grid stability.

- **AnS Market Participation of DERs**: The Danish energy market supports the real-time involvement of DERs through demand response and virtual power plants (VPPs), enabling them to contribute to the ancillary services market.

- **Advanced Wind Forecasting Systems**: Denmark employs sophisticated forecasting methods, utilizing meteorological data and machine learning to accurately predict wind power generation. This allows the Danish Transmission System Operator, Energinet, to effectively schedule power generation and manage the grid.

- **Integration with Grid Operations**: These forecasts are integrated with grid operations to proactively adjust generation schedules and enhance grid flexibility, optimizing the use of both renewable and conventional power sources.
Use Case for Power System Reliability Improvement – South Korea, KEPCO

Smart Power Grid Devices + Advanced Automation and Control + Advanced Asset Management Technologies

High-level outcomes

✓ Reduced SAIDI (scale of a few minutes)
✓ Drastically improved losses
✓ Improved load factor and asset utilization

Key Smart Grid Technologies

✓ KEPCO has developed a top-level platform (xGrid) that connect various system in transmission & distribution and integrate them in real-time to better manage and operate national grid
✓ Smart Sensors, IEDs, DER monitoring, DMS/EMS solutions
✓ Self-healing networks, Advanced Grid Analytics
✓ Advanced asset condition monitoring and asset performance management solutions
Use Case for Combination of Flexibility Resources - Turkiye

Hydro and Natural Gas Power Plants + Interconnections + Market Mechanisms + Analytics and Smart Grid Solutions

✓ Advanced analytical techniques and widespread field measurement systems for forecasting renewable forecasting
✓ RES owners having a balancing responsibility, leading to implementation of forecasting solution and park control system
✓ Good interaction of TSO-DSO grid management systems, including interface substations
✓ Well-established Ancillary Services Market (FCR, aFRR) and Balancing Market: Proper Market Platform, Competitive Environment, Real-time Measurement and Control Solutions
✓ Distribution Ancillary Services Mechanism is under preparation
✓ 12 GW Distributed Solar Generation is achieved via Smart Grid components including SCADA/DERMS
✓ In 2024, with the new mechanism, ~30 GW BESS pre-licenses and connection have been provided to be implemented together with RES facilities (1MW wind/solar and 1 MW BESS approach)
Demand Response and VPP Use Cases from US

California: SCE-Stem VPP

SCE-Stem VPP delivers potentially 50MW/340MWh Based on Market Signal from CAISO.
Baltimore Gas & Electric Managed Charging Pilot Framework

BGE is working with WeaveGrid to provide EV telematics (monitoring cars, trucks, equipment, and other assets by using GPS technology and on-board diagnostics to track the assets’ movements.)
RES Participation to Ancillary Services

Country Practices for VRE Integration into Ancillary Services:

- **Germany**: Uses wind and solar power to provide frequency regulation through innovative control technologies and market mechanisms that allow participation in balancing markets.

- **United States**: Several regions, including CAISO and ERCOT, enable solar and wind generators to participate in ancillary services markets, with special provisions for variability and forecasting accuracy.

- **Australia**: Implements advanced forecasting tools and flexible market participation rules to allow wind farms to provide grid support services like frequency control and reserve power.

- **Spain**: Employs wind energy extensively for voltage support and frequency regulation, integrating advanced control systems within wind turbines to enhance grid stability.

- **Canada**: Focuses on regional trials, particularly in Ontario, where wind farms are tested for their ability to contribute to ancillary services such as voltage control and spinning reserves.
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**Stages of RES Integration vs. Power System Flexibility**

**Phase 1:**
RES has no noticeable impact to the system flexibility.
- Minor changes to the operational practices and ramping requirements.
- Get the grid RES ready.

**Phase 2:**
RES has minor to moderate impact on the system flexibility.
- Significant variability of net load, ramping requirements, reserve requirements and power flow.
- Increase the flexibility resources.

**Phase 3:**
RES starts determining the operation pattern of the power system from time to time.
- Inertia and ramping requirements start to be key challenges at high-RES hours especially.
- Increase the existing flexibility resources.

**Phase 4:**
System experiences hours where RES makes most of the generation.
- Longer potential periods of deficits for ramping sources and reserve.
- Ensure system wide stability and add new flexibility resource.

**Phase 5:**
Growing amounts of RES surplus (weeks to months).
- System stability and flexibility philosophy to be changed.
- RES to be operated as conventional generator (virtual inertia, participation to AnS).

**Phase 6:**
Seasonal or inter-annual surplus or deficit of RES surplus.
- Seasonal storage of synthetic fuels or hydrogen to be considered.
Smart Grid Roadmaps towards Reliable and Flexible Systems

Smart Grids Layer Model for the Electric Infrastructure

Developing Smart Grid Roadmap for CWEA Utilities

1. Define Objectives and Priorities
2. Assess Current Infrastructure
3. Identify Key Technologies and Projects
4. Collaborate and Seek Partnerships
5. Establish Implementation Phases
Recommendations for Central Asia Power System

1. Grid and RES Monitoring and Automation
   - Analysis of current IT/OT systems, data management practices, and analytics capabilities.
   - Identification of existing gaps, challenges, and opportunities in current operations.

2. Adaptive Operational Strategies for Grid Flexibility
   - Utilize advanced operational technologies like DLR, ANM to enhance grid flexibility. These strategies adaptively manage transmission capacities and grid resources.

3. Identify the Target Level of Reliability
   - This analysis will guide the level of automation and telecontrol needed to achieve or surpass the targeted reliability standards.

4. Participation of RES to Balancing and Ancillary Services
   - Balancing responsibility of RES
   - Adaptation of Grid Codes
   - Advanced telemetry telecontrol
   - RES Forecasting Techniques
   - Active DER management

5. Long Term Planning as the Assurance of Flexibility
   - Assessment of required technology upgrades or new implementations.
   - Plan for building or enhancing necessary infrastructure, including hardware and software needs

6. Start Piloting New Flexibility Sources
   - Demand Response
   - New Ancillary Services Products
Thank You
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1. Real Time Monitoring and Control for Optimal Grid Management (1/2)

**Enhanced Frequency Stability (Flexibility for Power):**
Real-time monitoring allows for continuous observation of grid frequency and the immediate detection of deviations from set thresholds. Automated control systems can initiate corrective actions almost instantaneously, using resources like fast-ramping generation units to adjust outputs, thus maintaining frequency within safe limits.

**Improved Congestion Management (Flexibility for Transfer Capacity):**
By monitoring power flows and system conditions in real-time, smart grids can identify and predict points of congestion. With this data, grid operators can reroute power flows or adjust generation levels to alleviate congestion and optimize the use of transmission lines. This not only helps in reducing congestion costs but also minimizes the risk of outages.

**Voltage Regulation (Flexibility for Voltage):**
Smart grids employ real-time data to maintain voltage levels across the network. Automated voltage control devices, such as on-load tap changers and voltage regulators, respond to real-time inputs to adjust transformer tap settings or reactive power flows. This dynamic adjustment helps keep the voltage within prescribed limits, ensuring stable and reliable power supply, especially in regions with high penetration of renewable energy sources that can cause voltage fluctuations.
1. Real Time Monitoring and Control for Optimal Grid Management (2/2)

Technological Enablers:

- **Remote Terminal Units (RTUs):** RTUs are field devices installed at various points in the grid to collect data from electrical equipment and send it back to central control systems. They play a key role in gathering granular data that informs real-time monitoring and decision-making processes.

- **Wide Area Monitoring Systems (WAMS) /PMUs:** WAMS utilize Phasor Measurement Units (PMUs) distributed across the grid to provide high-resolution, synchronized measurements of electrical waves. This data helps in assessing grid stability and managing dynamic conditions, thereby enhancing the ability to respond to fluctuations in power supply and demand, particularly in managing Flexibility for Power and Voltage.

- **Wide Area Control Systems (WACS):** WACS leverage the data provided by WAMS to execute control actions that maintain or restore the desired operational state of the power system. This includes automatic adjustments to power flows and system configurations, which are crucial for addressing Flexibility for Transfer Capacity and managing congestion.

- **SCADA:** SCADA systems are essential for real-time monitoring and control of the electrical grid. They provide operators with a comprehensive view of the grid's operational status, enabling immediate responses to changes in load and generation. This capability is crucial for managing short-term balance between power supply and demand, thus supporting Flexibility for Power and Flexibility for Voltage.

- **EMS (Energy Management System):** EMS use data from SCADA to optimize the operation of power systems, focusing on efficient generation and transmission management. By predicting and adjusting to changes in energy demand and supply, EMS enhance long-term energy balance (Flexibility for Energy) and help manage congestion (Flexibility for Transfer Capacity).

- **DMS (Distribution Management System):** DMS extends the capabilities of SCADA/EMS into the distribution network, enabling more refined control and management of energy flows at the local level. This includes managing voltage levels and optimizing the routing of electricity to alleviate congestion and ensure reliable power delivery, thereby supporting Flexibility for Voltage and Flexibility for Transfer Capacity.
Testing and Assessment:
- Regular testing of power plants is essential to determine their operational efficiency and capability to provide ancillary services. This includes testing for response rates, ramp-up and ramp-down capabilities, and reliability under different load conditions.
- Such assessments help identify areas where upgrades are necessary to meet current and future demands of the power system, particularly in scenarios involving high renewable penetration where variability and unpredictability of power supply can be significant.

Modernization Efforts:
- Modernizing power plants involves upgrading turbines, control systems, and other critical infrastructure to enhance their flexibility and efficiency. This includes the integration of advanced digital controls that allow for faster response times and more precise adjustments in power output.
- Implementing advanced combustion technologies can also improve the environmental footprint of power plants, reducing emissions and increasing the overall sustainability of power operations.

Enhancement of Ancillary Services (Flexibility for Power and Voltage):
- Modernized plants are better equipped to provide essential ancillary services such as frequency regulation and voltage control. By improving the speed and accuracy of these services, power plants can effectively respond to grid instabilities and maintain system reliability.
- For instance, modern gas turbines with fast ramping capabilities are increasingly used to complement renewable energy sources by quickly balancing power fluctuations due to changes in wind or solar output.
Governor Systems, Automatic Voltage Regulators (AVR), and Power System Stabilizers (PSS): TSOs oversee and regulate the testing and modernization of these critical systems to ensure they meet performance standards for maintaining grid frequency, voltage stability, and overall system reliability. This includes setting testing frequencies, methods, and compliance with grid codes to ensure that governors, AVRs, and PSSs respond accurately and effectively to grid conditions.

Establishment of Ancillary Services Mechanism/Market: It is key to establish and manage mechanisms (markets for ancillary services such as frequency (primary/secondary/tertiary) regulation, voltage control, and spinning reserves. These markets incentivize power plants to upgrade their technologies and capabilities to meet the demand for these critical services.

Performance Standards: TSOs need to develop and enforce performance standards for generation plants, ensuring they have the necessary capabilities to provide reliable ancillary services. This includes standards for responsiveness, power quality, and operational flexibility, which are crucial for integrating renewable energy sources and maintaining grid stability.
3. Energy Forecasting for Improved Flexibility (1/2)

Energy forecasting plays a key role in enhancing the flexibility of power systems by enabling more informed and proactive management of both demand and renewable energy sources (RES).

1. Long-term Forecasting:
   ✓ **Demand and RES Forecasting:** Long-term forecasting helps TSOs, and energy planners anticipate future energy needs and the integration of RES like wind and solar power. By understanding potential growth in energy demand and the variability in RES production, TSOs can plan for necessary grid expansions and upgrades to accommodate new generation capacities and demand centers. This forecasting supports Flexibility for Energy by ensuring that the power system can meet future energy demands reliably.
   ✓ **Grid Expansion Planning:** Accurate long-term forecasts are crucial for planning the development of transmission and distribution infrastructure that can handle expected increases in load and generation, particularly from intermittent RES. This strategic planning is essential for maintaining system stability and managing the voltage across the grid.

2. Short-term Forecasting:
   ✓ **Real-Time Demand Response:** Short-term forecasts allow for real-time adjustments in grid operations, helping to balance supply and demand dynamically. This is crucial for Flexibility for Power, where rapid adjustments are needed to respond to changes in demand or generation within seconds to minutes.
   ✓ **Integrating RES Forecasting:** With the increasing incorporation of RES, short-term forecasts of wind speeds and solar irradiance become critical. These forecasts enable grid operators to anticipate fluctuations in power generation and adjust dispatchable sources accordingly to maintain frequency and voltage stability, thereby supporting Flexibility for Voltage.

3. Impact on Ancillary Services: By accurately forecasting both demand and RES output, TSOs can more efficiently schedule ancillary services like frequency response and reactive power support. This optimizes the use of resources, reduces operational costs, and minimizes the risk of power outages or system failures.
3. Energy Forecasting for Improved Flexibility (2/2)

**Smart Grid Tools:**

- **AMI:** Provides detailed and timely data on energy usage and generation at the consumer level. AMI enhances demand forecasting accuracy and enables more effective demand response strategies, crucial for adjusting demand to match variable renewable supply.

- **Grid Metering and Monitoring:** Offers granular data on grid elements like transformers and feeders, crucial for enhancing Short-Term Load Forecasting. This detailed monitoring allows for immediate adjustments in power distribution and system configurations, improving operational response to load changes and maintaining grid flexibility.

- **Advanced Meteorological Models:** Utilized for more accurate RES forecasting, these models predict weather patterns that affect RES outputs, especially for wind and solar energies.

- **Machine Learning and AI:** These technologies are increasingly applied in energy forecasting to analyze historical data and improve the accuracy of demand and RES output predictions. This helps in adjusting the operations of grid-connected storage and peaking power plants to meet the forecasted demand.

- **Wind Measurement Infrastructure:** Provides precise, real-time data on wind conditions, crucial for forecasting wind energy output. This enables TSOs to better manage grid stability and integrate wind power efficiently, supporting both short-term power balancing and long-term energy planning.

- **RES Forecasting Software:** Impact on Flexibility: Uses data from various sensors and historical weather patterns to accurately predict the output from renewable sources. This forecasting aids in balancing generation with demand fluctuations, essential for maintaining grid stability and managing intermittent renewable sources.

- **Distributed Energy Resource Management Systems (DERMS):** Optimizes the operation of distributed energy resources to enhance grid reliability and responsiveness. By managing these resources effectively, DERMS contribute to smoother integration of renewables, improved demand response, and enhanced voltage control.
4. Dynamic Equipment Rating (1/2)

Dynamic Line Rating (DLR) or Dynamic Equipment Rating (DER) refers to the methodology used in power transmission systems to calculate the real-time capacity of overhead lines, transformers, and other electrical transmission equipment based on prevailing environmental conditions. Unlike static ratings, which are based on conservative assumptions and fixed environmental conditions, DLR dynamically adjusts the capacity ratings according to actual conditions such as ambient temperature, wind speed, and solar radiation. This approach leverages sensors and real-time data analytics to continuously monitor these conditions and adjust the load-carrying capacity of the equipment accordingly.

Key Contributions to Grid Flexibility:

- **Optimized Power Transfer Capacity (Flexibility for Transfer Capacity):** DLR/DER allows for real-time adjustments in the power handling capacity of transmission lines and other equipment. By taking into account actual environmental factors like temperature, wind speed, and loading conditions, DLR/DER can increase the power transfer capacity safely during favorable conditions. This capability is crucial during peak load periods or when there is a high availability of renewable energy generation, allowing for more efficient utilization of the existing transmission infrastructure.

- **Enhanced Congestion Management:** By dynamically adjusting equipment ratings, TSOs can manage congestion more effectively without extensive infrastructure upgrades. Dynamic ratings help in identifying potential bottlenecks in advance and adjusting operations to alleviate these bottlenecks, thereby reducing congestion costs and enhancing overall system reliability.

- **Improved Integration of Renewable Energy:** As renewable energy sources are inherently variable, dynamic ratings help in accommodating sudden spikes or drops in energy generation from sources like wind and solar. This flexibility supports a higher penetration of renewables by maximizing the use of transmission capacity during times of high renewable output.
4. Dynamic Equipment Rating (2/2)

Smart Grid Tools for Dynamic Line Rating (DLR) / Dynamic Equipment Rating (DER)

- **Real-time Monitoring Systems:** Real-time monitoring systems in the context of DLR/DER are critical for dynamically managing the capacity of transmission lines and other grid equipment. These systems incorporate a network of sensors placed along transmission lines and at key grid points. These sensors gather real-time data on environmental conditions such as ambient temperature, wind speed, solar radiation, and line current. The data collected is crucial because these environmental factors directly influence the thermal behavior of transmission lines, which in turn affects their current-carrying capacity.

- **Advanced Analytical Tools:** Advanced analytical tools process the vast amounts of data collected from real-time monitoring systems to dynamically calculate the optimal capacity of transmission lines. These software tools use sophisticated algorithms to analyze and interpret environmental and operational data, adjusting the line ratings in real-time. The outcomes are then communicated to grid operators and integrated into the energy management systems (EMS). This integration allows for operational recommendations to be made, such as rerouting power or adjusting generation outputs to maximize the efficiency and reliability of the power transmission network. These tools are essential for enabling proactive management of the grid, ensuring that capacity is utilized optimally based on actual conditions, and reducing the risk of overloading the system.
5. FACTS and Advanced Controllers as Enablers for Optimal Grid Use (1/2)

Flexible AC Transmission Systems (FACTS) combined with advanced controllers are integral for enhancing the operational flexibility and efficiency of power systems. FACTS devices, such as Static VAR Compensators (SVC) and Static Synchronous Compensators (STATCOM), alongside advanced control systems, enable precise management of power flows and voltage levels across the grid. These technologies adjust reactive power dynamically and regulate voltage in real time, responding swiftly to fluctuations in demand and supply, especially from intermittent renewable energy sources.

Benefits for Power System Flexibility:

- **Improved Transfer Capacity**: FACTS and advanced controllers optimize the use of existing transmission infrastructure, allowing for increased power flow without the need for new lines. This is crucial for managing peak loads and integrating geographically dispersed renewable energy sources effectively.

- **Enhanced Voltage Stability**: These technologies maintain voltage stability across the grid, which is vital for ensuring reliable power delivery and system integrity, especially in scenarios where the grid is subject to rapid changes in power output from renewable sources.

- **Congestion Management**: By providing greater control over power flows, FACTS and advanced controllers help alleviate congestion in transmission networks, ensuring that electricity can be distributed efficiently from sources of generation to centers of demand.
5. FACTS and Advanced Controllers as Enablers for Optimal Grid Use (2/2)

Smart Grid Tools

- **Static Var Compensators (SVC):** SVCs are used to provide fast-acting reactive power compensation on high-voltage electricity transmission networks. They are capable of dynamically adjusting the voltage to the grid's needs, enhancing stability and reducing flicker.

- **Static Synchronous Compensator (STATCOM):** A STATCOM is a solid-state converter that provides controllable reactive power support independent of the voltage level. It is more effective than an SVC in scenarios where the system voltage is low.

- **Thyristor Controlled Series Capacitor (TCSC):** TCSCs are used to control power flow over the transmission lines by dynamically adjusting the impedance of the line. This capability allows for better control over load sharing between parallel lines and increasing the power transfer capacity of the network.

- **Unified Power Flow Controller (UPFC):** UPFCs allow for the flexible control of power flows along transmission lines and also provide dynamic reactive power support. This dual functionality makes them particularly valuable in complex grid environments with multiple power flow paths.

- **Digital Automatic Voltage Regulators (AVR):** AVRs automatically control the voltage level and reactive power outputs of generators, adapting to changes in load or operational conditions to maintain stability across the grid.

- **Adaptive Protection Systems:** These systems dynamically adjust protection settings in real-time, considering changes in the network configuration, load levels, and generation patterns, which is crucial for preventing cascading failures in dynamic grid environments.

- **Real-time Monitoring Systems:** Essential for FACTS operation, these systems use sensors to continuously monitor grid conditions and provide data necessary for dynamic adjustments.

- **Control Algorithms:** Advanced software algorithms analyze data from the grid to make real-time decisions about adjustments needed in FACTS devices to optimize power flow and maintain voltage levels.
6. Coordinated RES/Management as a Source of Flexibility (1/2)

1. **Dynamic/Pro-Active RES curtailment to be considered as an important option for flexibility provision:** Keeping some reserves in certain hours in WPP/SPPs and implementation of Dynamic/Pro-Active RES curtailment for infrequent extreme ramping rate events could be a valid flexibility option.

2. **Telemetry, telecontrol and accurate forecasting analytics:** Implementation of proper telemetry and telecontrol of RES power plants and accurate forecasting analytics are crucial for integration of Renewable Power Plants.

3. **Adaptation of Dispatch Center Operational Procedures** for Pro-active RES curtailment applications.

4. **Balancing Responsibility of RES:** It’s important to have proper regulations and rules defining that RES power plants should be made responsible about their imbalances.

5. **Participation of RES producers in the balancing market:** Balancing market can be an initiative instrument for RES producers to provide flexibility.
6. Coordinated RES/Management as a Source of Flexibility (2/2)

**Dynamic/Pro-Active RES Curtailment:**

- **Technical/Operational Pre-requisites**
  
  √ Accurate short-term load, generation and weather forecasting with analytical tools,

  √ Proper systematic for measuring restricted RES generation

  √ RES Curtailment Management System

  √ Direct Integration of Wind and Solar Power Plant Controllers and Switching Equipment to Dispatch Center (for directly sending set points to PPs) (can be implemented either via Delta Power Constraint or Direct P-set)

  √ Transformation of dispatch procedures for effective implementation of this flexibility instruments.
7. Virtual Power Plant

Virtual Power Plants: Enhancing Power System Flexibility

1. Aggregation of Distributed Resources: VPPs aggregate the capacity of numerous small-scale DERs, creating a collective output that can be significant enough to influence power system dynamics. This aggregation allows for the flexible operation of resources that might otherwise be too small or inefficient to participate in the energy market. By pooling these resources, VPPs can offer substantial power supply or demand reduction that can be dispatched based on grid requirements.

2. Balancing Supply and Demand: One of the primary roles of VPPs in enhancing system flexibility is their ability to balance supply and demand dynamically. Through advanced forecasting tools and real-time data analytics, VPPs can predict power shortages or surpluses and adjust the output of their aggregated resources accordingly. This capability is especially critical given the intermittent nature of renewable energy sources like solar and wind, enabling VPPs to compensate for their variability and ensure a steady power supply.

3. Provision of Ancillary Services: VPPs contribute to power system flexibility by providing ancillary services such as frequency regulation, voltage control, and spinning reserves. These services are essential for maintaining grid stability and reliability. By managing the output and capabilities of diverse DERs, VPPs can quickly respond to grid operator requests for ancillary services, helping to smooth out fluctuations that could otherwise affect power quality and reliability.
8. Demand Response

1. Peak Load Management: Demand response is instrumental in managing peak load demands. By encouraging consumers to reduce their load or shift it to off-peak times, DR helps flatten the demand curve, which can prevent overloading of the grid infrastructure. This management of peak demand is crucial, especially in systems with high penetration of intermittent renewable energies, such as solar and wind, which can cause significant fluctuations in power availability.

2. Enhanced Grid Reliability: Demand response enhances grid reliability by providing operators with an additional tool to quickly balance supply and demand without the need for ramping up additional power plants, which can be costly and time-consuming. In emergency situations, such as unplanned outages or extreme weather conditions, DR can be activated to immediately reduce the load, thus maintaining grid stability.

3. Frequency and Voltage Support: DR can provide ancillary services such as frequency response and voltage support. By adjusting the demand side quickly in response to minor frequency and voltage fluctuations, demand response helps maintain the operational standards of the grid without solely relying on supply-side solutions.
9. Power Storage

1. Balancing Supply and Demand: Energy storage is pivotal in balancing electricity supply and demand over different timescales. It can store surplus renewable energy generated during peak production times (e.g., midday solar power) and release it during peak demand periods or when renewable generation is low. This capability is crucial for mitigating the effects of renewable intermittency and ensuring a consistent energy supply.

2. Enhancing Grid Stability: Storage systems contribute to grid stability by providing ancillary services, including frequency regulation and voltage support. By rapidly absorbing or injecting energy, storage can help maintain the frequency of the grid within the required operational boundaries, compensating for sudden changes in load or generation.

3. Peak Shaving and Load Leveling: Energy storage can be used for peak shaving—reducing demand on the grid during peak times to avoid using less efficient and more expensive power plants. Similarly, load leveling (or load shifting) involves shifting energy consumption from peak to off-peak periods, thus flattening out demand variations and allowing utilities to operate more efficiently.

4. Facilitating Advanced Grid Management Techniques: Advanced grid management, including the operation of virtual power plants (VPPs) and the provision of grid services from aggregated DERs, relies heavily on the flexibility offered by storage systems. Energy storage enables more sophisticated energy management and service offerings, contributing to a smarter, more responsive grid.
10. Sector Coupling and Multi-Purpose Energy Infrastructure (1/2)

Enhanced Demand Response Capabilities

Sector coupling expands the scope of demand response beyond just the electrical sector. By integrating thermal and mobility sectors, there are new opportunities for shifting and managing loads. For example, excess electricity can be used to heat water in thermal storage systems during periods of low demand and high renewable generation, and then the stored heat can be used later, reducing the demand on the electrical grid during peak times.

Stabilization of Renewable Energy Integration

Integrating sectors such as gas and heat with the power sector allows for the storage of excess renewable energy in non-electrical forms, such as through power-to-gas technologies where electricity is used to produce hydrogen. This hydrogen can then be stored and either converted back to electricity or used in other sectors like transportation or industry. This capability is crucial for managing the variability of renewables, as it provides additional flexibility in how and when energy is used.

Increased Utilization of Distributed Energy Resources (DERs)

Sector coupling inherently involves increasing the number and diversity of DERs by incorporating elements like electric vehicles, heat pumps, and home energy management systems into the grid's operational framework. These resources can be managed in a way that enhances grid flexibility, such as by charging electric vehicles during times of excess renewable generation or using residential heat pumps to balance short-term fluctuations in energy supply.
10. Sector Coupling and Multi-Purpose Energy Infrastructure (2/2)

Provision of Ancillary Services

With a broader array of connected devices and energy systems, multi-purpose energy infrastructure can provide a more diverse set of ancillary services to the power grid. This includes services like frequency regulation and voltage support, which are vital for maintaining grid stability. The ability to draw on a wider pool of resources for these services, especially from sectors traditionally not involved in electricity markets, adds depth to the grid's flexibility options.

Reduction in Peak Energy Loads

Sector coupling can significantly reduce peak energy loads on the power grid by distributing energy usage more evenly across different sectors. For instance, using surplus renewable energy to generate and store hydrogen or to power industrial processes during off-peak times can level out the demand curve, which decreases the need for peaking power plants and reduces stress on grid infrastructure.

Enhanced Economic Dispatch

The integration of multiple energy sectors allows system operators to perform more economically efficient dispatch of available resources. By having access to a more interconnected and versatile set of energy assets, operators can make decisions that minimize operational costs while maximizing system performance and reliability. This flexibility is essential for adapting to real-time market conditions and for optimizing the grid in the face of increasingly complex energy patterns.