The control room of the future: At the heart of *grid modernization*

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Modern electric grids require a new type of control room – one that enables innovative functions and full automation

Decarbonization is shaking up market dynamics and network operations around the world, bringing new complexities such as decentralized generation resources like solar and wind, which increasingly require updated market service and intelligent technologies.

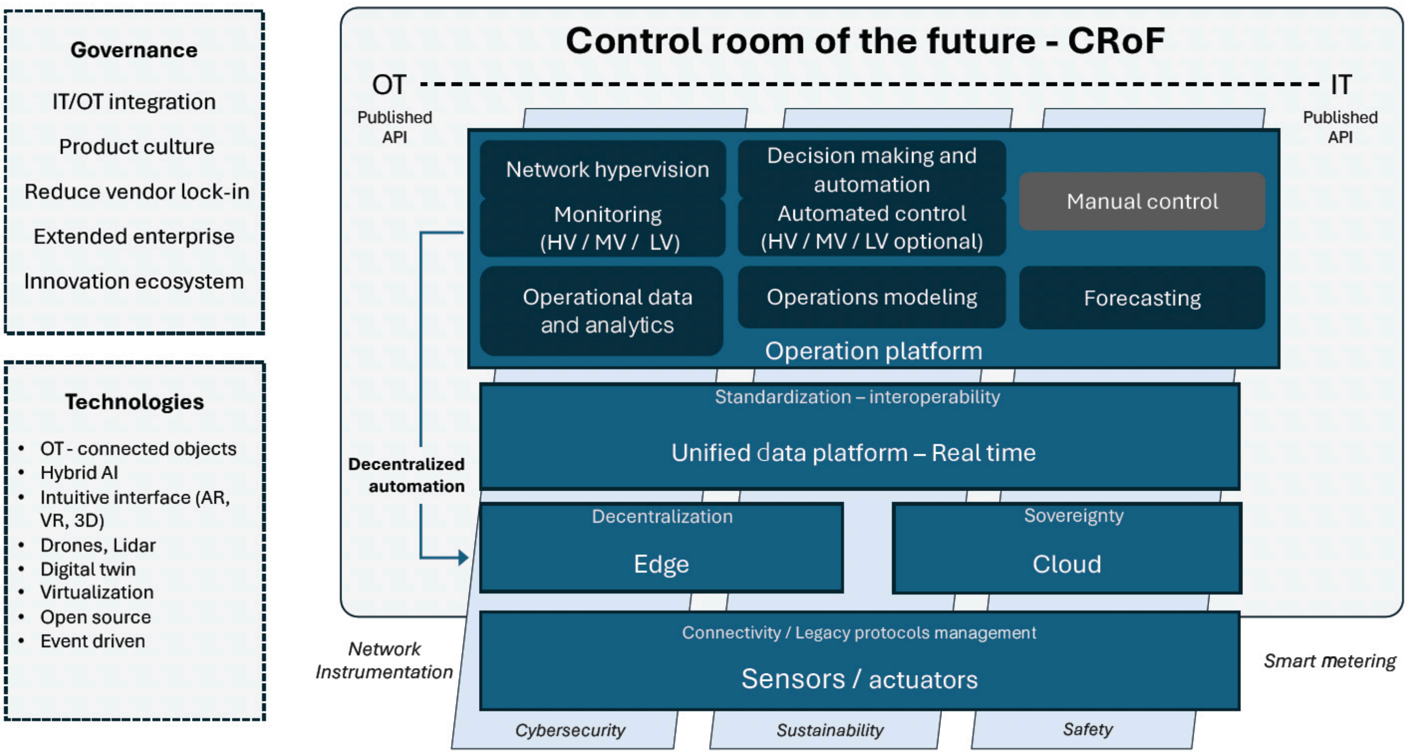
Energy demand is also experiencing significant changes, with behind-the-meter solar, heating and transportation electrification, cooling, stationary batteries, data storage, microgrids, and demand-response initiatives making forecasting and managing real-time demand less predictable and more complex. This evolution risks congestion and increased difficulty in managing outages. Weather events – like hurricanes, floods, extreme heat, and wildfires – add further complexity, with a need for enhanced low-voltage grid monitoring, renewables curtailment, and storage.

At the heart of these developments is the control room, the nerve center of modern network operations. Control rooms have evolved alongside technology to manage the increasing complexities of grid operations. The control room of the future uses intelligent technologies to provide operators with new capabilities, including:

- **Automated control actions and decision support.** This allows operators to adjust the system or intervene when needed.
- **Accurate and centrally managed data.** Centralized data makes operations more efficient and minimizes the need for constructing new assets. These new capabilities also make it possible to manage the integration of renewables, oversee the electrification of heat and transport, and foster an adaptive and self-healing network.
- **Real-time monitoring and predictive analytics.** With predictive data, disruptions can be anticipated and mitigated, enhancing overall system performance.
- **A heightened focus on customer-centricity.** Data-driven communication channels provide consumers with insights into their energy usage, personalized tips for efficiency improvements, and timely assistance during outages, guaranteeing a seamless experience.

Automate supervision system (the control room) and integrate a variable share of distributed intermittent generation	**Optimize** network operations, outages, and energy flow	**Leverage** data for real-time grid operations and asset management	**Enable** DSO functions (flexibility, storage, load planning, and capacity management)
Network resilience	**Safety and efficiency**	**Asset availability**	**Demand/supply optimization**
• Improved and enriched supervision with real-time awareness, alerts, and guided actions • Automated control scenarios coupled with contingency scenarios and self-learning algorithms	• Optimized reliability, efficiency, two-way flow, asset management • Efficient workforce management • Improved safety, reliability, and power quality management	• Improved planning, operations, and maintenance through predictive maintenance • More reactive and accurate asset health management and fault prevention	• Defined operational vs agency roles and performance framework • Stakeholder engagement and time integration platforms • Intelligent decision making, execution, and notifications

Technologies like AI-driven analytics, IoT devices, demand-response systems, and advanced energy storage will be key to making the grid more flexible, reliable, and sustainable. To support this shift, organizations must implement a new global architecture for control room operations, which spans IT and OT systems, and is a centralized capability, as shown here:



Control room of the future: A closer look at use cases and benefits

The control room of the future centralizes network operations and orchestrates – through processes or data – other components across the smart grid. This connected ecosystem unlocks new use cases that accelerate modernization, boost operational efficiency, reduce downtime, and support decarbonization efforts. Here are some of the top use cases, capabilities, and benefits that a control room of the future can bring to your organization.

Automation. Artificial intelligence and generative AI will play a pivotal role in furthering automation across modern network operations. Automation will progress step by step, with vigorous field testing to ensure grid reliability, and applied across different functions, like distributed energy resource management (DERM) or self-healing, for example.

The benefits. The benefits include power quality improvement, operational excellence, better intervention results, and enablement of command actions like congestion management, load demand balance, and flexibility commands.

Self-healing. In the case of an outage, it's now possible to quickly reconnect power to cut customers using AI. Most outages result from an unexpected event, like a component failure or a voltage excursion, where the network still operates and there is limited damage to infrastructure. There are also outages caused by hurricanes or massive floods, which damage underground and overhead lines.

Manual network inspection and power reconnection from a traditional control room can take hours. AI-powered self-healing modules analyze network health, find new routes to transport and distribute electricity (in case of damaged components), and successfully activate substation actuators to reconnect cut lines and delivery points.

The benefits. Quicker outage resolution can increase customers satisfaction, boost operational excellence, maintain continuity of supply, and reduce losses.

End-to-end digitization. End-to-end digitization enables efficient, reliable, and flexible grid management by integrating digital technologies across all grid operations. Examples include advanced data collection and monitoring, predictive analytics and AI, DERMs, and enhanced communication networks, cybersecurity, user engagement, demand response, regulatory reporting, and communication with stakeholders and customers. Digitization also creates the foundation for digital engineering and digital twins, which further supports future grid modernization.

The benefits. Digitization impacts the entire grid, improving reliability and stability, operational efficiency, and adaptability across core capabilities, including:

- Improved demand-response capabilities
- Enhanced operator decision-making
- Better dispatch management, proactive maintenance, and reduced grid downtime
- Enhanced cybersecurity
- Improved customer engagement, regulatory reporting, and communications.

Low-voltage (LV) grid monitoring. It has not made sense to equip low-voltage grids (with sensors and actuators) with feeders and lines that served very few clients and transited low volumes of energy. But, with distributed generation as well as new demand, low-voltage connection points are growing rapidly. Enhancing low-voltage management has become a priority for distributors – and integrating smart meter data into control room operations can help provide the intelligence needed to make smarter decisions.

The benefits. Integrating smart meter data as part of the control room of the future can help locate outages, improve customer experience, manage capacity, and accelerate grid planning and performance.

Digital twins and virtualization. Digital twins are virtual models that accurately represent the physical components and operations of the grid. This digital replica is continuously updated with real-time data from sensors and other monitoring devices, allowing operators to simulate, analyze, and optimize grid performance in a virtual environment.

An operator's role is to ensure efficient, reliable, and safe electricity delivery to residential, commercial, and industrial customers. Digital twin integration within a control room of the future provides comprehensive network visualization by replicating the entire electrical distribution network, including substations, transformers, power lines, and customer connections. This accelerates and de-risks the operator's role by giving them a real-time visual of issues and potential intervention points which might take time to decipher without digital twin support.

Virtualization across multiple platforms also enables efficient management of the smart grid. By using a software-based system, virtual devices can be deployed across grid architectures, reducing hardware requirements and enhancing scalability. This new virtual environment helps streamline your approach to hardware and software management.

The benefits. Virtualization and digital twins bring a lot of benefits, including improved situational awareness, enhanced predictive maintenance, optimized grid operations, scenario planning, asset and risk management, reduction of hardware requirements, enhanced decision-making, and skill development.

Expanded grid flexibility. The control room of the future should have insight into the available capacities that can safeguard the system from congestion as new sources of energy are added. Relevant data, including data from the grid, external, IT, and OT sources, should be available in the planning and real-time operational phases.

The benefits. New sources and devices will continue to be added to the energy system, both from the supply and demand side. Increased visibility into new energy sources can provide more proactive grid management and reduce outages.

Network convergence. Electricity is becoming the backbone of converged energy networks due to its versatility and ability to be generated from multiple sources. Advanced smart grids can coordinate with other energy networks to ensure supply and demand are met dynamically, with the best choice for the planet. For example, efficient clean electricity generation can be used to produce hydrogen through electrolysis during periods of high renewable generation and can be commanded by a control room of the future.

The benefits. Excess electricity can be stored in the form of hydrogen which can then be used as a fuel or converted back to electricity when needed.

Dynamic line rating. Electric lines can sometimes become congested for very limited periods of time. In these cases, it would not make sense to reinforce or double the capacity of these lines. Combined with demand-response within a control room of the future, dynamic line rating (DLR) algorithms indicate whether it's possible to exploit a line above its nominal capacity. DLR assesses, depending on weather conditions and various other measures, if the line deformation can be accepted.

The benefits. This approach helps provide more energy through existing lines, while avoiding building new lines – maximizing return on investment.

Anticipating connected generation impact and demand. With exponential load growth coming from electric vehicle adoption, heat pumps, distributed energy resources (DER), and other energy storage technologies, manual forecasting and management of interconnections can no longer keep up with growing demand.

A control room of the future integrates various data sources and provides a comprehensive visualization of the physical network and its assets. AI enables integrated forecasting models that go beyond traditional historical usage patterns to include weather, real-time demand, EV, and DER for anticipating interconnection requirements.

The benefits. Data models supplied by a control room of the future provide a comprehensive view of network performance and future investment needs. This helps in making informed decisions and identifying areas where investments are most needed for asset investment planning.

The importance of real-time data

Many of the use cases described above require real-time data and automated decisions that are constrained by legacy processes. With advancements in predictive algorithms and AI agents, these benefits can be realized through automated decisions.

Leveraging data for grid automation and optimization is imperative for modernizing power grids, enhancing their efficiency, reliability, and sustainability. Some sample future use cases include:

- **Automated assessment of weather patterns,** energy demands, and supply chains for optimized power generation and pricing across the grid
- **Real-time asset health conditions** and predictive maintenance
- **Voice-enabled natural language** instructions for field maintenance workers
- **Customer service personalization** and offers based on individual customer usage patterns and preferences.

An important aspect of architecture is the security surrounding the IT systems data, the OT systems data, and the overall security fence around the control room to provide end-to-end security.

Getting started: Key considerations

Modernizing the grid and implementing a control room of the future is a monumental task that will span five to 10 years. Here are some key considerations to maximize time-to-value on your investments as you embark on your modernization journey.

Plan for short-term and long-term goals	Use cases that yield benefits sooner will be easier to justify. And those with the highest potential value are likely to require longer runways, so be sure to obtain buy-in and investment early.
Prioritize based on operational readiness	Assess the technical and operational readiness of the organization. This includes evaluating existing infrastructure, identifying potential integration challenges, and ensuring that the necessary resources and expertise are available to support a control room of the future. A phased approach, starting with pilot projects and gradually scaling up, can help mitigate risks and ensure a smoother implementation process runways, so be sure to obtain buy-in and investment early.
Consider cultural shifts	Shifting an internal culture towards a different way of working is always a barrier to manage and consider. Think about which groups will be most affected, how to upskill at scale, and which people you can rely on to be your internal champions.
Go across the enterprise	When identifying high priority use cases, include stakeholders from across the organization as part of the process. Having team members involved from the start will get the required buy-in during pilot and implementation phases.

Overcoming challenges

Implementing a control room of the future is a complex and multifaceted task that comes with several inherent challenges. Here are some things to look out for as you navigate your implementation journey.

Standardization. Standardization is essential when setting up a control room of the future because it ensures interoperability between devices, enables unified monitoring and management capabilities, and helps maintain reliable and efficient operations. Adopting common communication protocols and interconnection standards – such as those defined by IEEE, IEC, and regional requirements – lays the foundation for a resilient, future-proof architecture. This architectural standard adherence will define the protocols, build interoperability and display standards that will:

- **Support interoperability** by moving to a common architectural framework, communications protocol, and tech specifications
- **Define a backbone of technology** that informs your approach for each smaller set of systems, keeping everything aligned
- **Standardize data integrations,** making the system easier to maintain
- **Provide a platform for standardized analytics,** leveraging grid and IT data
- **Create a standardized security** model across IT and OT data that extends into the integrations, data storage, analytics, and display on local, remote, and cloud platforms.

Sovereignty. For electric grids, sovereignty means control of equipment supply (hardware), including parts, required rare earth and metals, and software and services. In some places, sovereignty policies take the form of legal platforms or regulatory measures. Consider what is required to meet changing regulatory needs, establish resilience, avoid disruption, and remain complaint – especially during times of geopolitical or economic uncertainty.

Procurement and ecosystems management. The decision to move towards a control room of the future will not be made by utilities alone. Given accountability to both governments and the public, automation and transformation will require buy-in by multiple stakeholders and regulatory bodies. The challenge will be to form ecosystems of solution and service providers that provide the right blend of innovation, sovereignty, strength, sustainability, and commitment to help get the required buy-in.

Weather resiliency. Critical infrastructures like electric grids must be reinforced to resist weather events like floods, high-speed wind, fires, and heat waves. The control room of the future can play a critical role in operational resiliency by assisting with flood or lightning detection, equipment fatigue assessment, heat measurement, vibration monitoring, vegetation management analysis, interventions commands, enhanced predictive maintenance, and self-healing in case of outages.

Biodiversity management. Utility operations can significantly impact habitats, wildlife, and biodiversity. Any infrastructure project should consider the environment when approaching transformation.

The control room of the future can play a crucial role in mitigating and managing the impacts on biodiversity through several advanced technologies and strategies.

- **Real-time monitoring.** GIS network data and data analytics, powered by IoT devices and wildlife sensors, track environmental conditions and wildlife movements. Features can be included to identify sensitive habitats where automated and remote operations reduce the need for on-site maintenance, minimizing human disturbances.
- **Data sharing with environmental agencies, conservationists, and other stakeholders.** A control room of the future can measure networks impact on wildlife, provide real-time data on environmental conditions, biodiversity, and habitat health, so you can work more effectively with conservation groups on addressing issues like habitat fragmentation and species protection.

Cybersecurity. Cybersecurity is particularly important for utilities, given the potential for disruption of essential services, and the impact on public health, safety, and economic loss. As utilities move towards an automated control room of the future, it is important that employees oversee the outcomes of AI agents and algorithms to ensure the right decisions are being made, and appropriate precautions are enforced. Anomaly detection will be another key security feature to help utilities move towards a safe and responsible control room of the future.

System performance management. Implementing a control room of the future is a significant investment across time and resources. Because investments are often driven through investors or public spending, tracking progress in the form of benefits realization, spending, and pace of adoption is required to drive accountability and confidence from investors and end customers. When quantifying progress, keep these key performance indicators in mind:

- OPEX efficiency relative to peers as well as compliance with regulation targets
- CAPEX return-on-investment of pilot and production-level control room of the future use cases, tracking expenditures against budgets and timelines
- Use case-specific metrics, like reliability, customer satisfaction, line losses and others
- Financial KPIs related to ROI, ROA, EBITDA improvement, and more.

Powering the future of grid modernization

Data, digital technology, and automation play critical roles in modernizing power grids by enhancing efficiency, reliability, and sustainability.

The control room of the future sits at the center of these modern grid operations, orchestrating other smart grid components and connecting data across systems and devices to enable smarter, safer, and more proactive ways of working.

The journey to establish this modern infrastructure isn't an easy one. Implementing new systems architecture, establishing meaningful partnerships with third-party players and regulatory bodies, and navigating organizational and cultural change all pose significant challenges. Understanding the risks and planning transformation effectively can help reap the right rewards – both in the short-term and when establishing lasting resiliency.

Capgemini works with utilities organizations to define strategic direction, develop governance structures, and implement delivery plans that turn your vision into tomorrow's ground-breaking services and solutions. Contact us to learn how we can help you bring your control room of the future to life.

Please contact Bill Brooks, US Smart Grid Lead

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