The Control Room of the Future

At the heart of energy transition

Capgemini

Modern electric grids, at the heart of the energy transition, require a new type of control room – one that enables innovative functions and full automation.

As the electric system's architecture undergoes energy transition and massive electrification, real-time electric grid operations are also evolving. For an electric grid, the main goal has always been to keep the power supply steady and make the network more performant and resilient. A common response of grid operators in this emerging energy landscape has been the reinforcement and extension of the grid. Extending the existing grid is not enough – we need smart, data-driven solutions.

At the heart of this development is the control room, the nerve center of network operation. Control rooms have evolved alongside technological advancements to manage the increasing complexities of grid operations. To manage the significant changes in network dynamics, operators need grid control rooms that are:

- adaptable, with advanced enough technology to maintain reliability and security.
- reactive in real-time.
- agile enough to respond to new challenges.

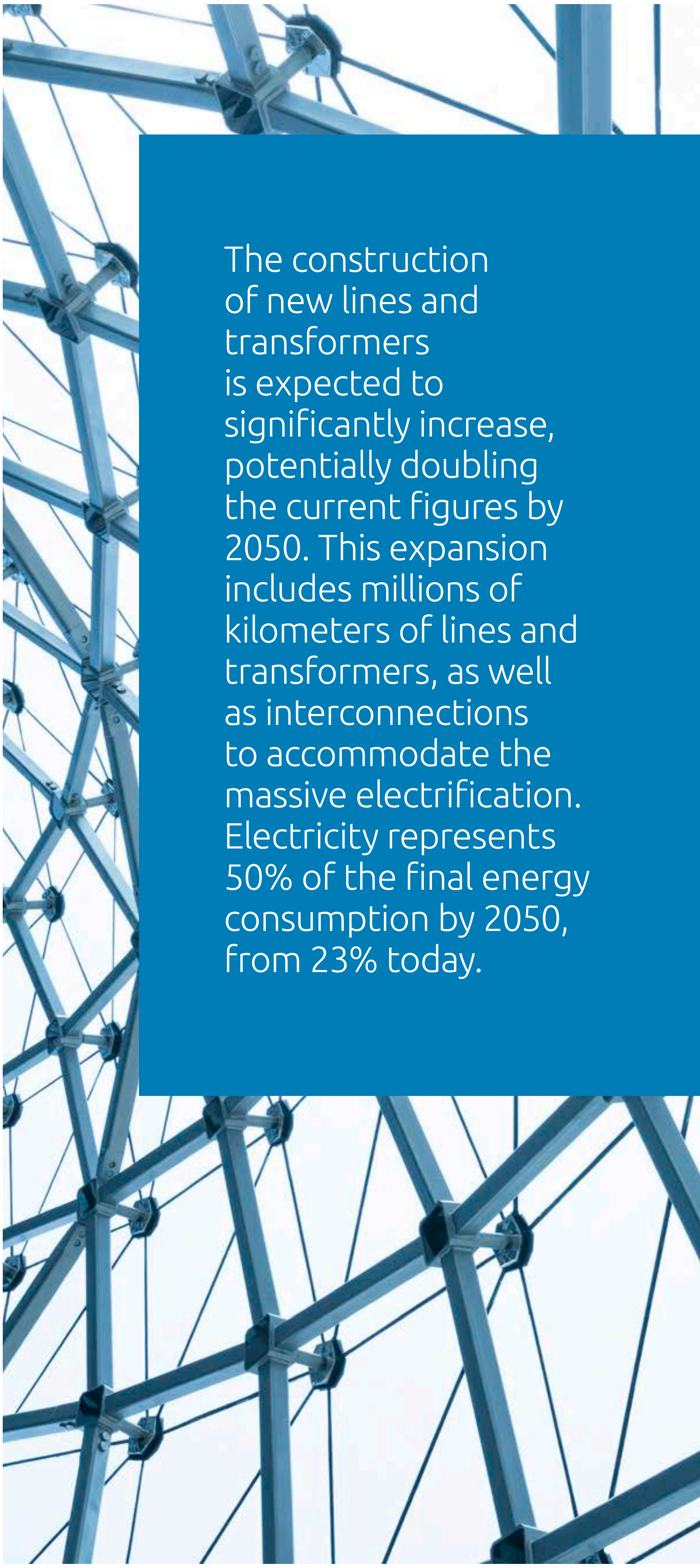
New solutions for control room operations will reduce the costs for further grid investments and help effectively manage the complexities of modern energy landscapes, ensuring uninterrupted, sustainable and affordable power delivery to consumers.

Dynamics, transitions, and challenges in the new energy landscape

The global move towards decarbonization is transforming how we generate and use energy. We are moving away from centralized dispatchable thermal or nuclear plants, towards decentralized, variable, renewable sources like solar PV and wind. This change is shaking up market dynamics and network operations around the world, bringing new complexities as different generation resources require updated market service. Consider, for example, the changes that must take place when one-way flow turns into two-way flow with decentralized generation.

Simultaneously, demand for energy is experiencing significant changes, with less predictable and faster-growing patterns due to factors such as behind-the-meter solar, electrification of heating and transportation, massive growth of cooling, electricity storage (stationary batteries) and the adoption of demand response initiatives. Operators face substantial challenges in forecasting and managing demand in real-time, especially during periods of high solar PV output that can obscure actual demand levels. The balance between load and demand has become increasingly complex. This rapid evolution has led to congestion and increased difficulty in managing outages.

As a result of this change, the construction of new lines and transformers is expected to significantly increase, potentially doubling the current figures by 2050. This expansion includes millions of kilometers of lines and transformers, as well as interconnections to accommodate the massive electrification. Electricity represents 50% of the final energy consumption by 2050, from 23% today. Transmission and distribution networks have seen relatively little development in the past 20 years, resulting in congestion and making it harder to manage outages.



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Electric networks need also to become intelligent to manage the new paradigm, and to leverage the fantastic progress made possible by new technologies. Intelligence will also be necessary to manage intermittent and distributed generation (wind and solar renewable farms), stationary and distributed storage, and increased demand with large electric assets ballooning (EV charging, heat pumps, AC, data centers etc.), as well as microgrids connected to public grids.

Grid balancing issues with intermittent generation also require a range of solutions, including:

- Ancillary services
- System inertia requirements
- Pairing batteries storage with solar and wind farms
- Congestion management and curtailment in case of excess capacity compared to the demand
- Flexibility and demand – response
- Low voltage grid monitoring, and more

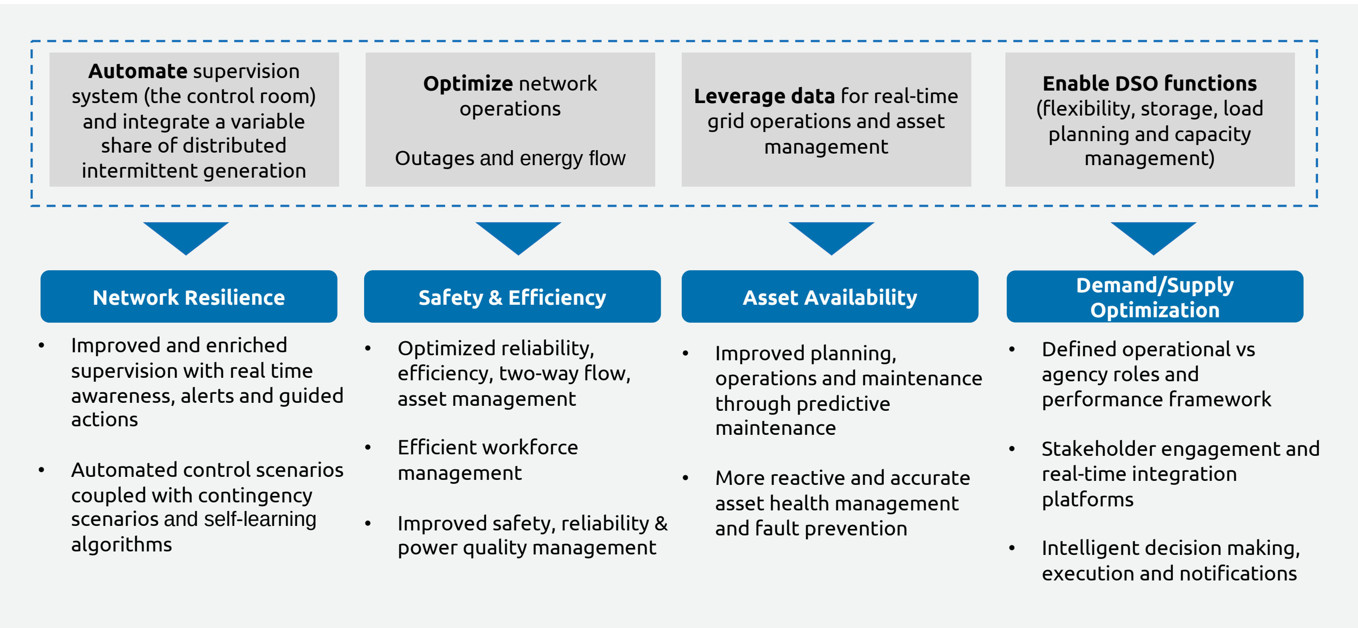
Efforts to tackle these challenges include expanding internal high voltage AC cable networks, increasing High-Voltage Direct Current (HVDC) connections between countries or with offshore windfarms, and adopting smart network technologies. It will also take new, smart substations and smart grids at scale in various dimensions.

Weather events such as hurricanes, floods, extreme heat, and wildfires add further complexity. These events necessitate adaptation measures, as well as enhanced monitoring and management of decentralized resources on distribution networks by system operators, including LV grid monitoring with better control, renewables curtailment, and storage.

The future-ready control room: transforming grid operations

The control room of the future (CRoF) uses intelligent technology and strategy to provide operators with a new level of capabilities. These include automated control actions and decision support, allowing operators to adjust the system or intervene when needed or relevant. Accurate and centrally managed 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 high shares of renewables, to oversee the

Figure 1: Functions of the control room

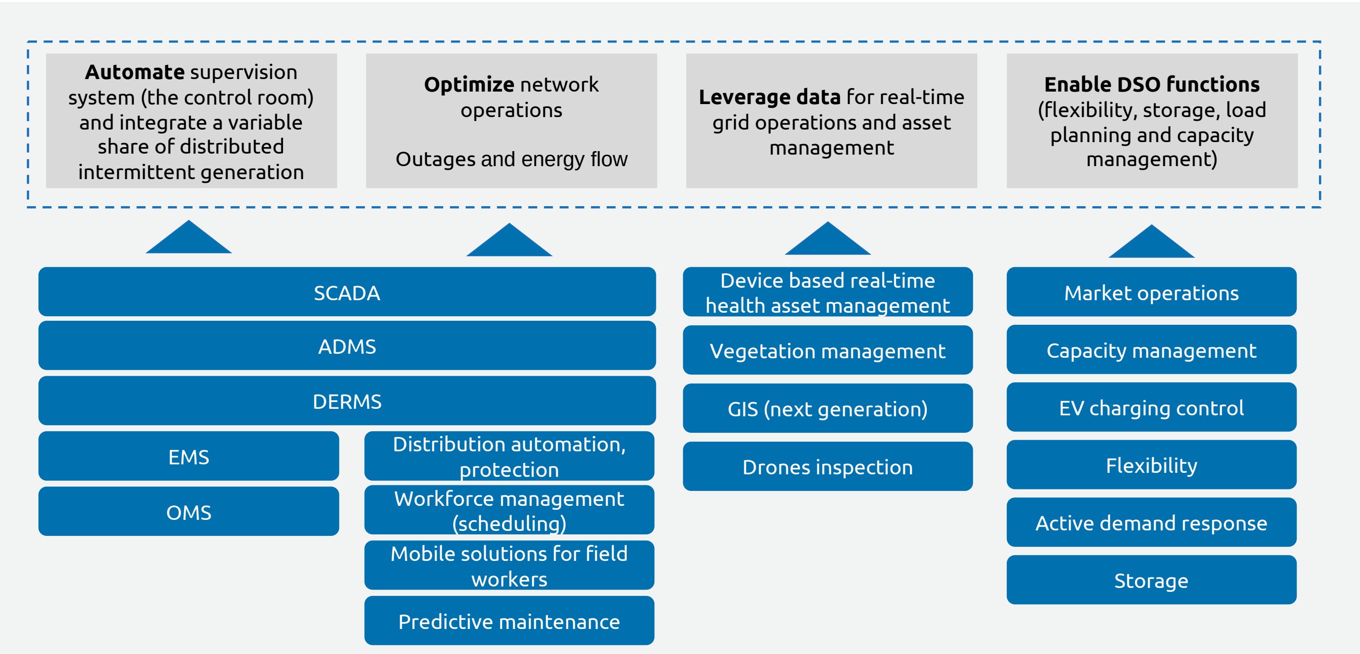


electrification of heat and transport, and to foster an adaptive and self-healing network. Finally, through real-time monitoring and predictive analytics, disruptions will be anticipated and mitigated, thereby enhancing overall system performance.

Additionally, a heightened focus on customer-centricity will elevate customer service standards. Enhanced communication channels will provide consumers with insights into their energy usage, personalized tips for efficiency improvements, and timely assistance during outages, guaranteeing a seamless experience. In essence, leveraging data for grid automation and optimization is imperative for modernizing power grids, enhancing their efficiency, reliability, and sustainability.

Innovative 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. Here are some traditional solutions and technologies that continue to play a crucial role and are to be augmented / completed in the development of control room of the future:

Figure 2: Key solutions in the control room of the future

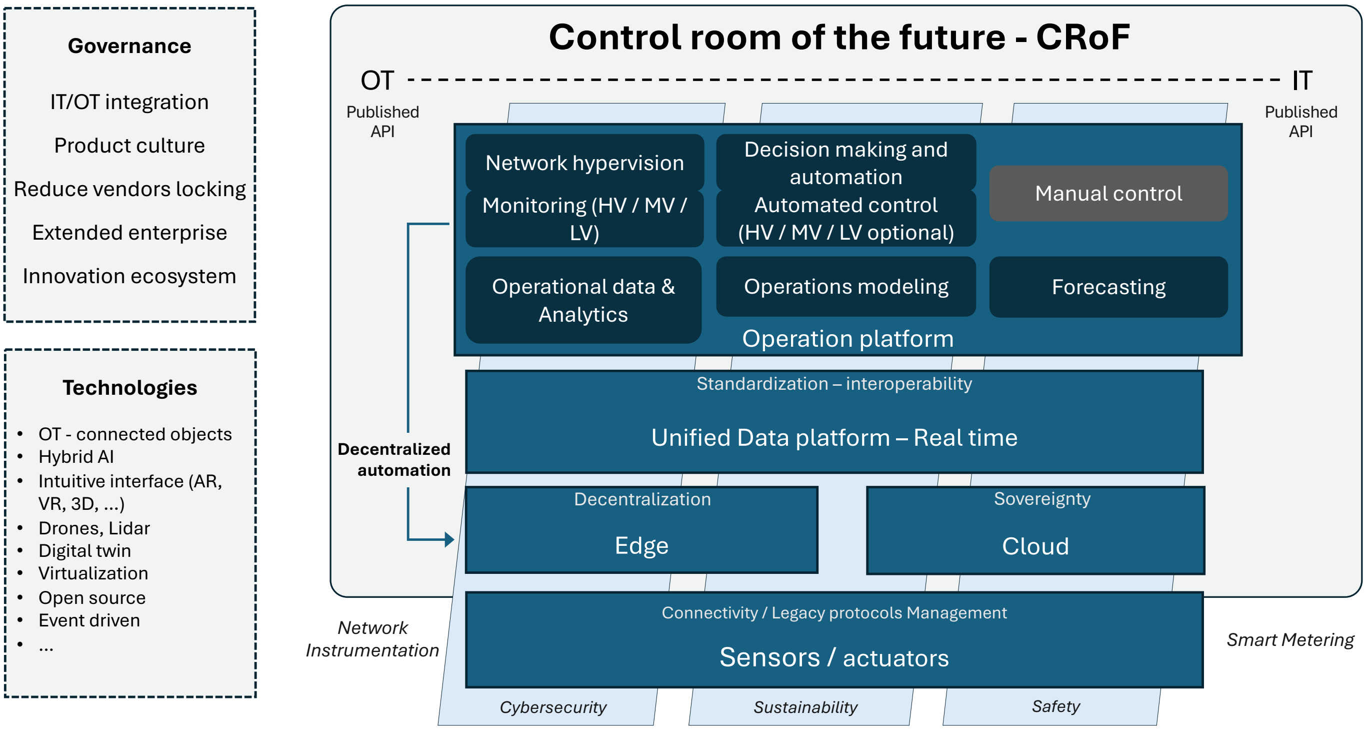


Control room of the future (CRoF) architecture and features: real-time and non-real-time operations

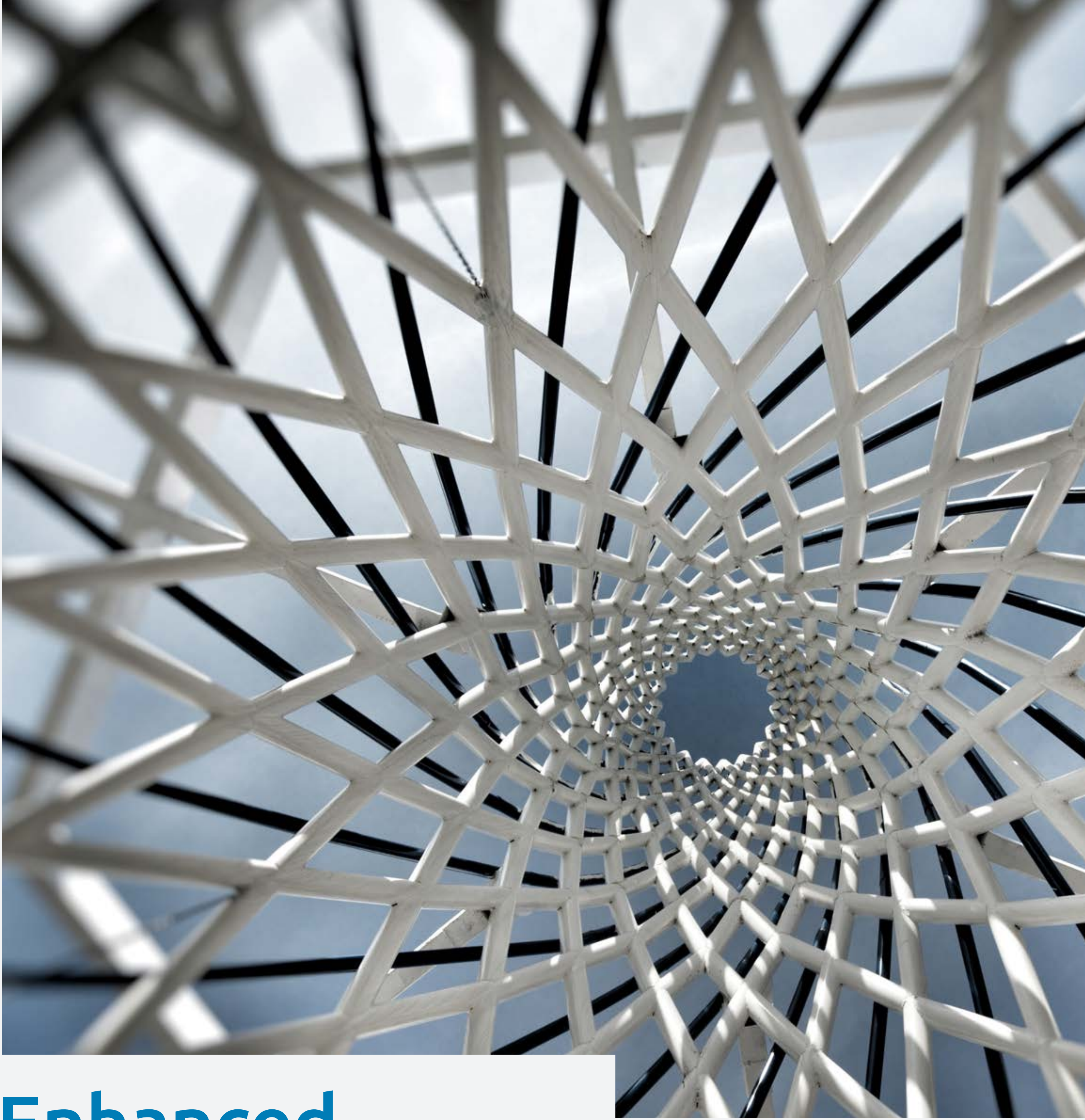
The control room of the future features are built on top of actual control-room functions like real-time monitoring, predictive analytics, remote operations, and enhanced visualization.

The new CRoF framework requires a new global architecture view[1], which spans across IT and OT systems, and is a centralized capability, as shown here:

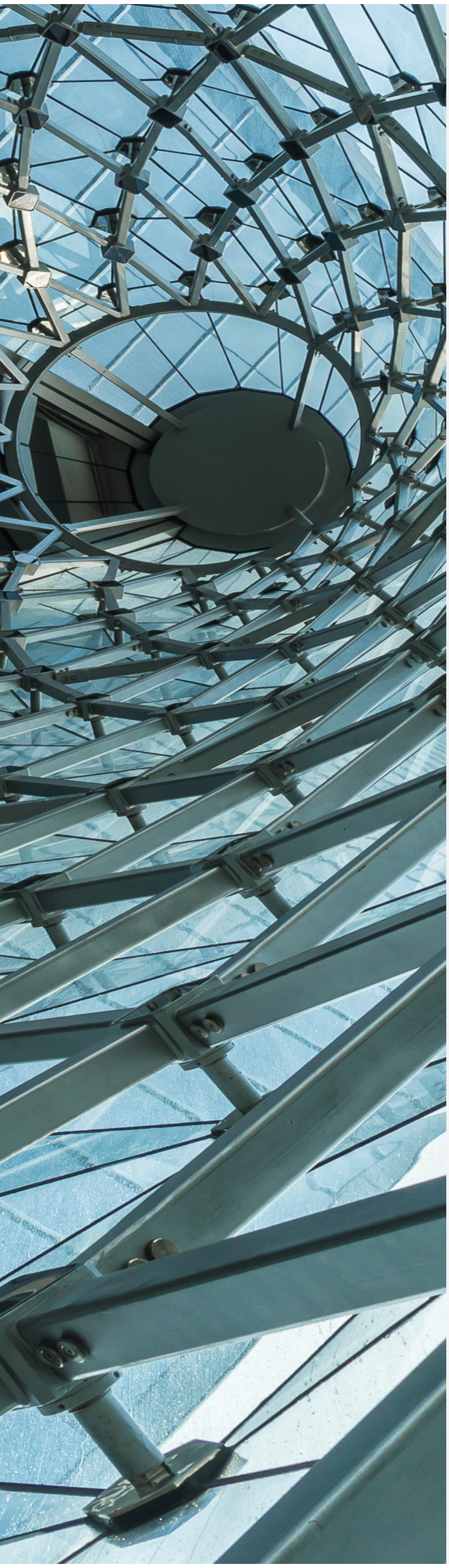
Figure 3: Typical Architecture level 1



1 Our vision leverages the "Vision for the Control Room of the Future" prepared by the Global PST Consortium. https://globalpst.org/vision-for-the-control-room-of-the-future-report/



Enhanced features of CRoF



A fully automated control room:

(at the latest stage of development), notably for HV/MV networks. Network operation, through the control room and various other components (edge computing at substation level – network instrumentation) will be progressively fully automated, leveraging AI / Gen AI technologies, as well as actuators and other devices. Decision-making functions, like self-healing, DLR or DERMS (as examples) are included in the related scope. Human intervention will be, in the medium term, limited to hyper vision and exceptional actions management. Automation will progress step by step, requiring rock-solid field testing to ensure grid reliability.

Note: it will probably not make sense to automate the LV grid (no proven ROI yet). Many benefits are expected from automation: power quality improvement (SAIDI), operational excellence. Reduction of human workforce, better intervention results, and enablement of command actions, like self-healing, congestion management, load demand balance and flexibility commands, etc.

Self-healing:

In the case of an outage, it's now possible to reconnect automation for about 99% of cut customers in less than 2 minutes. Most outage cases result from an unexpected event, generally technical like a component failure or a voltage excursion, where the network still operates and there is limited damage to infrastructure (Unlike outages caused by hurricanes or massive floods, which damage underground and overhead lines.)

Manual network inspection and power reconnection from a control room takes hours. Self-healing modules (AI powered) included in the control-room can analyze the network health, find new routes to transport / distribute electricity in case of damaged components (transformer, line), and in most cases, successfully activate substations actuators to reconnect automatically cut lines and delivery points.

Benefits include: customers' satisfaction, operational excellence, continuity of supply, reduction in losses.

Successfully implemented by Enedis (French distribution company, EDF subsidiary).

Integrated dimensions:

As already stated, the control room of the future becomes the nerve center for grid operations, orchestrating, through processes or data, the other smart grid components: metering data, smart connected substations with connected devices, asset management, and the grid data repository. CRoF also enables digital twinning and virtual power plants / demand response.

This makes possible management at any level (substation or feeder level, local, regional, national, interconnections), including connected micro-grids to the public grid. AMI 2.0 meters provide stronger locational awareness not only from a geospatial capability, but also from a grid locality perspective.

By having more grid-aware, grid-locational points / sensors in the field, there are more points to define the system diagram for the grid. With more location data, true locational awareness provides a platform for better monitoring of grid assets and responsiveness for grid outages, integration of DERs / MicroGrids, and optimizing/ enhancing grid resilience.

End-to-end digitization:

Comprehensive integration and utilization of digital technologies across all aspects of the electricity grid's operations. This involves the seamless flow of data and information from generation to distribution to consumption, enabling more efficient, reliable, and flexible grid management.

Numerous expected benefits from end-to-end digitization: enhanced grid reliability and stability, improved operational efficiency, increased grid flexibility and adaptability, improved demand response capabilities, enhanced operator decision-making (including maximization of existing grids vs new infrastructure development), proactive maintenance and reduced grid downtime, better dispatch management.

Digitization also creates the foundation for digital engineering and digital twinning capability. And enhanced cybersecurity, environmental, improved customer engagement and satisfaction, scalability and futureproofing, customer interruptions (CI) & Customer Minutes Lost (CML).

Examples include the integration of: advanced data collection and monitoring, data integration and management, (predictive) analytics and AI, automation and control, DERMs, cybersecurity measures, enhanced communication networks, user engagement, demand response, regulatory reporting, stakeholders and customers communication.

LV grid monitoring:

Historically, LV grids (distribution network last mile) remain the blind side of electric grids. It didn't make sense to equip with sensors and actuators feeders and lines serving very few clients and with low volume energy transiting.

But, with distributed PV generation as well as new demand paradigms (EV charging, heat pumps, demand electrification more broadly), LV connection points are mushrooming. Enhancing LV management has become a priority of distributors – in fact, a 2024 Schneider Electric survey[2] has shown that 90% of European grid operators are planning to work on LV grids.

Some DSOs are already leveraging Smart Metering data to better locate outages. Some others, notably the ones which don't get access to metering data (like UK) have installed sensors on more sensitive feeders / lines.

The most important use cases for LV grid management are enhancing customer experience, grid planning and OPEX performance. Other use cases may include capacity management for LV feeders, outage management, flexibility load and generation control. More use-cases may be added to this list, depending on their ability to demonstrate ROI.

Digital twin:

This is a virtual model that accurately represents the physical components and operations of the electricity grid. This digital replica is continuously updated with real-time data from sensors and other monitoring devices across the grid, allowing operators to simulate, analyze, and optimize grid performance in a virtual environment.

A Digital Twin (or functions) brings a lot of benefits, including: improved situational awareness, enhanced predictive maintenance, optimized grid operations, scenario planning and risk management, enhanced decision-making, training and skill development, facilitation of innovation and experimentation, and more.

Example: Within the CRoF for a DSO, the operator's role is to ensure efficient, reliable, and safe electricity delivery to residential, commercial, and industrial customers. Digital twin Integration into the CRoF provides them with comprehensive network visualization. The digital twin replicates the entire electrical distribution network, including substations, transformers, power lines, and customer connections. It provides a dynamic, real-time visual representation of the network's current state. 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 precious time to decipher without the Digital Twin support. Enabling digital twining from a CRoF opens many other digital twin capabilities (simulation, predictive features, asset management like asset investment planning) and many more…

2 Low Voltage grid management report (Schneider Electric)

Flexibility:

New flexy sources and devices will continue to be added to the energy system, both from the supply and demand side. Even smaller devices such as electric vehicles, batteries or electric heaters can support the system. The control room should have insight into the available flexibility capacities (from large industrial objects to residential devices and building equipment) to safeguard the system both from a congestion and a balancing management perspective. The relevant data should be available both in the planning- and the real-time operations phase. Data from the grid, but also data from external sources, OT and IT data. Depending on the relevant regulation (which truly differs per region), the future control center will have to be ready to benefit from these new flexibilities.

Preparing network convergence:

Electricity being the central carrier (gas, hydrogen, heating, cooling networks, but also micro-grids or district grids connected to the public grid)

Electricity is becoming the backbone of a converged energy networks due to its versatility and ability to be generated from multiple sources (Power to X, X to Power). By using electricity as the primary carrier, 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 CRoF instance.

In this way, 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 be congested, sometimes for very limited periods of time. But it would not make sense to reinforce or double the capacity of these lines. Combined with demand-response, Dynamic Line Rating (DLR) algorithms indicate whether it's possible to exploit a line above its nominal capacity (110% or even far more).

DLR assesses, depending on weather conditions and various other measures, if the line deformation can be accepted (technical compliance). More power transiting through the line than nominal capacity means joule effect and line deformation.

Expected benefits: provide more energy through an existing line and avoid new lines build (investment).

Anticipating connected generation and demand assets impacts:

(renewables, EV charging infra, heat pumps, various storages)

- With exponential load growth coming from electric vehicle adoption, heat pumps, distributed energy resources and other energy storage technologies, manual forecasting and management of interconnections can no longer keep up with growing demand.
- The proliferation of AI has allowed for integrated forecasting models that go beyond traditional historical usage patterns to include weather, real-time demand, advancements in GIS and EV/DER for anticipating interconnection requirements.
- The combination of exponential electricity demand with advancements in AI will further accelerate the adoption and benefits of an automated control room of the future, with many utilities planning to nearly double the percentage of renewable energy generation in their portfolio by 2030.
- The CRoF integrates various data sources and provides a comprehensive visualization of the physical network and its assets. The data model from CRoF with data from various sources like demand, forecast, asset info etc. provides 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 activities.

Data hub feeding real time:

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

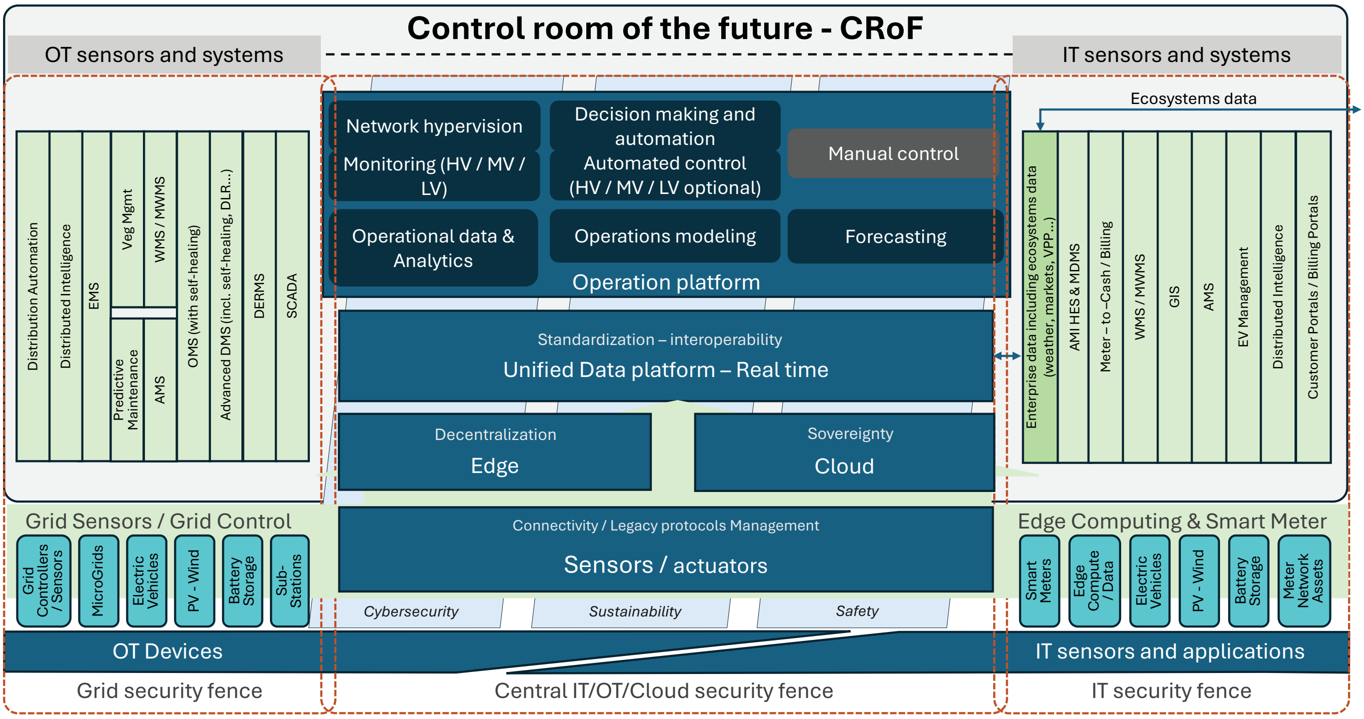
Some sample future use cases include:

- Automated assessment of weather patterns, energy demands and supply chains for optimizing power generation and pricing across the grid
- Realtime health assets conditions (component overheating) and next level predictive maintenance
- Voice-enabled natural language instructions for field maintenance workers
- Customer service personalization and offers based on individual customer usage patterns and preferences to optimize the grid

By enabling the above functionality, the Level 2 Architecture shows supporting systems and data. An important aspect of the architecture is the security surrounding not only the IT systems/data and the OT systems/data, but also the overall security fence around the CRoF to provide end-to-end security from sensor to management to display.

evaluating the existing infrastructure, identifying potential integration challenges, and ensuring that the necessary resources and expertise are available to support the transition to CRoF. A phased approach, starting with pilot projects and gradually scaling up, can help mitigate risks and ensure a smoother implementation process.

Figure 4: Typical Architecture level 2



Prioritization perspective and implementation journey

Modernizing the grid towards the control room of the future is a monumental task that will span five to ten years or even more to be done successfully. Given the time-to-value and required investments, we have summarized some of the key considerations for prioritization and implementation towards the control room of the future. These include:

- **Time-to-value:** Use cases that yield benefits sooner will be easier to justify. Those with the highest potential value are likely to require longer runways, so be sure to obtain investment early.
- **Implementation feasibility**: Assessing the technical and operational readiness of the organization to adopt new technologies and processes. This includes
- **Cultural considerations and appropriate organization:** Shifting an internal culture towards a different way of working is always a barrier to manage and consider. To best manage this, think about which groups will be most affected, how to upskill at scale, and which people you can start small wins with to be your internal champions.
- **Go across the enterprise:** When identifying the highest priority use cases, include stakeholders from across the organization and include them as part of the process. Having team members involved from the start will get the required buy-in during pilot and implementation phases.

Implementing the control room of the future

Implementing a control room of the future is a complex and multifaceted task that comes with several inherent challenges. These include:

Standardization	To enable the CRoF ecosystem, creating a standardized approach is critical. (Staying aligned to that approach is just as important!) This helps ensure interoperability between devices, and enables unified monitoring and management capabilities, ultimately enhancing system reliability and efficiency. 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 to support a more cohesive solution for the CRoF 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 based • 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.
Virtualization	Virtualization creates a digital representation of physical computing resources, allowing multiple virtual machines (VMs) to run on a single platform. This approach replaces the need for separate hardware for different software components. In the control room of the future, virtualization across multiple platforms 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, and supports: • Virtual devices that can in turn support multiple hardware and configurations • Reduction of hardware requirements • Optimized solutions that can scale across fleet and can be rolled out faster • Simpler monitoring through simplified management • Lower overall costs
Sovereignty	In a tough geopolitical and uncertain environment, electric grids – as well as other energy infrastructure components – provide essential services, enabling people's lives, wellbeing and development. Governments and grid operators are responsible for energy continuity of service, resilience, efficiency, affordability and independence in the related infrastructures growth and operation.

	In some places, sovereignty policies take the form of legal platforms. These platforms include national (or regional) preferences, boarder taxes for imported goods or services, obligations, and a panel of solutions to prevent foreign dependence. The US, Europe, Canada, and even China in specific cases have set their regulatory measures. For electric grids, sovereignty means control of equipment supply (hardware), including their parts and the required rare earth and metals, and also software and services. And this question doesn't end by listing goods and services supplier origin and compliance, but also by securing an offer market large and diversified enough to avoid any disruption in supply and guarantee fair and competitive prices.
Adaptation to climate change / resilience	Critical infrastructures like electric grids must be reinforced to resist events, floods, high-speed wind, fires, and heating waves. The control room will play a critical role in operations resiliency. Examples include flood detection, lighting event detection and equipment fatigue assessment, heat measurement, vibration monitoring, to prevent lines and connectors failure, vegetation management analysis and interventions commands, detection of equipment to reinforce or maintain (enhanced predictive maintenance), self-healing in case of outages.
Industrial policies (procurement and eco-systems management)	The decision to move towards a CRoF will not be made by utilities alone. Given their accountability to both governments and the public, the degree of automation and transformation will require buy-in by multiple stakeholders and the regulation body. The degree of stakeholder buy-in will translate into policies, funding and support that determine the pace of utilities transformation. Being able to tell a compelling story of the benefits of CRoF and justify pilots and business case that deliver real value will be an important success factor for moving towards CRoF. Then, the challenge will be to form ecosystems and select solution and service providers, including various key characteristics of these ecosystems: innovation, sovereignty, strength, sustainability, commitments to the results and of course, competitiveness.
Grid operation changes and user adoption risk	There is a significant risk that the ultimate solution may not be adopted by the end users, particularly the operators who will be using the system daily
Bio-diversity management	Utility operations can significantly impact biodiversity through habitat destruction, fragmentation, water pollution or temperature elevation, and wildlife mortality. Power plants, transmission and distribution lines, and infrastructure development can destroy natural habitats, disrupt migration routes, and contribute to pollution, including chemical runoff and thermal discharges into water bodies. Fossil fuel-based generation exacerbates climate change, further threatening ecosystems, while renewable energy projects and grids may still displace habitats. Electromagnetic fields, invasive species spread, noise pollution, and chemical waste also pose risks to wildlife. For all these reasons, any infrastructure build project should integrate biodiversity impact assessment as a criterion. The control room of the future will play a crucial

	role in mitigating and managing the impacts of electricity on biodiversity through several advanced technologies and strategies. CRoF can include integration of real-time monitoring, GIS network data and data analytics, powered by IoT devices and (wildlife) sensors, can track environmental conditions and wildlife movements, allowing for timely disposals to prevent wildlife collisions with power lines (bird diverters for instance). Features can be included to identify sensitive habitats where automated and remote operations reduce the need for on-site maintenance, minimizing human disturbances. CRoF can act as a hub for data sharing with environmental agencies, conservationists, and other stakeholders. By protecting biodiversity, measuring networks impact on wildlife, but also providing real-time data on environmental conditions, biodiversity, and habitat health, utilities can work more effectively with conservation groups to address issues such as habitat fragmentation and species protection.
Cyber resilience	An automated CRoF means a larger number of sensors, endpoints and automation across the grid. Digital exchanges with third parties will also significantly increase and become central. Inherent in this is a higher-level risk of cyber resiliency. This risk is particularly important the utilities industry given this critical infrastructure's potential to disrupt essential services, public health, safety and significant economic losses. As utilities move towards an automated control room, it is important that knowledgeable employees oversee the outcomes of AI agents and algorithms to ensure the right decisions are being made, and the appropriate security precautions and access rights are enforced. Anomaly detection will be another key security feature to help utilities move towards a safe and responsible CRoF.
Complexity of Brownfield Projects	These projects are inherently complex due to existing infrastructure and systems that need to be integrated or upgraded.
IT/OT Convergence	For this type of project, integrating IT and OT is essential, but challenging.
New architecture design / urbanism – Integration	The architectural design of the control room of the future is built to support the new intelligent grid and includes back-end systems supporting the grid enablement, integration of information technology and operations technology systems, along with data in a more IT/OT convergent environment. This new architecture allows for the grid to be optimized with high fidelity data from more points of data with the use of smart metering sensors that proliferate the grid landscape. Using integrations from IT systems, like AMI and Analytics, leveraging external data as well, the grid operation team can leverage these sensor and external data points to support better grid management. From the architecture defined above, the control room of the future will provide a transparent real time view of data to support quicker identification of potential issues in the grid, better insight into grid assets like DERs and MicroGrids, and

	visibility into EV introductions and management across a single control entity and presented through a single pane of glass. As utilities see large impacts of electric vehicles, photovoltaic growth, battery storage and other new DER impacts, the integration of data between systems across the IT/OT border is becoming more important.
Skills enhancement and management	In just few decades we are moving from an electrotechnics-only grid to an electrotechnics and digital grid. That means new skills. In the same time, baby boomers are retiring, and the massive electrification requires bigger grids to build or reinforce, and more engineers and workers to build and operate it, in a new way of working. By implementing the CRoF, utilities can leverage a ubiquitous data system across both IT based systems, like the systems supporting the meter-to-cash flow, and OT systems that support grid operations, that can help in easier cross-training of the workforce with skills to support the entire ecosystem. By optimizing the visualizations in the CRoF, and by building commonality and standardization to the visualization designs, the workforce can grow skills to operate and maintain systems, define and optimize analytics and produce onscreen, near real-time reporting. This capability will support the growth of the current workforce as well as upskilling individuals reinforced by better teamwork and collaboration through a common platform and visualization. This will also strengthen management of systems and people in a more harmonious approach by having people trained using the same visualization standards. The skills enhancement and management can span across multiple disciplines within the CRoF, including: • Grid Operations and Management • Data and Analytics • Smart Metering Monitoring and Management • Renewable Energy Monitoring and Management • Outage Management • Vegetation Management • Predictive Maintenance • Project Management • and others Hybrid profiles mastering technical and digital aspects are essential. The rapid development of standards (e.g. IEC 61850) and digital technologies that are being integrated into the smart grid means that we need to work together as a network, in partnership with engineering schools, universities and partners such as integrators and suppliers who are committed to developing long-term. This means setting up communities and regularly updated online training courses. IT/OT convergence, with the spread of virtualization technologies to OT environments, is bringing about a change that requires appropriate training.

Performance management	Implementing a control room of the future is a significant endeavor across time, resources and investment costs. Because investments are often driven through investors or public spend, tracking progress in the form of benefits realization, spending and pace of organizational adoption is required to drive accountability and confidence from investors and end customers. Common KPI's to consider include: • OPEX efficiency measures relative to peer utilities (e.g. cost per megawatt-hour or per kms of lines), as well as compliance with regulation targets • CAPEX ROI of pilot and production-level CRoF use cases • Digital platforms to monitor the status of CAPEX projects and tracking expenditures against budgets and timelines • Business KPI's include reliability, customer satisfaction, line losses and others. These should be specific to the use cases being implemented • Financial KPI's related to ROI, ROA, EBITDA improvement and more.

Conclusion

Progress in technology, electric systems and grid changes are so important that we need to consider new grid operations platforms (and ways of operating it). These platforms are commonly named control room of the future (CRoF). From an R&D project 10 years ago, we have moved to the need to take forward seriously this concept and the first implementations time.

What is CRoF?

Compared to actual control rooms, CRoF relies on a new architecture platform, enabling disruptive ways of operating electric grids. This platform, also a smart grid integration component, must be solid enough for decades of operations, whatever the electric grid architecture and technologies evolutions will be, leveraging IT/OT convergence as well as enterprise systems integration. Of course, this platform shows the highest levels of standardization, inter-operability and cyber risks protection.

What are the key characteristics of these CRoF platforms? CRoF brings new features to the grid operations, notably:

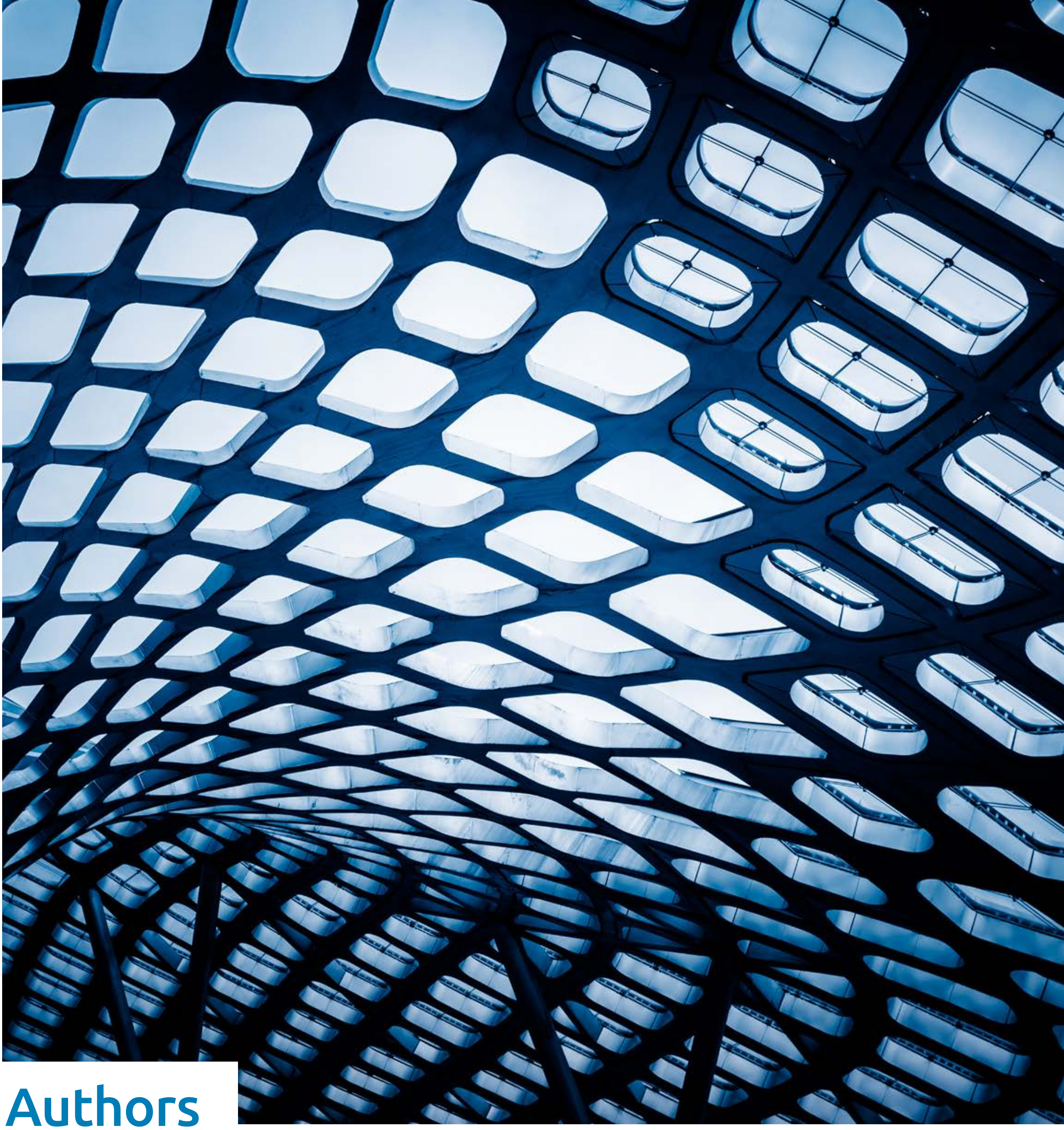
- Fully automated grid operations, self-healing capable and including all flexibility levers (generation, storage and demand side)
- Data and AI powered digital twin ready
- Able to integrate electric grids and other networks convergence (micro-grids, gas, H2, heating & cooling networks) with a power to X / X to power paradigm
- Advanced modeling and forecasting features

Many benefits are expected from the CRoF:

- Maximum use of the available grid capacity
- Deferment or even avoid grid investments
- Operating cost for balancing and congestion management reduction
- Mean Time Between Failure increase (MTBF) while Mean Time to Repair (MTTR) decrease
- And, at the end, energy transition enabled

No utility can escape from this transformation. Journey considerations

- Getting to an automated CRoF will be a 5-10+ year journey. Prioritization of high value use cases will be required to drive focus and show results along the way. With the proliferation of AI and AI Agents, combined with exponential load growth and grids architecture transformation, there is no better time to invest in an automated CRoF
- Cultural barriers and upskilling will be required as jobs change. Like any major technological progress, jobs will move up the value chain and workers will need to adjust
- Use cases and roadmap of steps will vary by utility, local requirements, and regulations. Use objective measures like a quantified business case to prioritize actions, and KPIs to track progress and maintain accountability.



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