Control rooms must evolve to handle the *modern electric grid*

Capgemini | CIGRE Canada

Control room operators hear every few years that some new technology will revolutionize their work. Sometimes it brings genuine changes. Other times it's merely media hype.

Operators know that the risks involved in managing control rooms are too large to experiment with untested tools or processes. Trusted strategies must be respected. At the same time, it's important to acknowledge that artificial intelligence (AI) will change control rooms as we know them. This isn't a matter of if. It's a matter of when.

But there are good reasons to cautious. Even with helpful, transformational automation, operators need the ability to intervene and act – there's too much on the line to turn over trust to the machines completely.

Operators must ask themselves, "Who will be in the driver's seat? AI or me?" That's one of the reasons Capgemini has dedicated so much time to developing our solutions and services for building the control room of the future (CRoF).

Why control rooms are destined to change

People are using electricity in new ways, such as charging electric cars (EVs) or generating their own power with solar panels. The rise in renewable energies and innovative distribution methods complicate the already difficult job of predicting and managing energy demand.

Transforming the control rooms of electric utilities and grid operators can help address this challenge – providing reliable, affordable, and environmentally responsible energy. Control rooms are the centralized command centers for managing virtually every aspect of the grid's complex operations. Given their significance to the entire energy system, they rank among the most effective places to deploy new technologies and ways of working for lasting change.

Recently, with a transatlantic team of Capgemini colleagues, I co-authored a paper on how energy companies can move toward smarter, more resilient control rooms. We will present our paper, *Benefits and challenges of an advanced architecture for the control room of the future,* at CIGRE 2025 International Symposium in Montréal. The event brings together key players from the electric power sector (e.g., business leaders, regulators, manufacturers) to explore the latest trends and developments and highlight new research.

What follows is a high-level overview of why energy companies must transform their control rooms and how they can achieve this.

The challenges facing utilities today

We identified five major interconnected challenges that electric utilities need to address to navigate the energy transition successfully.

1. **Integrating distributed energy resources (DERs):** Private residences and commercial enterprises alike can have small-scale energy sources (e.g., solar panels, EVs, smart thermostats) that connect to the electrical grid and compete with traditional resources in wholesale electricity markets.

2. **Meeting fluctuating demands:** The electrification of transportation (e.g. battery supply chains, charging infrastructure, hydrogen fuel cells), heating (e.g., heat pumps, heating systems), and other services are increasing the demand for electricity rapidly. But its variable nature makes it difficult to predict.

3. **Managing bi-directional power flows:** High levels of energy prosumers, who both produce and consume, require operators to manage power flows in both directions (i.e., from the utility to the public and vice versa). This requires voltage control, system balancing, and traffic regulation.

4. **Responding to extreme weather:** Climate change exacerbates hurricanes, floods, wildfires, winter storms, and so on. This necessitates heightened rapid-response capabilities and resilience strategies.

5. **Moving beyond legacy systems:** Most businesses rely on some outdated systems that lack the flexibility to rise to today's challenges. This is especially true for energy company's existing control room architectures, which are often based on older SCADA (supervisory control and data acquisition) systems designed for centralized, one-way power flow

The CRoF: Reliable, efficient, resilient

System operators will need to evolve the capabilities of control rooms to handle increasingly complex energy demands.

The energy transition is a massive international challenge, and the CRoF is not a single concept developed by one company or group. It is a global concept emerging across various companies, universities, and industry associations.

Capgemini has developed its own framework for building the CRoF on top of existing functions, like real-time monitoring, predictive analytics, remote operations, and enhanced visualization. It requires establishing a centralized view of the global architecture across information technology (IT) and operational technology (OT) systems.

Architectural shake-up: From monolithic to modular

Transitioning from traditional, one-size-fits-all to modular, microservices-based architectures will allow control rooms to make the necessary changes. Without overhauling the entire system, utilities can incorporate DERs, EVs, and renewables as well as advanced tools for predictive analytics and system optimization.

Distributed event streaming platforms like Apache Kafka capture real-time data from various applications and databases, allowing for fast responses to power surges and similar issues, while supporting predictive decision-making.

On-premises systems will still be able to handle real-time control (i.e., fulfilling low latency requirements), while cloud environments accelerate the deployment of emerging technologies for scalability, high-performance computing, and much more.

Edge computing will bring data processing closer to DERs and smart meters to improve accuracy. And data governance platforms will protect the flow of information back to the control room.

Dynamic grid models will evolve to represent real-time grid conditions, providing predictive insights to support proactive management. Digital twin technologies will create virtual replicas of the grid, allowing for simulations of various scenarios.

Among many other use cases, artificial intelligence (AI) and machine learning (ML) will automate fault detection and adjustments, minimizing the need for manual intervention and creating a largely self-healing grid. The technological framework that guides this type of implementation is known as FLISR (fault location, isolation, and service restoration). The AI and ML tools will continuously learn from operational data to provide new insights on driving system efficiency.

Finally, as the energy market becomes more participatory, the CRoF will need to be architected to interact with a growing ecosystem of external players. This will require the integration of secure, standardized application programming interfaces (APIs) and interoperability frameworks.

These are the key enablers for establishing the foundation for the CRoF.

The human element: Supervising intelligent systems

Virtualization, the creation of a simulated computer environment instead of a physical machine, can increase flexibility, scalability, cost savings, etc. When it comes to control rooms, virtualization will enable remote supervision, cross-jurisdictional support, and so forth.

But human workers will still be essential for successful control rooms. Their roles will simply be different, which will require upskilling. Rather than managing every event directly, operators will act as supervisors to the intelligent systems: validating automated decisions, intervening during anomalies, and managing forecast-based operational risks.

Operators need to know why AI systems make certain decisions and have the chance to either affirm or counteract them.

The CRoF framework combines several practices for human-machine collaboration: human-in-the-loop operations, explainable AI, and operations readiness. Control rooms will need the efficiency of automated operations as well as the security and expertise of human oversight.

1. **Human-in-the-loop operations:** ML and AI engines generate real-time recommendations and automate routine tasks. Operators use their judgement for high-stake decisions and validate, adjust, or override automated decisions as needed.

2. **Explainable AI:** Automated systems and programs provide transparent and easily understood explanations for their choices and predictions. Understanding the rationale builds trust between the humans and tools but also empowers workers to reverse or prevent actions with which they disagree.

3. **Operations readiness:** Digital twin simulations can be used to recreate the grid in a virtual environment so operators can train in realistic, high-stakes scenarios. Establishing these training centers will help operators develop and improve their situational awareness.

The evolution of control rooms: What lies ahead

The energy sector will unlock transformative potential of the CRoF only after investing in the necessary digital technologies, upskilling the workforce for this framework, and strengthening cybersecurity. Here's how we foresee the CRoF rolling out across the industry in the coming years.

- **The short term (1–3 years):** Utilities will integrate legacy systems and start introducing automations gradually. Operators will still control most operations (with some AI assistance) and start training for roles supervising automated systems.

- **The medium term (3–7 years):** AI and ML tools, cloud and edge computing, IoT-based sensors, and XAI will become the norm. Operators will transition to supervisory roles.

- **The long term (7+ years):** Full AI autonomy and global interoperability will require minimal human intervention, and humans will strategically oversee autonomous systems and customer-centric operations.

If you're interested in going deeper into the precise technologies, you can read the full paper online. Please reach out if you would like to discuss how our Capgemini team can help you achieve the CRoF for your organization. Contact Diljeet Singh, Senior Director, OT Leader, Capgemini Canada, or Olivier Ebert, Director, Capgemini Canada.

About Capgemini

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