Future Control Room Architectures For Grid And Market Integrated Operation

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DIGITAL4GRIDS

DECARBONIZING ENERGY SYSTEMS

What We Discuss In This Report

Current SCADA control rooms play a central role within the organization and distribution of energy. These control rooms have been matured over the last 50 years and served us well. Vendors of these systems have progressively migrated their original EMS, DMS and MMS platform towards Service Oriented Architectures, making this architecture central to their product strategy and roadmap.

However, these Service Oriented Architectures aren't able to solve modern problems, like the growing quantities of interconnections, within the energy space.

This whitepaper aims to provide information about the current paradigm, the limitations of this paradigm and how a modern control room architecture based on open-source technology would look like.

Key Takeaways

- **Adoption of open-source platforms:** transitioning towards platforms like Apache Kafka for effective data streaming and management.
- **Evolution from SOA to event streaming:** shifting from service-oriented architectures to more flexible event streaming frameworks.
- **System operators (TSOs, DSOs) as technology integrators:** emphasizing the need for TSOs to embrace their roles as integrators of cutting-edge technologies.
- **Importance of digital transformation:** highlighting digital transformation as essential for efficiently managing distributed energy resources.

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Introduction – New Control Room Challenges

For years, the primary obstacle to moving toward the clean energy transition and ultimately climate neutrality has been the cost-competitiveness of renewable sources. Today, the challenge of the clean energy transition is no longer about the investment costs in new renewable generation assets but about how to complete system integration of these assets and manage in a cost-effective way the increasingly variable energy system. The fast deployment of renewables in the power system inevitably increases the system flexibility needs: this is where European energy users will have to play a crucial role by unleashing their demand-side flexibility, meaning their ability to flexibly adapt their energy consumption, storage and on-site generation to external signals.

The Role of Digitalisation in Promoting Demand-Side Flexibility

Digitalisation in energy is inherently linked to decentralisation and the development of new prosumer-centric approaches and business models promoting demand-side flexibility to enable further active participation of consumers to the clean energy transition. Availability, reliability and real-time access to energy and other data (e.g. prices, tariffs, forecasts, CO2-content, etc) is the backbone of a consumer-centric and smart energy system. These data can help consumers to better manage their energy usage by generating, storing and consuming energy when it is best for them and the system and to participate in demand-side flexibility programmes.

The Evolution of Grid Digitalisation and TSOs' Digital Transformation

Digitalization of the grid infrastructure has already become a key priority for most of TSOs and DSOs over the past 3 years and several of them have moved forward in accelerating the digital transformation of their whole organizations looking at developing new business models. Over the coming years, TSO should expect a complete shift in the way the system will be operated through digitalization.

The Shift Towards Automation and Cross-System Coordination

The growing complexity of the Power system – turning into a System of Systems to be federated across different business boundaries - will soon prevent TSOs from relying on pure human know how. Control rooms will progressively shift towards automation and machine learning where Control Room operators will turn into trainers and analysts of machine intelligence making use of of real-time streamed data. Furthermore the growing need for coordination required at Pan-European levels as well as nationally across TSO, DSO and market participants requires to not only integrate real-time information from one's own private asset domains but establish real-time transactive Interfaces across systems to be federated.

Introduction – New Control Room Challenges

New System of System approaches

The impact of renewables, distributed energy resources, and growing electricity demand due to increased sector electrification has major implications. It affects future grid capacity and its operation. Moving towards further sectorial integration is crucial. This includes green hydrogen production and deploying decarbonized heat networks in cities. It also involves installing heat pumps in residential settings and creating Vehicle to Grid charging infrastructures. These steps are key to ensuring that decarbonization of the overall energy system is managed at the lowest cost to end users.

The Role of Storage and Interconnectivity

Storage plays a significant role in the emerging solution across various energy sectors. The interconnectivity of systems and smart integration are crucial for TSO & DSO Grid Operators. They need this to deliver the capacity and flexibility required. This is essential to advance through the complex stages of the European energy transition.

Prosumers at the Heart of Integration

Prosumers, at any scale, will become central to cross-sectorial integration. They will explore the best financial options to mitigate the impact of the current energy crisis. Their goal is to decarbonize their processes and operations. This minimizes their exposure to Emission Trading Schemes, which are expanding beyond energy-intensive sectors. All sectors are expected to develop metrics and KPIs to measure their carbon footprint efficiency. This involves expanding real-time data exchange across sectors. This exchange is coordinated through Grid operator control room environments. Tracking carbon origins across different energy value chains will become more important. It indirectly supports the development of new, auditable carbon measurements across sectors. This introduces new needs to secure, certify and audit data transactions from edge hardware throughout the energy value chain.

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Questioning Infrastructure Planning Methods

These new approaches indirectly challenge traditional methods used for infrastructure planning. This involves moving towards cross-sectorial cost-benefit analyses, as seen with Power & Hydrogen. It also affects tools used for system operation. Here, grid flexibilities will need to be identified across sectors. This requires defining critical cross-sectorial interfaces and interoperability principles.

Towards a Coordinated Energy System

The future energy system will be a coordinated system of interconnected systems working seamlessly together. Each sector will manage its operation within its operational requirements as historically developed around SCADA. Yet, it will open new “market coupling interfaces” using the best available standards. The required digital infrastructure will evolve. It will move from central, monolithic, closed environments seen in SCADA control rooms. It will transition to new Platform of platform architectures. Here, data streaming, interoperability, and Open Application Programmable Interfaces will be crucial. They will provide suitable data interfaces for prosumers. Prosumers will wish to flexibly participate in the system. This could include smartly disconnecting during grid emergency situations.

Key takeaways

- **Energy Transition:** Now focused on integrating renewables and managing variability rather than on investment costs.
- **Digitalization:** Key to enabling consumer flexibility and active participation in the energy transition.
- **TSO Transformation:** Embracing digitalization to adapt to new operational models and business opportunities.
- **System Complexity:** Automation and advanced coordination are required for efficient operation and data management.
- **Integration:** Critical to incorporate renewables, green hydrogen, and decarbonization technologies for a comprehensive transition.
- **Storage & Connectivity:** Essential for the flexibility and capacity needed in the evolving energy landscape.
- **Prosumer Role:** Central to achieving decarbonization goals and enhancing system efficiency through smart participation.
- **Planning Evolution:** The future energy system necessitates innovative planning methods and digital infrastructure for seamless integration and participation.

Introduction – New Control Room Challenges

Expanding Data Integration Boundaries

TSOs are well-known experts in balancing supply and demand. Yet, the current energy transition introduces new complexities. These complexities require integrating new vertical coordinated approaches with DSOs. Expanding the Grid quickly enough to match the growth of renewables and electrification is becoming practically impossible. This situation necessitates exploring grid optimization alternatives. Such alternatives are needed to compensate for the growing congestions observed through physical infrastructure constructions.

Demand Side Dynamics and EV Development

The rapid development of electric vehicles (EVs) and further electrification of the heat sector are set to change demand side dynamics significantly. This change will come through the accelerated adoption of virtual power plant aggregation. More resources, mainly at the residential level, will become available to balance the system. However, these resources will be much more dispersed, requiring the development of real-time digital connectivity to the lowest voltage levels at the edge of the electrical system.

Shift in Market Operation and Prosumer Environment

Over the coming years, we should anticipate a significant shift in how the market operates. The market will move from interacting with a few large power plant entities to engaging with multiple flexibility resources in residential prosumer environments. This environment may include several flexibility service providers, as suggested by recent market design recommendations. This shift poses new questions about the extent of the DSOs' role in future market facilitation. The majority of future flexibility will be connected to the distribution system at medium and low voltages. This creates new challenges in congestion management and requires innovative voltage control strategies.

Evolving System Operator Functions and Market Integration

Several System Operator functions are expected to evolve into coordinated processes across TSO and DSO. This evolution raises new questions regarding Control Room connectivity, integration strategies, and interoperability between these entities. To avoid the fragmentation of marketplaces and data exchange platforms across Europe, the key will be to expand interoperability and transparency. Ensuring level playing access for all distributed flexibilities across the value chain is crucial. This approach will ensure the best usage of available flexibilities across sectors.

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Interoperability must therefore be enforced across Europe while the number of market participants increases:

- Horizontally between Power exchanges & TSO marketplaces, as largely initiated through the integration of Pan European market processes such as Flow Based Market coupling on day ahead and intraday as well as coupling of European balancing platforms.

- Vertically between TSO and local DSO marketplaces to ensure the coordinated operation of flexibility from highest voltages down to residential lower, medium, and low voltage prosumers. Such coordination should cover all aspects of DER flexibility registration and qualification processes as well as baselining and real-time activations for fast acting flexibilities such as for storage resources (such as recently tested through Horizon Europe projects such as Interrface and Onenet and prototyped through the Eddie Common European Energy Dataspace project.)

- Between Grid operators, market participant and stakeholders, to ensure that DER integration is made with minimal entry costs into the system while ensuring level playing interactions between wholesale and distributed flexibility at Gridedge, which is today still not the case for a large majority of Grid service rules (often due to limitations in Grid Control room capability in observing and validating the performance of distributed assets at the edge of the system).

Flexibility services should be seamlessly traded through different marketplaces (day-ahead, intraday, balancing, local flexibility markets) and enable revenue stacking to ensure a fair flexibility remuneration. For such marketplaces to scale across Europe and to avoid fragmentation, further efforts should be made by TSOs and DSOs towards market interface interoperability and Control Room integration so that different market places and market participants can send each other relevant price signals and respond in real-time.

In the case of local flexibility markets, the size of these markets and therefore their liquidity, it is important for TSO & DSO to work at progressively consolidating flexibility marketplaces to increase the size of the market and therefore its liquidity. This needs to be supported by interoperability of the market data and product so progressive integration is smooth and seamless from a digital platform integration point of view.

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Exchanging with market stakeholders, future marketplace designs need to consider such interoperability as a base requirement, e.g. by having a published API, and work towards open standards to further promote open competition. Considering the large usage of CIM IEC62325 based APIs across the market platforms such as Xbid, as well as the new electricity balancing platforms. TSOs & DSOs should cooperate to guide a progressive transition of this interface towards harmonized APIs across Europe. Leveraging the CIM IEC62325 message profiles and formats is crucial (as successfully initiated by ENTSO-E through its transparency platform). This approach should naturally facilitate further vertical connectivity between TSOs and DSOs core operational processes and Control Room environments. In order to encourage DSOs to adopt the same standards, TSOs should progressively open up CIM standard developments to DSOs as prototyped through Horizon 2020 project TDX Assist, EU Sysflex or Interrface TDX Assets, EUSysflex, Interrface as well as Onenet and more generally to broad market participant stakeholder environments through Opensource environments.

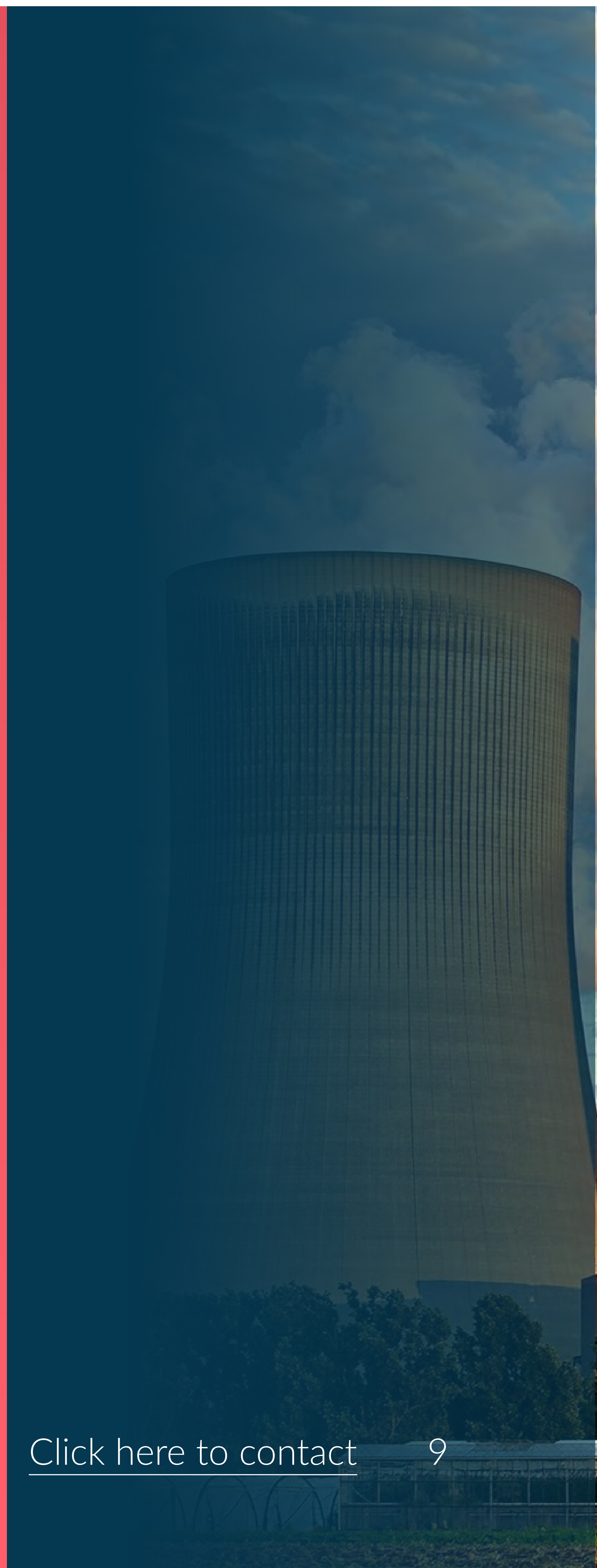
Key takeaways

- **Energy Transition Challenges:** TSOs must adopt coordinated approaches with DSOs and seek grid optimization to keep pace with renewable growth and electrification demands.

- **EV Impact on Demand Dynamics:** The surge in electric vehicles and electrification is reshaping demand, requiring virtual power plants and enhanced digital connectivity.

- **Market Operation Transformation:** The market is transitioning to a prosumer-centric model with dispersed flexibility resources, challenging traditional congestion and voltage management.

- **System Operator Evolution:** TSO and DSO roles are evolving towards interoperability and transparency to utilize distributed flexibilities effectively and avoid market fragmentation.



Introduction – New Control Room Challenges

Expanding Grid Situational Awareness

Market deregulation has led to an increase in market participants. This trend is expected to surge with the emergence of new prosumer-centric market designs. As a result, the architecture of Control Room environments needs rethinking. Traditional SCADA environments must adapt to handle larger volumes of data streaming. They need to incorporate lower granularity time series, moving from minutes to seconds, as system inertia decreases. New control room developments must include data processing through critical event streaming. This will enhance grid operator situational awareness and further automate and accelerate critical decision-making processes.

Integrating Renewables and Forecasting Complexities

The new sets of Regulations (EU GreenDeal, RepowerEU and new Electricity Market Design) aims to accelerate the integration of intermittent renewables into the grid at all voltage levels. This increases the complexity of forecasting and monitoring renewable energy injections across the grid. Classical renewable and load forecasts need adaptation. They must achieve higher granularity in timing and location. The closer forecasts get to real-time, the less grid security margin is needed. This releases more capacity to market participants.

Enhancing System Observability and Data Exchange

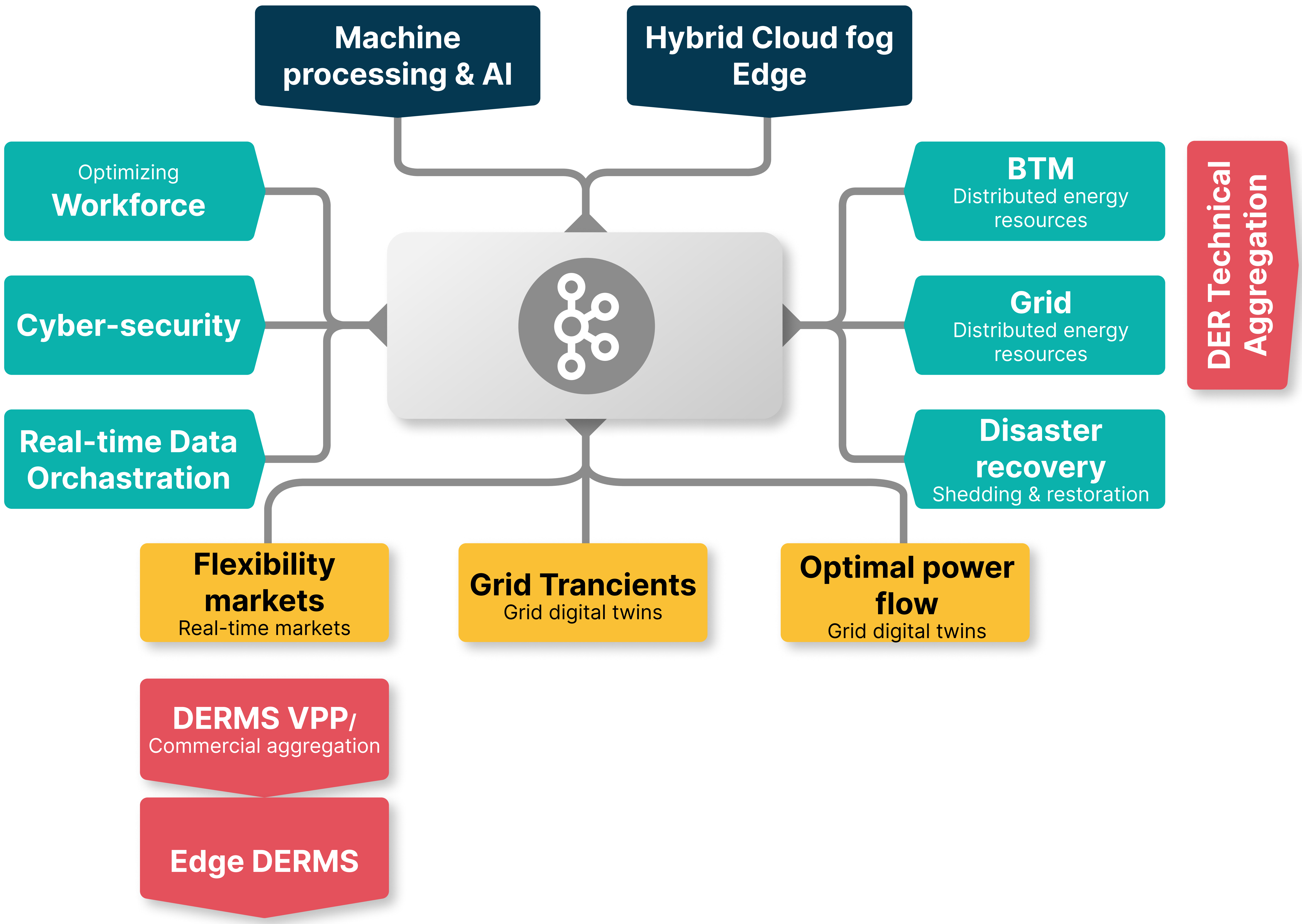
Improvements in compound forecasting methods are crucial. Yet, it is equally essential to expand observability across the entire system. The future will see high volatility in renewable infeed and prosumer net consumptions. These must be monitored in real-time, necessitating the development of new data exchange interfaces throughout the electricity system.

Control Rooms of the Future

Future control rooms will transform into new-generation situational awareness environments. These will provide operators with several digital twins of the grid state. They will incorporate steady-state and dynamic transient calculations. Additionally, they will include all relevant data related to potential cyber threats throughout the system. This evolution marks a significant shift towards more advanced, responsive, and secure grid management practices.

Introduction – New Control Room Challenges

New Kafka4Power Infrastructure



As Is Situation And Current Architecture Limitations

High Level Architecture principles & objectives

The main purpose of Control Room environments has been to manage and maintain the reliability of the power system. Clearly, this goal has been well achieved and the past 50 years' experience of using telemetry to improve the performance of the transmission grids has contributed to mature the SCADA and EMS (Energy Management System) industry and vendor products. Similar approaches have also developed through DSO control rooms.

New challenges have however appeared 20 years ago which has required to rethink the role of grid control centers and their associated functionality. The main challenges experienced have originally been the following :

- **Retiring work force** leading to lack of staff or inexperience in the control room.
- **Deregulation of the electricity industry** leading to new business models for transmission companies with new interactions with power generation units through complex wholesale marketplaces
- **Continuous load flow developments leading to greater stress** on the existing infrastructure and requiring more intelligence in the control center
- **Growing quantities of Interconnections** with potential cascading effects of black-outs requiring the analysis and simulation of larger networks through Regional Coordination Centers
- **Continuous cost reduction pressure** from regulators leading to growing expectation for a better standardization, integration and virtualization of control center environments to achieve corporatewide Grid asset management and operation, financial auditing and regulatory reporting at a lower cost of ownership.
- Lately **new cybersecurity threats** has led to new standards and expectations on EMS control room design and architectures.

As Is Situation And Current Architecture Limitations

Transition to Service-Oriented Architectures by Main Vendors

Main Vendors, have progressively migrated their original EMS and DMS platform towards Service Oriented Architectures, making this architecture central to their product strategy and roadmap. Main regulatory bodies in North America (FERC, NERC) and Europe (ENTSO-E) have been laying the roadmap for control centers on behalf of their member grid operators.
The Service Oriented architectures implemented through the last 20 years have originally been designed to respond to the following high level key objectives:

- Address the ever increasing complexity of control center applications and grow agility in new developments. The numerous regulatory changes introduced by deregulation has required the continuous development of new application making use of strategic Control Room operational data

- Increase the cybersecurity protection

- Reduce the system maintenance cost

Adapting to Competitive Pressures: Single Platform Strategies

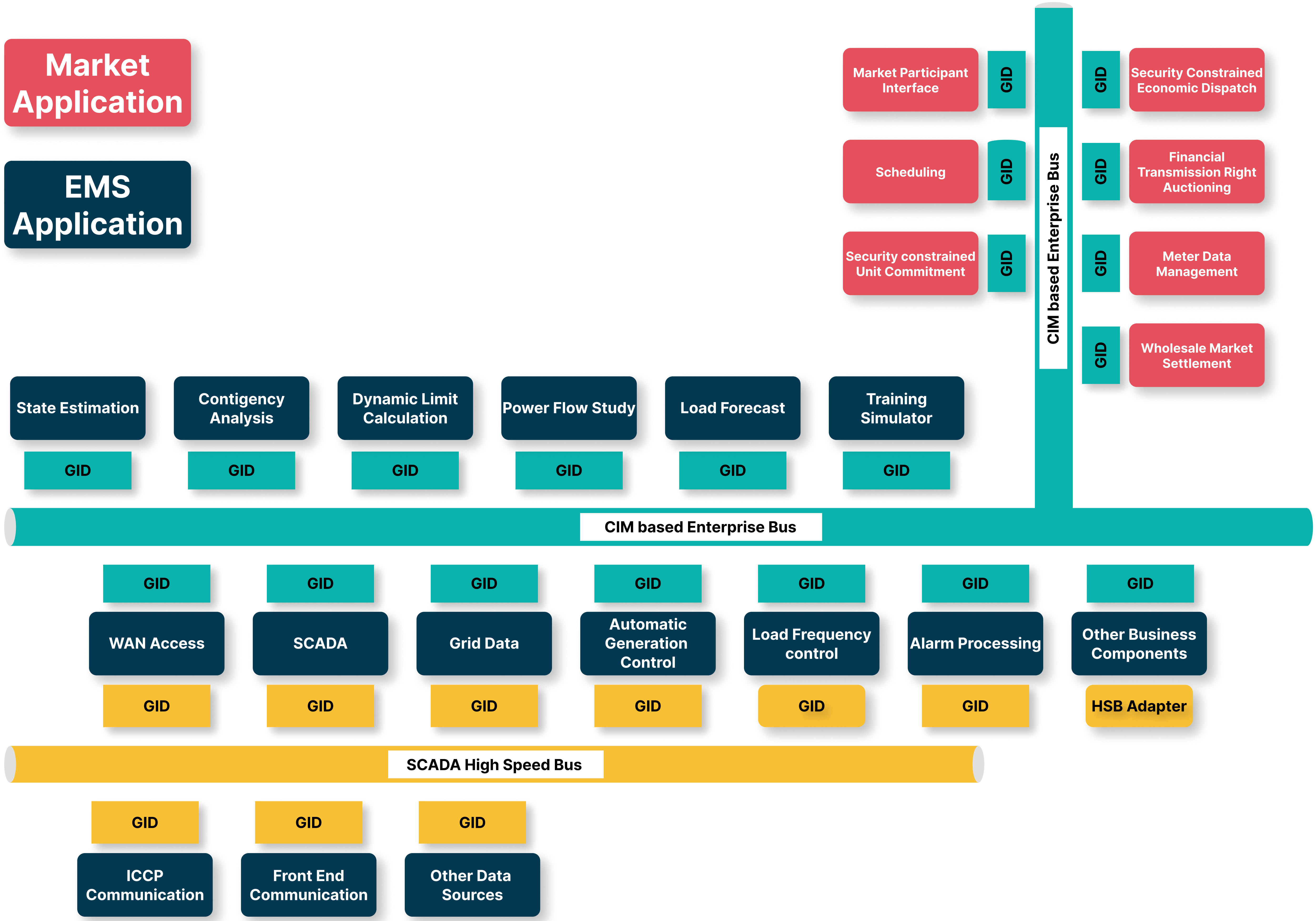
Control room vendors, facing competitive price pressures, have started adopting single platform architectures globally. These adaptations consider diverse IT strategies for control center implementations. Not all environments have middleware buses for integrating applications. Where middleware exists, these architectures capitalize on it using adapters. This approach incorporates a middleware abstraction layer, facilitating deployment both with and without an Enterprise Service Bus (ESB).

Transitioning to SOA: A New Era for Control Rooms

To meet the goal of a unified platform, vendors have modernized their decades-old SCADA systems into the Service-Oriented Architecture (SOA) model. This shift leverages emerging data exchange standards, like those derived from CIM/CME. The transformation involved creating software interface definitions and a common services library. It aimed at evolving Energy Management Systems (EMS), Distribution Management Systems (DMS) and new market applications into a suite of components. These are designed to be standalone, reusable, and interoperable across different vendors' offerings.

As Is Situation And Current Architecture Limitations

This architecture is coherent with the requirements originally formulated through the CIGRE working group, D2.24 (as shown of the following diagram) which has been used as a key reference driving these developments. One of the key objectives was to maintain or exceed the requirement of high performance, security and availability as historically known in the SCADA industry.



As Is Situation And Current Architecture Limitations

The three main tasks that vendor had to focus through these re-engineering efforts have been:

- To standardize the common software services for re-use across all applications and for lower cost of maintenance. One of the key objective was to ensure interoperability of these applications across vendor leveraging CIM standards

- To develop a new common set of services and interfaces for all user interfaces.

- To transform monolithic applications into individual modules for better interoperability within the control center suite of systems.

- To progressively develop adapters to the enterprise service bus for flexible process management using a common IT strategy.

Key takeaways

- **Control Room Transformation:** Control rooms have evolved from focusing on power system reliability to addressing new challenges like workforce dynamics, deregulation impacts, infrastructure stress, and cybersecurity threats, prompted by technological and regulatory changes over the last half-century.

- **Vendor Evolution to SOA:** In response to these challenges, major vendors have migrated to Service-Oriented Architectures (SOA), enhancing agility, cybersecurity, and reducing maintenance costs, aligning with global standards and regulatory expectations.

- **Strategic Objectives:** The move to SOA aims to manage complex applications, improve cybersecurity, and lower maintenance costs, leveraging single platform architectures to meet competitive and regulatory pressures globally.

- **Re-engineering Efforts:** This transition involves standardizing software services for interoperability, developing a unified suite of services, and modularizing applications for better integration and flexibility within control center operations.

As Is Situation And Current Architecture Limitations

Architecture bottlenecks & limitations

Although the original concept of Service-Oriented Architecture (SOA) was promising, its real-world implementation has faced many challenges. These include difficulties in opening up and connecting with new data streams outside traditional substation grid boundaries. This has led to increasing limitations.

The Complications of Integration Solutions

Integration solutions like the Enterprise Service Bus (ESB) were designed to decouple systems in SOA deployments. However, the need for applications to both publish and subscribe to data simultaneously has kept systems intertwined. Each vendor's unique definition of Common Information Model (CIM) derived interfaces complicates integration. This situation has led to increased dependencies on back-end IT systems for control room projects, making these deployments more complex despite appearing open on paper. The limited interoperability has deterred many grid operators from taking on their own control room integration projects.

The Increasing Complexity of Enterprise Integration

SOA architectures have made enterprise integration more complex. The development of new deregulation processes and the integration of diverse new data streams have emphasized the need for sophisticated integration within control room environments. This includes dealing with various technology stacks, programming languages, application architectures, and communication paradigms. Such as:

- the integration of various Technology stacks as control room platforms have typical long lifecycle of 10 to 20 years : standards like SOAP, REST, JMS, MQTT, data formats like JSON, XML, Apache Avro or Protocol Buffers, open frameworks like Nginx or Kubernetes and proprietary interfaces like CIM webservices, EDIFACT or SAP BAPI

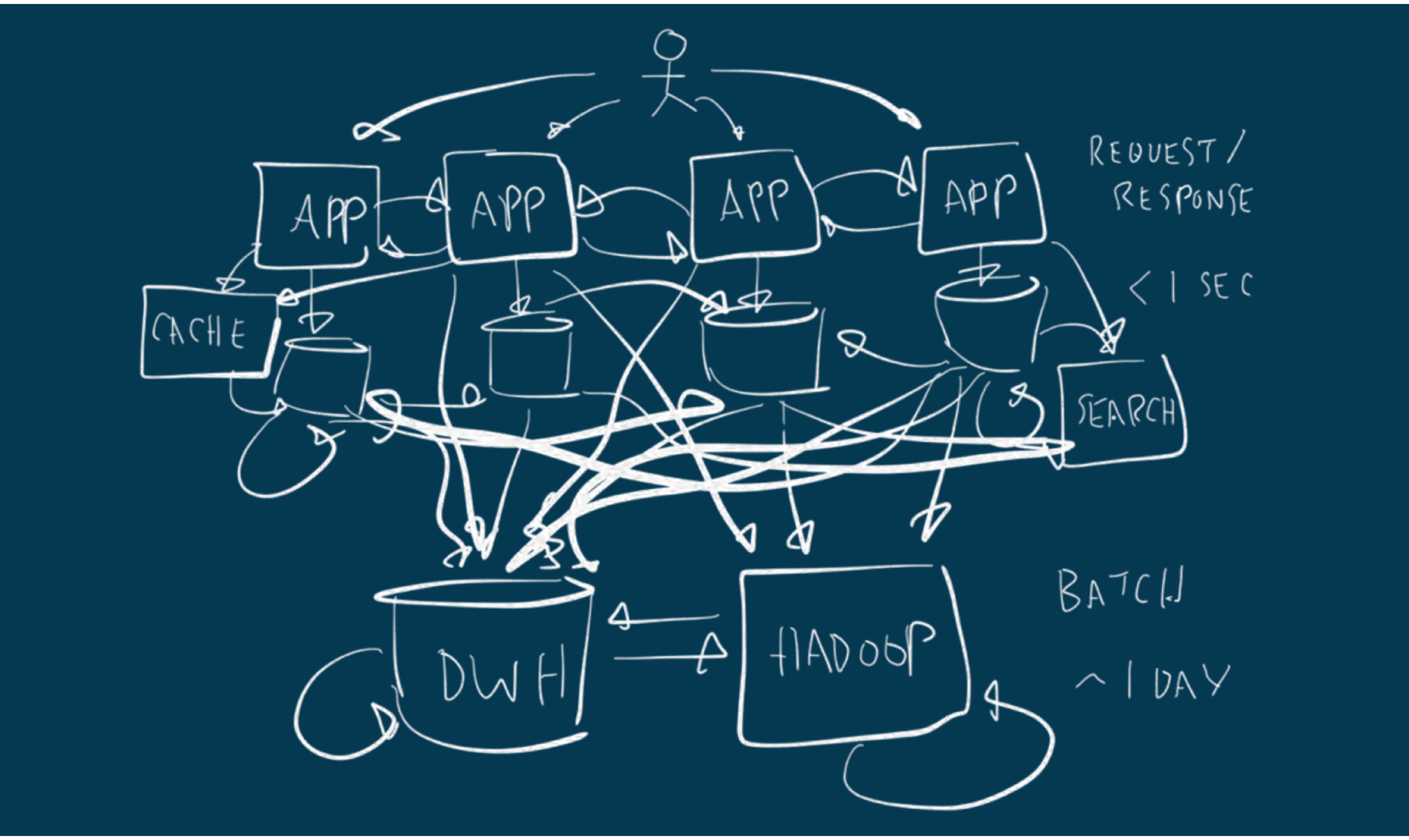
- the management of different generation of programming languages and platforms depending on the application maturity, such as typically Fortran, Java, .NET, Go or Python

As Is Situation And Current Architecture Limitations

- the combination of various application architectures like Monolith, Client Server, Service-oriented Architecture (SOA), Microservices or Serverless

- the integration of new communication paradigms like batch processing, (near) real time, request-response, fire-and-forget, publish subscribe, continuous queries and rewinding

While SOA architectures were theoretically designed to move away from monolithic single source developments through loosely coupled interoperable software components, most of recent control rooms developments ended into complex integration architectures as follows :



A majority of SOA projects in the last two decades have therefore failed in delivering the expected agility, scalability and cost efficiency as originally envisioned. Instead of using too complex Entreprise Service buses, enterprises are therefore now quickly pivoting to new streaming platform architecture option to solve limitations of SOA architectures.

New event streaming platform architectures

New **event streaming platforms** leverage events as a core integration principle which is particularly relevant in Grid control rooms where the majority of key business processes are orchestrated around Grid data streams. In this new approach, the architecture is designed in view of event data flows while data processing is orchestrated on data while they are in motion. It has the following key characteristics and benefits :

- **Event-based data flows** as a foundation for (near) real-time and batch processing. In previous SOA architectures, applications were built on data stores (data at rest), which was making it impossible to build flexible and agile services to act on data very close to real-time.

- **Scalable architectures** for all events shared across infinite sources and sinks processes. As opposed to centralised monolythic applications, the architecture is built on scalable, distributed infrastructure, built by design for zero downtime, handling the failure of nodes and networks while being able to roll out upgrades online. Different versions of infrastructure (like Kafka) and applications (business services) can be deployed and managed in an agile, dynamic way. This approach minimises dependencies across application which is particularly complex to manage in SOA architectures.

- **Integrability of any kind of applications and systems.** Technology does not matter. The streaming environment connects anything: programming languages, APIs like REST, open standards, proprietary tools, and legacy applications which reduces the need to redesign existing legacy applications while allowing to benefit from new cloud development environments for the rapid prototyping of new applications. It reduces processing speed constraints on each application.

- **Distributed storage for decoupling applications.** The platform data streaming environment allows to store the state of a microservice instead of requiring a separate database.

- **Stateless service and stateful business processes.** Business processes typically are stateful processes. They often need to be implemented with events and state changes, for which remote procedure calls and request-response as considered through SOA architecture is not optimised.

Future Hybrid Cloud Architectures

As opposed to previous SOA architectures, new streaming platforms have significant benefits particularly fitting the context of real-time Grid control room environments, as follows :

- **Large and elastic scalability** regarding nodes, volume, throughput—all on commodity hardware, in any public cloud environments, or via hybrid deployments. This approach allows to flexibility allocate control room processes across most suitable computing environments whether from a cost, a security, an energy efficiency or a resiliency point of view anticipating new cognitive computing environments.

- **Flexibility of architecture.** integrate small service with larger one, sometimes still even monoliths core applications preventing too complex migrations of core SCADA applications.

- **Event-driven microservices.** the approach is particularly relevant to manage high throughput data flows as it asynchronously connects microservices across complex business flows and instantaneously move data to where it is needed for real-time computation.

- **Data openness without commitment to a unique technology or data format.** the architecture is able to integrate evolutions of CIM standards, protocols, programming language or development frameworks. The central streaming platform is open to be managed, deployed and federated by Grid Operators directly while connecting with proprietary sources or sinks applications such as proprietary SCADA data format or technology.

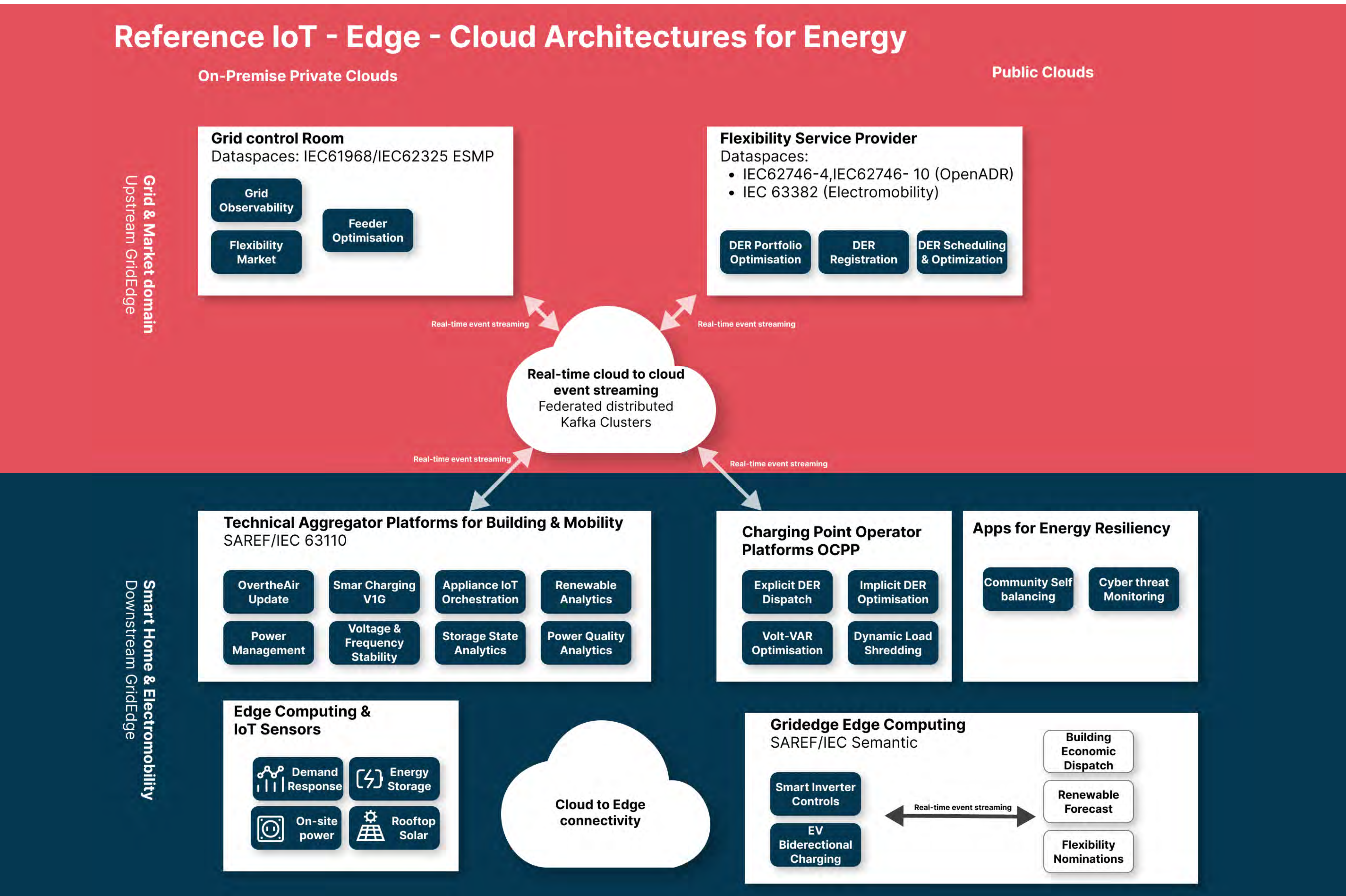
- **Independent and decoupled business services**, managed as products, with their own lifecycle in term of development, testing, deployment and monitoring. This loose coupling approach allows for very different processing speeds between different data producing and consuming applications, on/offline modes while handling backpressure. This approach perfectly match the combination of on-line, near-real time and off-line applications found in usual grid control room environments

- **Multi-tenancy** to ensure that only the right user can create, write to and read from different data streams in a single cluster. This allows to easily share application development across Grid operator such as Flexibility Registers, Grid State estimation as well as Short term netload forecasts..

Future Hybrid Cloud Architectures

- **Industrialized deployment** environments using containers, devops, and associated tooling deployed where needed, whether on premise, in the public cloud or in a hybrid sandpit environments.

The Apache Kafka, open source data streaming has become used and trusted by more than 80% of Fortune 100 companies. It allows for diverse actors to communicate very easily, reliably and in a scalable, de-centralised way through fast real-time environments. As a consequence these architectures have started to develop in Internet of Things (IoT) environments offering easy to integrate data interface from Grid edge. This fast and successful adoption has built sufficient credibility and experience to position event streaming architectures as the key foundation layer for future Grid control room digital transformation. These new platforms offer new agility to Grid operators to flexibility adapt to key regulatory changes positioning Distributed Energy Resources at the center of Grid control room environments.



Integrating Artificial Intelligence and Machine Learning into Grid operation decision support

Historically, TSO and DSO control rooms have relied on rule-based decision-making to enhance grid security. Over the last decade, TSOs have been working to harmonize these rules across Europe. They've incorporated these rules into Network Codes, which align limits and thresholds for triggering specific grid security actions. These rules have been implemented into Operational Technology (OT) systems and tools. This supports control room operators by facilitating decision-making in real time. The drafting of these networks has recently been opened to DSO participation as a result of the European Clean Energy Package with the new Cybersecurity as well as Demand side flexibility network codes which will soon have significant impact on Control Room key applications

The Impact of Digital Developments

Recent advancements in big data and artificial intelligence have significantly increased the capacity to automate these rules. Expert systems are being integrated into control rooms. These systems manage the streaming of larger information flows during critical events. They further integrate associated information into operator decisions.

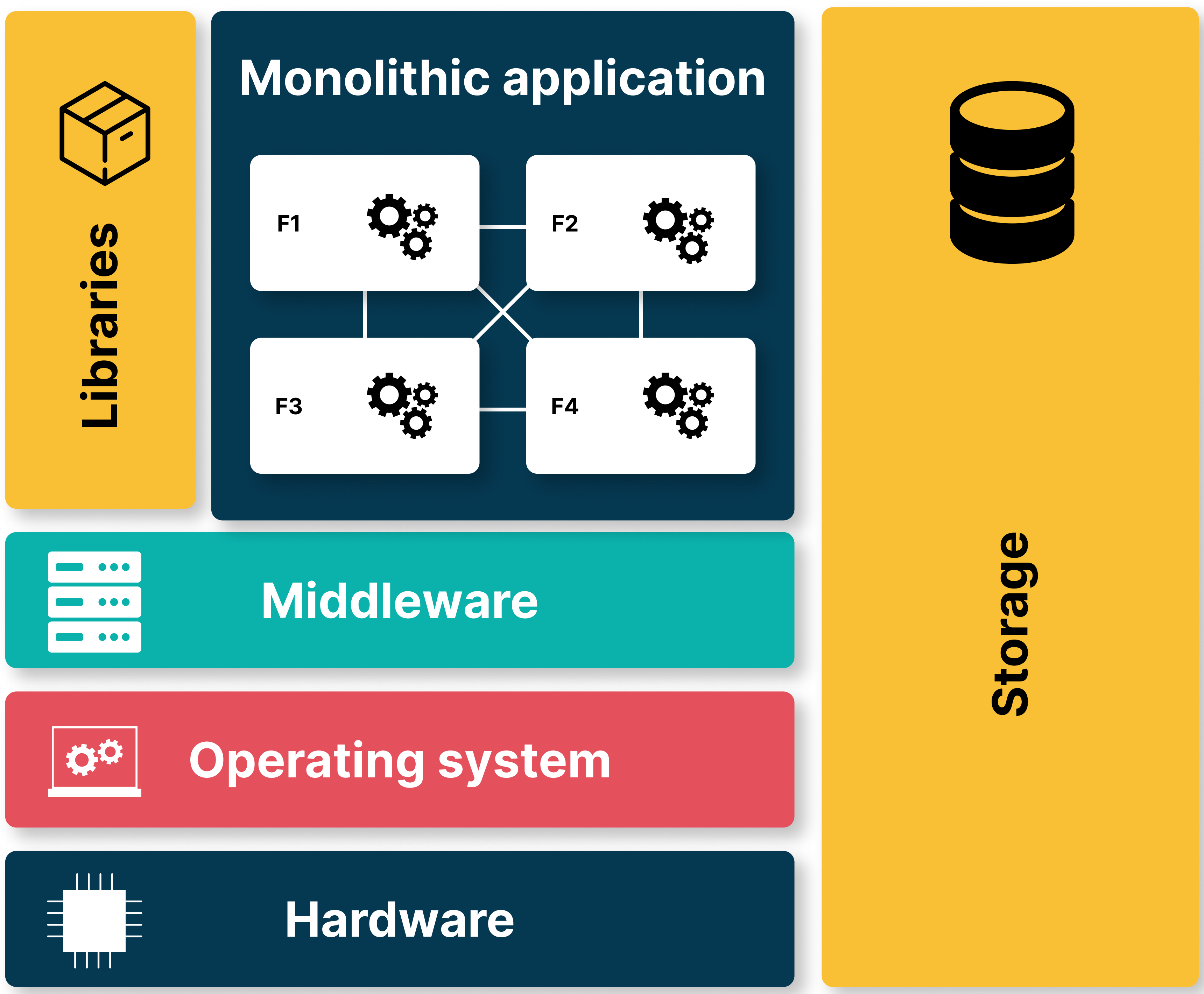
Future Control Room Environments

Control rooms are evolving towards newer generation situational awareness environments. These environments provide Control Room operators with several digital twins of the Grid state. They include steady-state and dynamic transient calculations. Additionally, they incorporate all relevant data related to new threats appearing throughout the system. This evolution marks a shift towards more advanced, automated, and secure grid management practices.

How to achieve necessary transformation

Historical SOA Project Implementation

In the past, organizations started developing their business applications in a single middleware language and a single technology platform largely based on a single SCADA vendor application. The advantages of this was the reduced complexity of developing, deploying, running and maintaining the applications relying on a single SCADA vendor to provide the solution. As companies had to reduce costs of maintaining different technologies and languages, this was the best approach to keep development and operational teams smaller and reduce the complexity of the functional cross-cutting concerns. This however has driven a significant dependency of Grid operator over the SCADA vendor which in return have enjoyed strong positions as being the sole service supplier able to expand this system (while in the same time often having limited engineering resources to support development of new applications).



Future Hybrid Cloud Architectures

Evolving Business Applications: Functionalities and Challenges

Business applications have continued to evolve, incorporating numerous functionalities within a single deployable unit. Traditionally, all business functions were encapsulated in one large file, written in a single backend programming language. However, this approach introduced several disadvantages. The need for bug fixes, the development of new functionalities, and system maintenance (like platform upgrades) often led to general service interruptions. These interruptions have become increasingly problematic as reliance on these applications and their functionalities has grown. Another significant drawback is how a single malfunction in any part of the application can destabilize the entire system, leading to unreliability.

The Monolithic Architecture Dilemma

In a monolithic application architecture, all business functions and services are integrated into a single backend application. This application is deployed on each server, running in its entirety, encompassing all business processes and services. Consequently, if a server encounters performance issues for any reason, the entire application, along with all its functionalities and services, is affected. This situation impacts all user sessions and backend processes hosted by that server.

Scaling Challenges and Resource Allocation

Although deploying monolithic applications across multiple servers (horizontal scaling) can mitigate the number of affected sessions, it does not reduce the area of impact. These applications are generally stateful, meaning the same session continues on the same server until it ends. Should a particular business function require more compute resources, a new server must be set up, and the entire application deployed anew. As a result, business functions and services that do not need extra resources still consume them on the new server, leading to inefficient use of computing power and memory.

Future Event streaming platform developments

Microservices allow business functions to be independently developed by different teams. Each service operates on its own, using distinct operating systems, languages, and tools. This independence facilitates deployment across various platforms, including hybrid clouds, improving scalability and performance. When issues arise in a microservice, the impact is limited to that service, preventing wider application disruption.

Empowering Development Teams

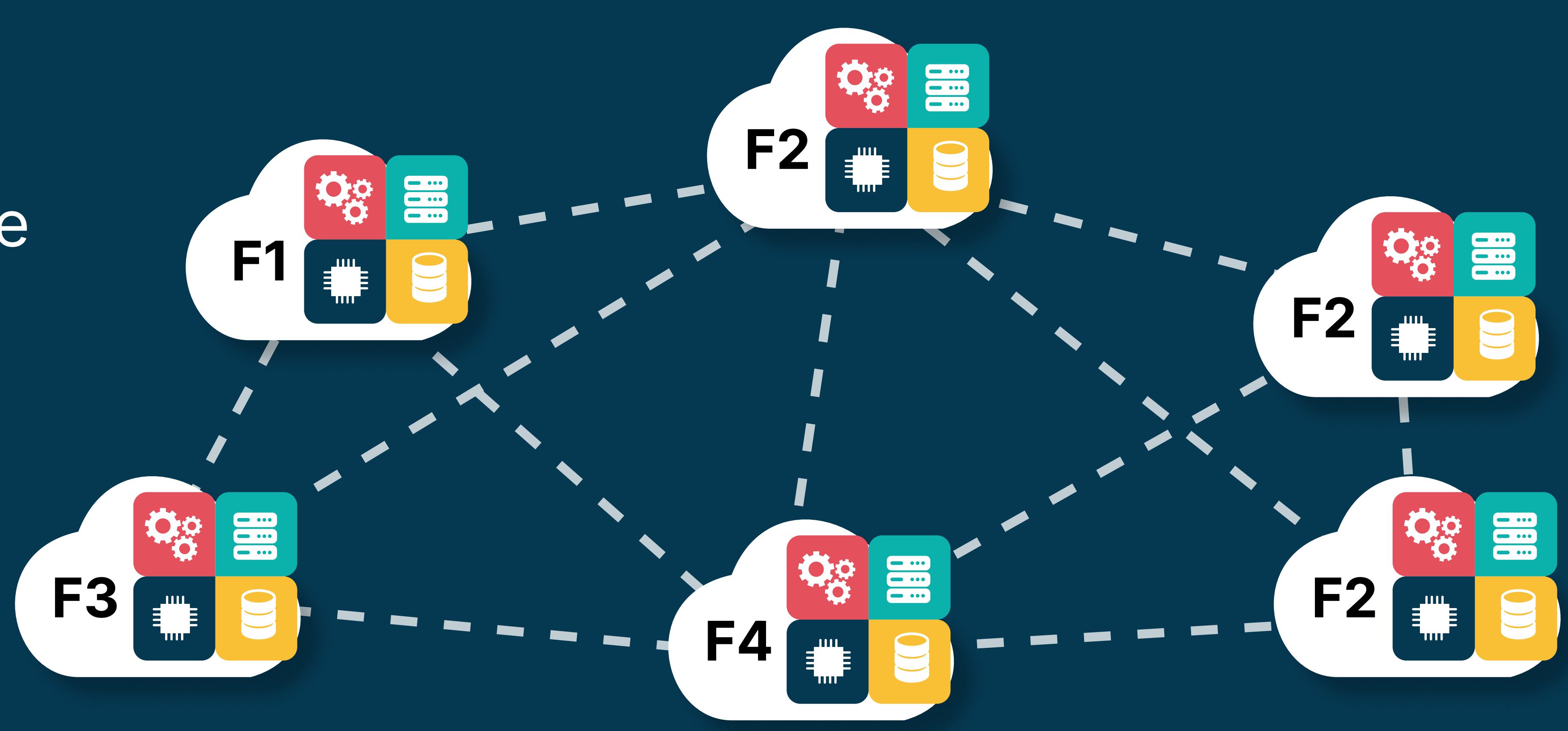
The development teams have the autonomy to choose the underlying operating system, programming language, and libraries best suited for delivering their specific business function or service. They often leverage publicly provided container operating systems. These are lightweight, minimalistic operating systems designed to support the middleware layer necessary for running application packages. This approach minimizes the system's footprint while ensuring the required middleware support.

Leveraging Public Libraries for Efficiency and Interoperability

Developers commonly use public libraries to incorporate necessary functionalities, speeding up development and ensuring compatibility. These libraries, created by a vast community, address common challenges and prevent the need to rewrite existing functional code, fostering a more efficient and interconnected development environment.

Microservices

- Microservices decouple business functions
- Enables independent development of these functions



Future Hybrid Cloud Architectures

Security in Microservices: Guarding Against Vulnerabilities

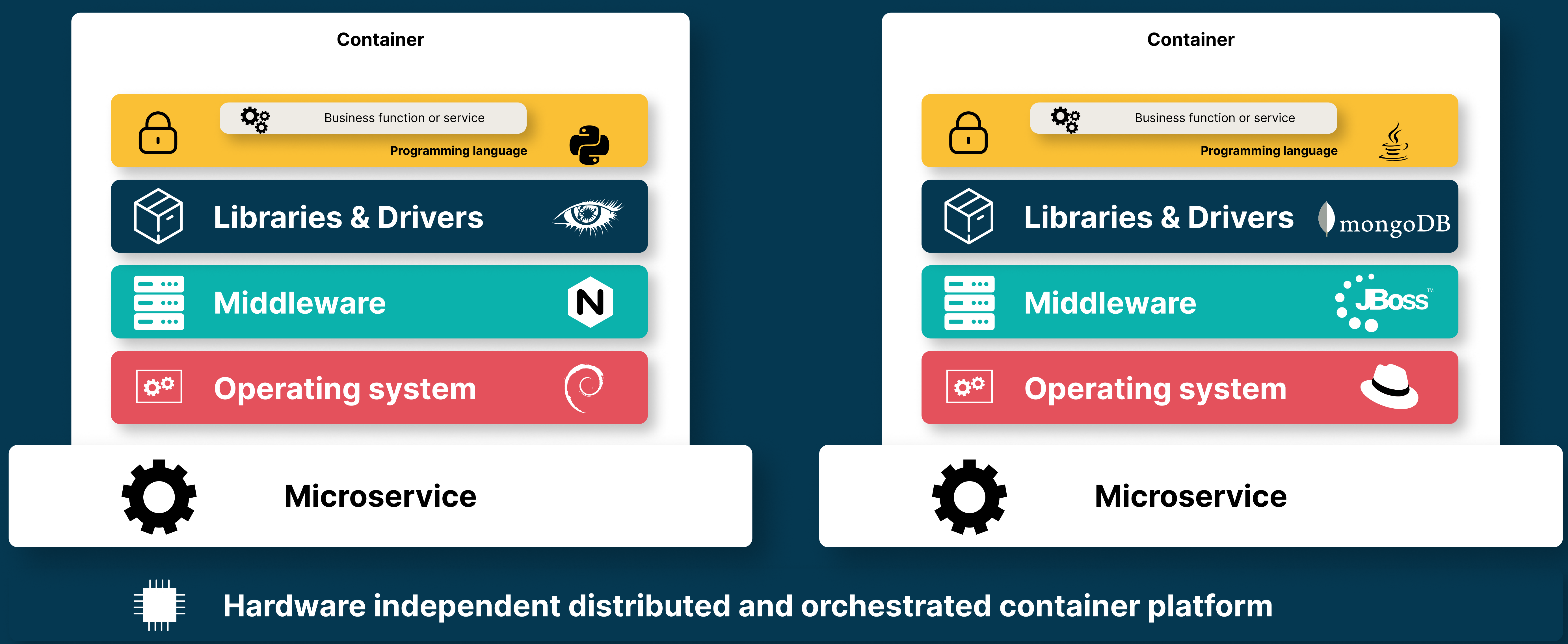
Since container operating systems, middleware, and commonly used libraries are often external, implementing additional security measures is crucial. These controls protect microservices from vulnerabilities in these components that could affect availability, integrity, or confidentiality. Ensuring security also safeguards connected microservices, applications, data storage, and user interactions from potential threats.

Data Responsibility Zones in Microservice Architecture

Microservices introduce "data responsibility zones," where each service manages its business data. This autonomy enables selecting the most suitable technology for handling this data within each microservice, optimizing data structure support.

Flexibility and Efficiency through Technology Swapping

Microservices' structure allows for easy swapping of underlying technologies, such as development languages or storage solutions, without affecting other services. This flexibility enhances a microservice's efficiency and interoperability with other systems, enabling continuous improvement and adaptation to evolving technology landscapes.



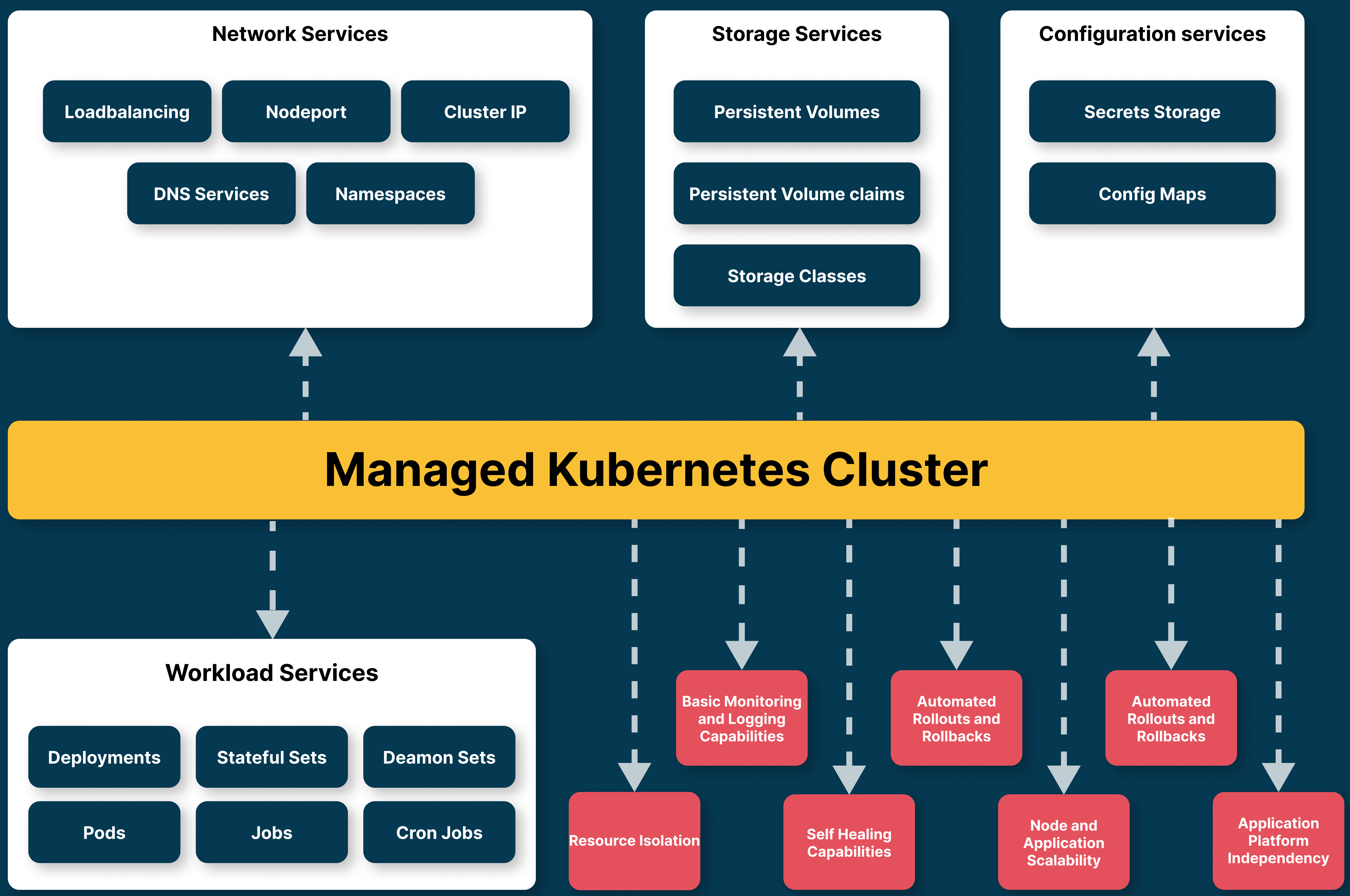
Future Hybrid Cloud Architectures

Kubernetes: The Core of Modern Architecture

In the emerging general reference architecture, Kubernetes stands out as the pivotal open-source platform for container orchestration. It's engineered to host microservices in containers, facilitating their interconnectivity and interaction with the external environment. Kubernetes brings essential tools for deployment, management, and security, acting as an abstraction layer above hardware and server operating systems. This flexibility makes it adaptable to a wide range of business needs and deployment scenarios, including on-premise data centers and various cloud configurations—ranging from self-hosted infrastructure services to fully managed container platforms.

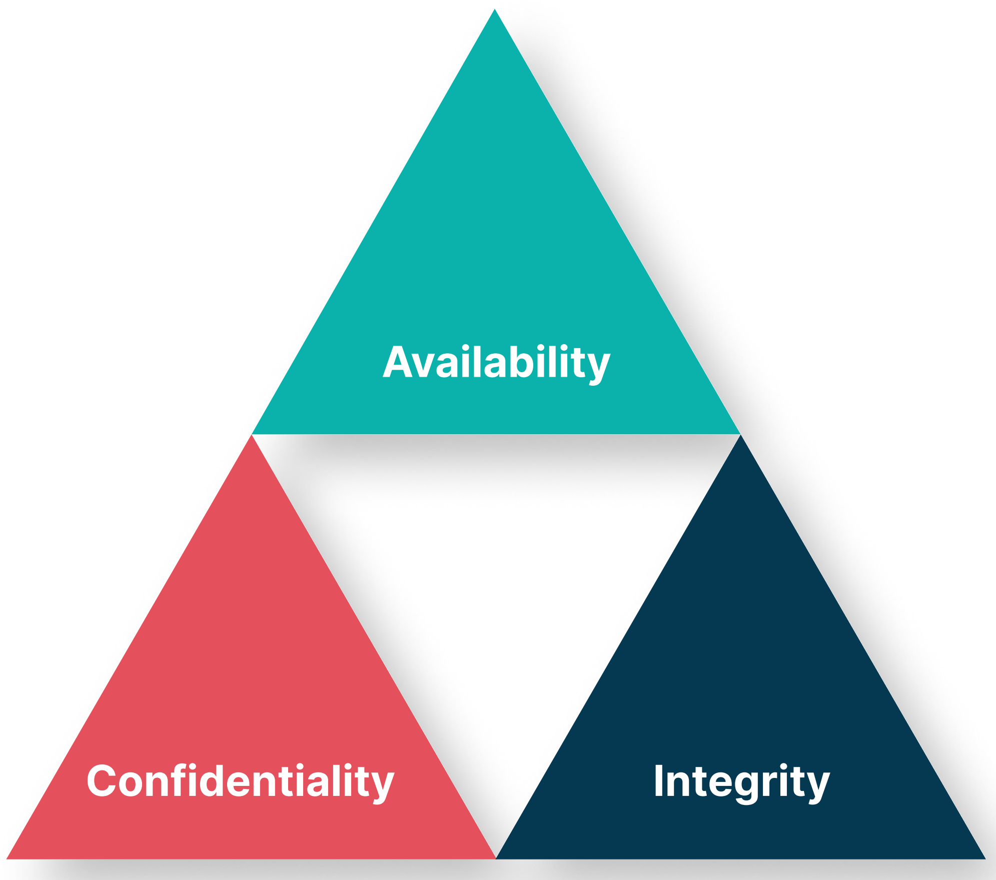
Flexibility and Security with Kubernetes

Kubernetes can operate both on-premise and in the cloud, accommodating self-hosting or being provided as a managed service. Its adaptability allows organizations to choose the most suitable deployment model based on their specific requirements. For development purposes, Platform as a Service (PaaS) solutions are frequently preferred for their convenience in implementing and testing security controls, closely mirroring a self-hosted Kubernetes environment.



Security

The best-known security model in Information Technology is called the CIA Triad. It explains the three main information security principles called "Confidentiality", "Integrity" and "Availability". Those form the cornerstones of the security infrastructure of an organization and are supported by the AAA principles (Authentication, Authorization and Accountability). By implementing the AAA principles, non-repudiation can be enforced by the ability to prove one's action done on or against the information system and its data.



The security reference architecture is based on the CIA best practices and describes the security controls that can be implemented to ensure a high level of protection for the whole microservice ecosystem on each of its layers from host to container and all related communication paths.
The security principles are briefly explained below.

Availability

Ensures the information systems and data are available and adequately accessible when required. Terms like "High Availability", "Performance", "Recovery Time Objective" and "Recovery Point Objective" are commonly used.

Confidentiality

Ensures that only authorized people or services can access data or an information system. It is imperative that all necessary access security controls are implemented in all layers (both business and technical) of an information system as a lack of access security controls can easily compromise confidentiality of business data.

Integrity

Ensures that data cannot be altered by an unauthorized person, system or process. It provides an assurance that data is accurate, complete and trustworthy. Hashing algorithms provide for means to verify the integrity of data sent by one and received by the other, while data encryption provides preventive measures against unauthorized people or systems to alter data in transit (e.g. to prevent a Man in the Middle Attack).

Authentication
Ensures one's identity by requesting several pieces of information that are unique to the person or process. More commonly, identity is proven by providing multi factor authentication, which at least consists out of a unique ID (account name) and at least two out of these three parts:

- Something you know (e.g. a password or passphrase)
- Something you have (e.g. a token generator or certificate)
- Something you are (e.g. biometric information like an iris scan or fingerprint)

Authorization
Ensures that an identity can only access resources it is required to access. Role Based Access Control is a general method of assigning access rights to an identity through the definition of roles. A role will be assigned with certain access rights and identities (users, systems or processes) will be assigned with a role.

Accountability
Ensures the traceability of the activities that a user performs on the information system. In general, this is achieved by enabling audit logging and keeping central audit trails. This way every action can be traced back to a identity and a point in time.

Key takeaways

- **CIA Triad Foundation:** The CIA Triad, consisting of Confidentiality, Integrity, and Availability, lays the foundational principles of information security, supported by AAA principles (Authentication, Authorization, Accountability) to ensure non-repudiation within an organization's security infrastructure.

- **Security Architecture:** Based on CIA best practices, this architecture outlines security controls for protecting the microservice ecosystem across all layers, from host to container, including communication paths, to maintain a high protection level.

Summary & Conclusions

TSO and DSO Control Room environments are critical cornerstones of the future Digital Grid system ensuring in the same time critical asset Management, power flow optimisation, congestion management and emergency controls as well as feeding critical Grid information data to Wholesale market mechanisms for day ahead, intraday and critical grid ancillary services.

The rapid changes of the underlying regulatory environment to accelerate the energy transition requires the rapid transformation of these critical environments historically built around applications organised in vertical business process silos whose Service Oriented Architectures as projected through the CIGRE D2.24 did not manage to disaggregate into more distributed multi-vendor developments.

Meanwhile new developments from the internet environment have matured into forward looking opensource platform – particularly for high throughput data streaming - which can today be leveraged for next generation Control Room implementation leading to new hybrid cloud architectures. This shift should not only be looked through the prospective of associated technologies and skills to be acquired but also through the impact it has on Grid operators to move their role into new technology integrator and consider alternative strategies to historical turnkey SCADA contracts which historically leads to monolithic vendor centric developments.

Talk to one of our experts

Laurent Schmitt
President, Digital4Grids

Jelle Wilders
CCO, Axual

Axual

Axual presents a suite of Kafka solutions tailored for TSOs en DSOs, offering both cloud and on-premise deployment options. Axuals simplifies the management of Kafka clusters with a user-friendly interface, visual data mapping and robust Role-Based Access Control (RBAC), ensuring secure and streamlined data oversight.

Digital4Grids

Digital4Grids work towards new Digital Opensource OT Platforms to accelerate DER integration across Energy & Transport sectors.

Unlock new possibilities for energy with Axual — a Gartner Representative Vendor. Our intuitive Kafka platform is used by forward thinking companies like TenneT, Enexis, Stedin and Eneco.

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