Reinventing the grid

Kyle Datta. Senior Advisory Roland Berger

ACEF 2020, Manila

Why should we consider reinvention of the utility grid?

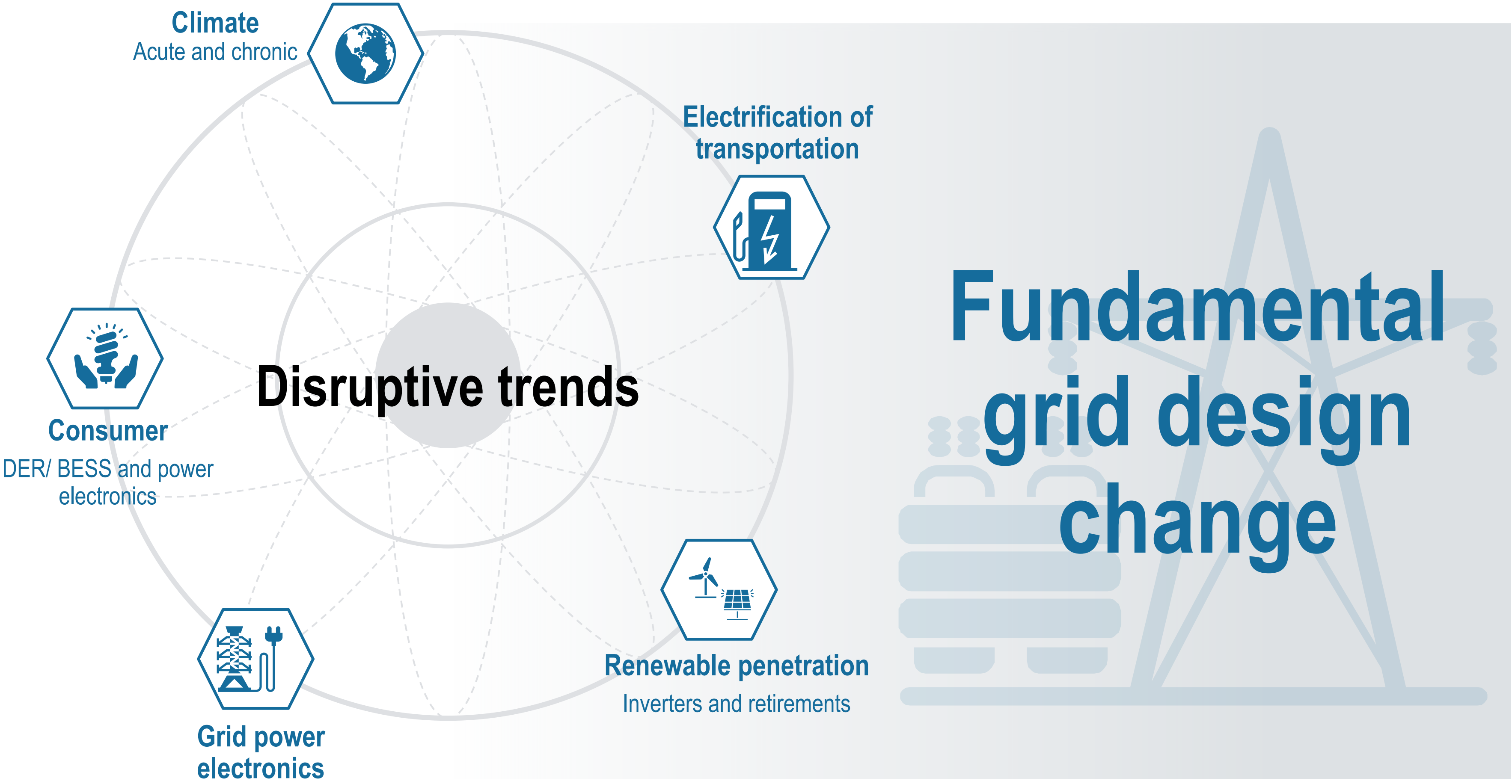
Key considerations

1. Do we understand the disruptive impact of simultaneous changes in bulk power and customer loads will have on the grid?
2. Can we see early signs that these impacts are happening and do we understand their trajectory?
3. What are potential technical solutions in terms of new technologies and the grid architectures in which these components are deployed?
4. Will we be ready in time?
   When will the technologies be ready and how long is the lead time for deployment?
5. Grid modernization is underway – Are we laying the right foundation for what comes next?

What drives change

Converging trends create momentum for fundamental change in the entire grid architecture

Grid implications of key emerging trends



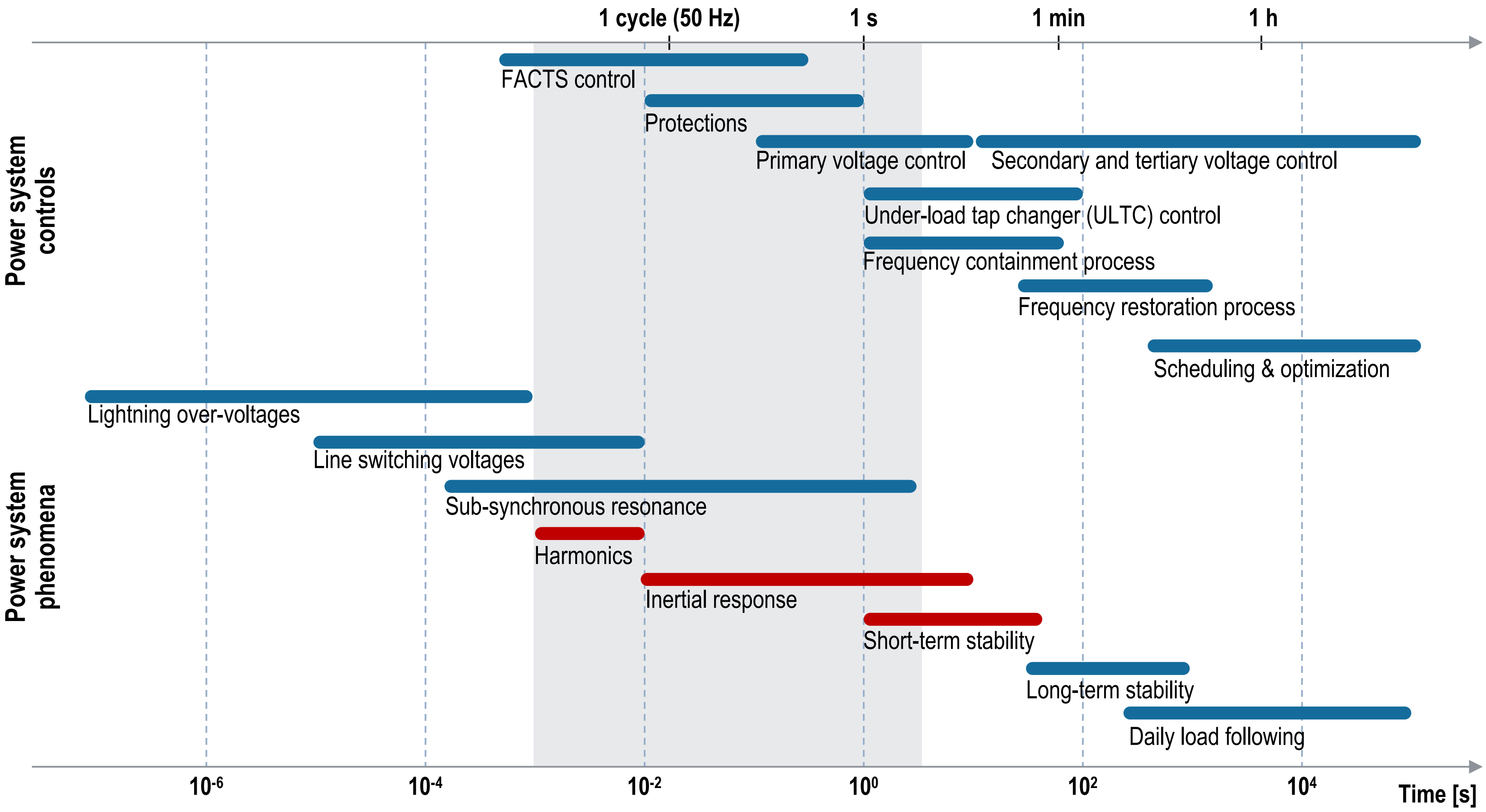
Within 15+ years, electric grids with high renewable and power electronic penetrations will face unprecedented challenges

Grid challenges

- Weather related loss of bulk power
- Inadequate system inertia
- Weather related severe grid disruptions (T&D)
- Power quality pollution (harmonics, Voltage)
- Safety (protection schemes)
- System stability at T&D layers (frequency,voltage, waveform)

These power system phenomena require control at <1 sec time scales – Beyond the capability of even modernized grids

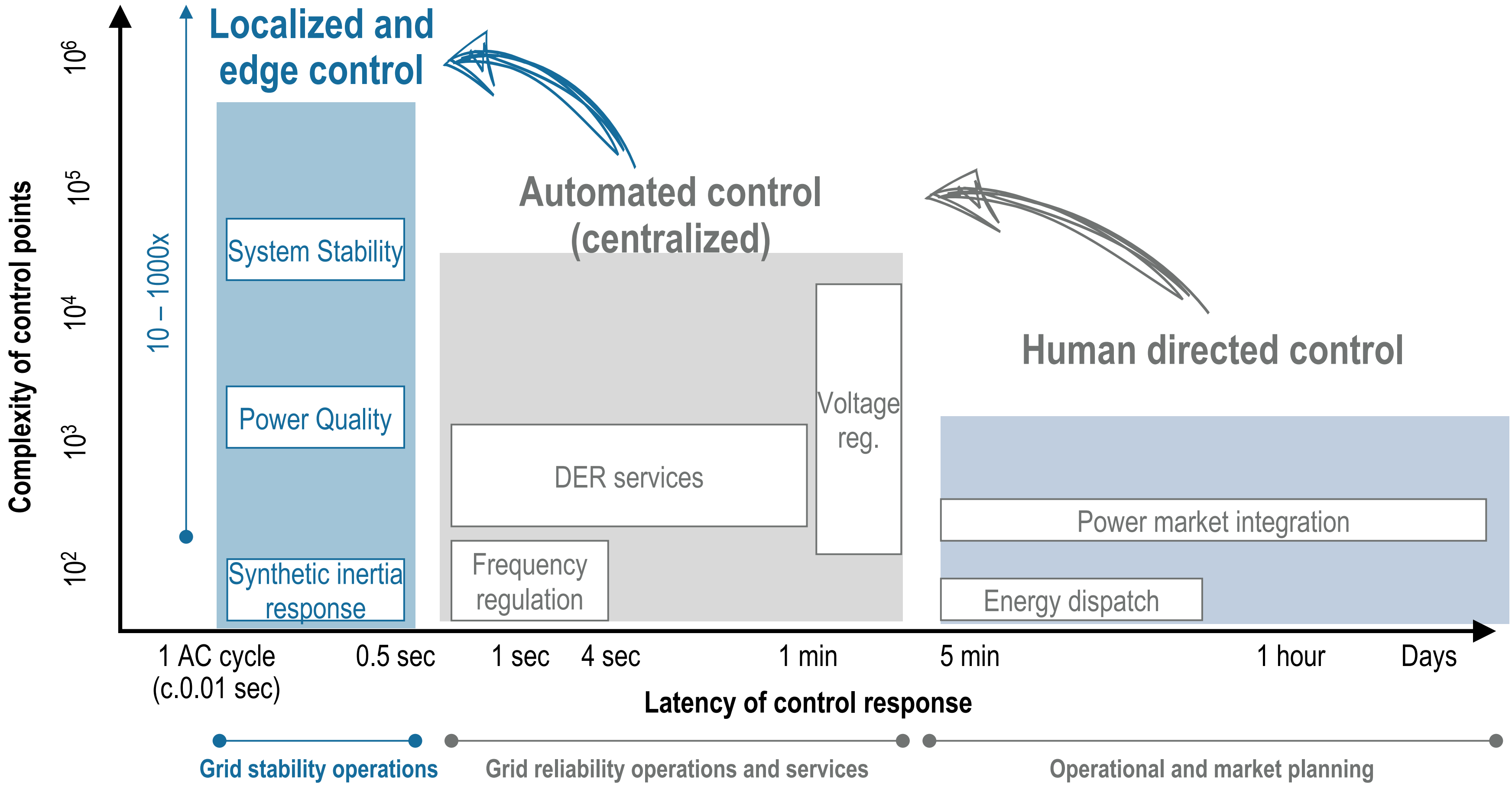
Control overview



Source: "The relevance of inertia in power systems" from Renewable and Sustainable Energy Reviews – Elsevier (2015)

Grid control schemes will have to evolve to manage ultra low latency and high complexity simultaneously

Evolution of grid control requirements



Who will be responsible when power harmonics “pollution” from customer & renewable IPPs reaches asset damaging levels?

Power harmonics situation

> Power harmonics are created from the combination of non-linear devices from both customers (power electronic machinery, battery charging) and inverter based renewable generation

> Total harmonic distortion has been steadily growing in the U.S. and Europe, and is currently addressed through passive filters, and equipment standards, but...

> As adoption of non-linear devices continues to grow, supra-harmonics which exceed the current standards, begin to appear

Warning Signs for Utilities

> This phenomenon is already damaging utility assets such as transformers and capacitors, and is starting to damage customer machinery

> The EU grid code makes the utility responsible unless it can identify the source of the harmonic emissions, but current grid sensors and remedial schemes may not meet this challenge

Future grid architectures, capabilities and technologies

Grid architectures combine distinct but interdependent layers to provide *foundational* and *functional* capabilities

Grid architecture framework

6 **Data and analytical systems**

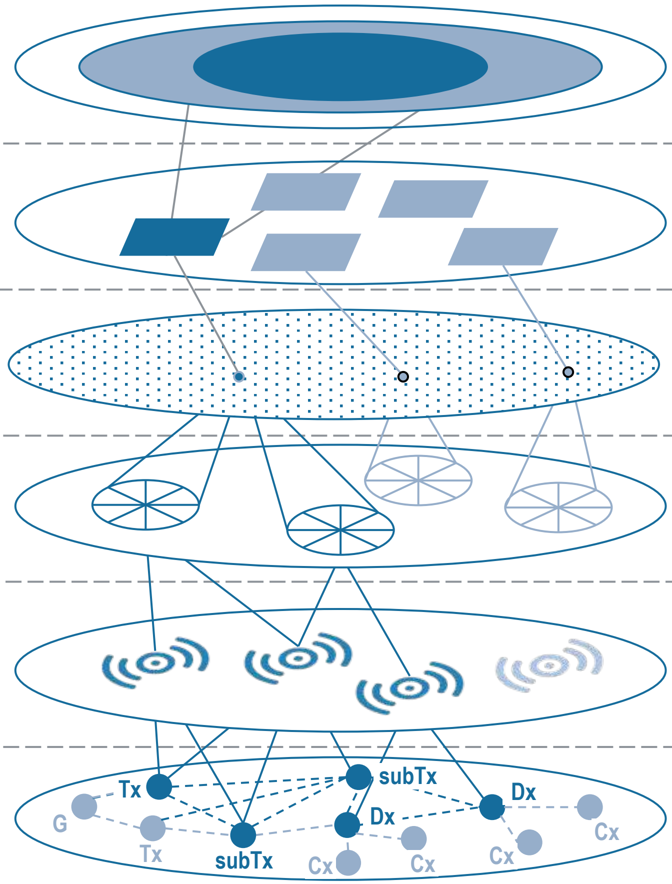
5 **Grid control systems**

4 **Cybersecurity**

3 **Communication networks**

2 **Sensors and edge computing**

1 **Power grid physical assets (utility and customer)**



The starting point is a profound shift of foundational capabilities in the sensing/communications/control and analytic layers

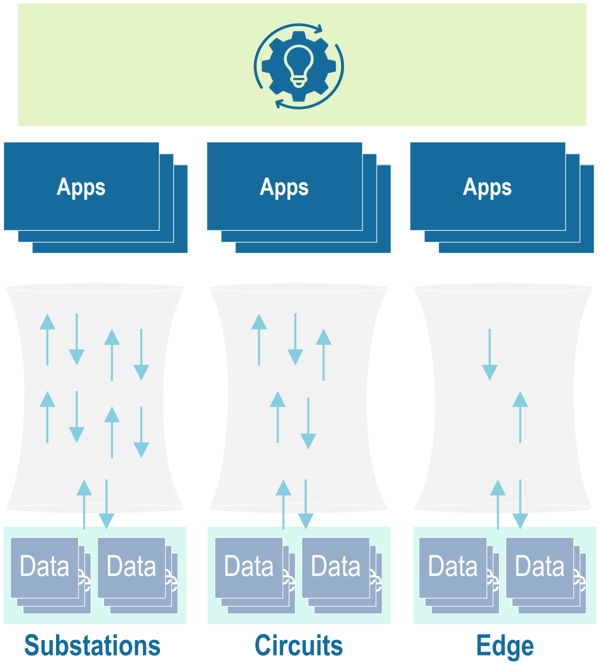
From **centralized** control, **low-latency** communication and **targeted** situational awareness w/ **siloed** data architecture…

Centralized grid control

Multiple systems, with integration friction

Low-latency and cybersecure communications

Targeted situational awareness w/siloed data architecture



… to **hierarchical layered** control, **Ultra low latency** communications and **ubiquitous** situational awareness w/ **interoperable** data architecture

Hierarchical control (w/ some local & edge control)

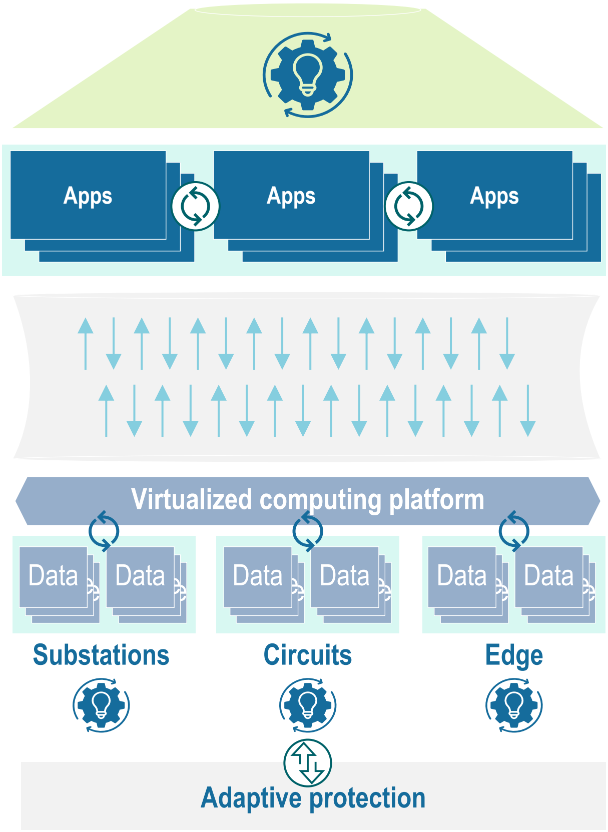
End-to-end advanced simulations and analytics

Ultra reliable, advanced cybersecure and low-latency comm.

Ubiquitous situational awareness w/inter-operable data

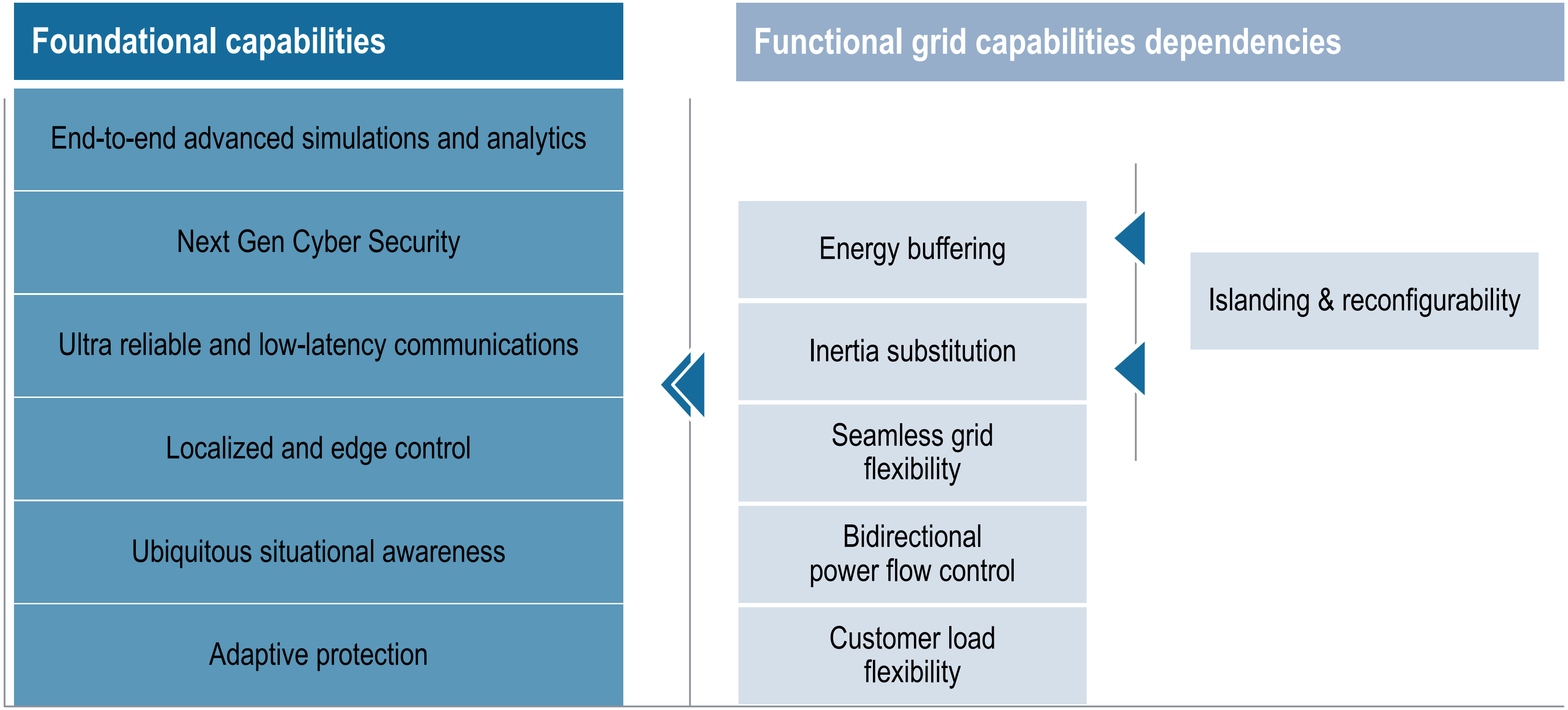
Localized & edge control

Adaptive protection



Functional capabilities are situationally deployed but universally dependent on foundational capabilities, informing sequencing

Foundational and functional capabilities sequencing



Foundational capabilities

- End-to-end advanced simulations and analytics
- Next Gen Cyber Security
- Ultra reliable and low-latency communications
- Localized and edge control
- Ubiquitous situational awareness
- Adaptive protection

Functional grid capabilities dependencies

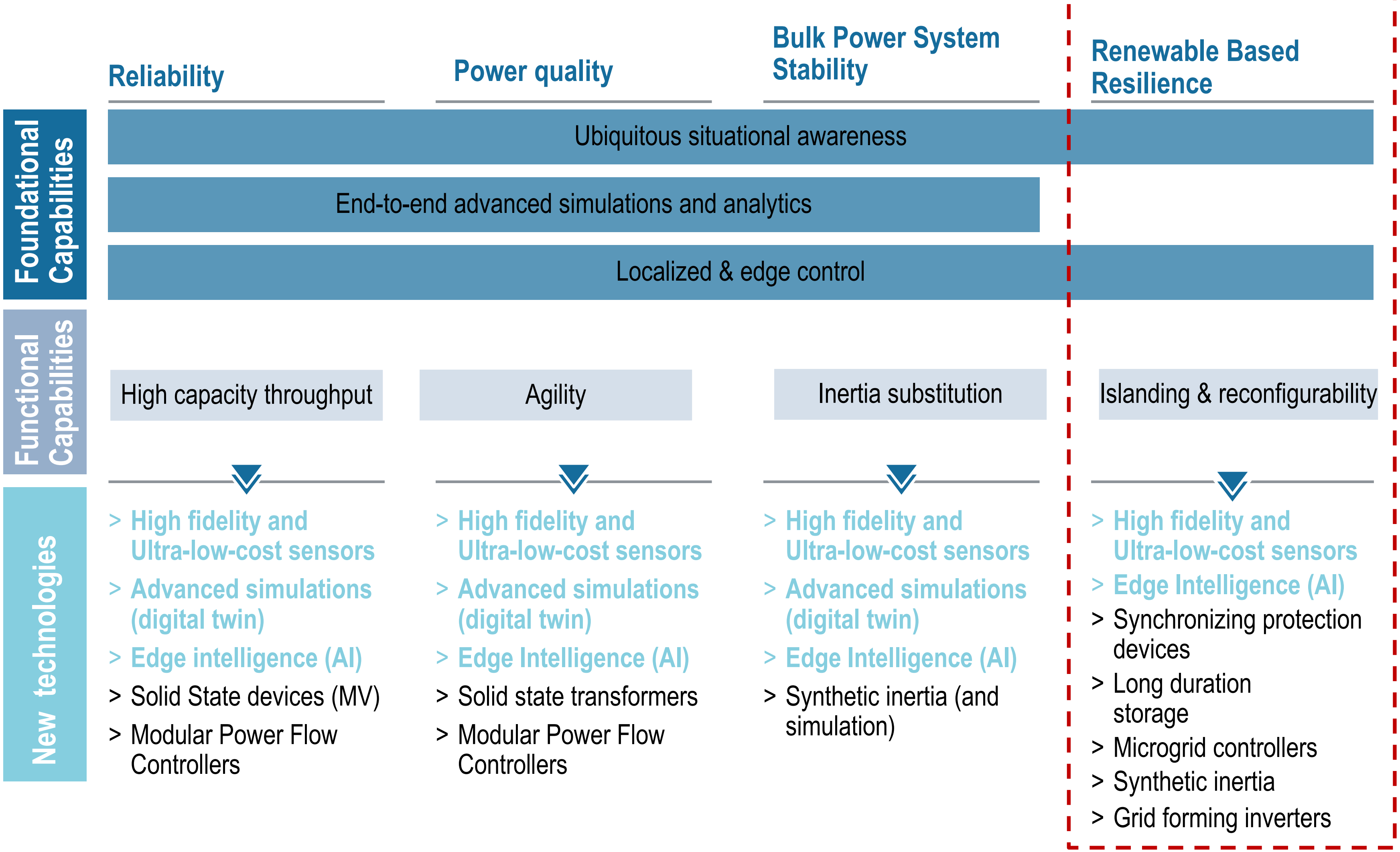
- Energy buffering
- Inertia substitution
- Seamless grid flexibility
- Bidirectional power flow control
- Customer load flexibility

Islanding & reconfigurability

◀ Dependent on prior technology

New technologies will be needed to enable the capabilities

Examples of capabilities and technologies



Reliability

Power quality

Bulk Power System Stability

Renewable Based Resilience

Foundational Capabilities

Ubiquitous situational awareness

End-to-end advanced simulations and analytics

Localized & edge control

Functional Capabilities

High capacity throughput

Agility

Inertia substitution

Islanding & reconfigurability

New technologies

Reliability:

- High fidelity and Ultra-low-cost sensors
- Advanced simulations (digital twin)
- Edge intelligence (AI)
- Solid State devices (MV)
- Modular Power Flow Controllers

Power quality:

- High fidelity and Ultra-low-cost sensors
- Advanced simulations (digital twin)
- Edge Intelligence (AI)
- Solid state transformers
- Modular Power Flow Controllers

Bulk Power System Stability:

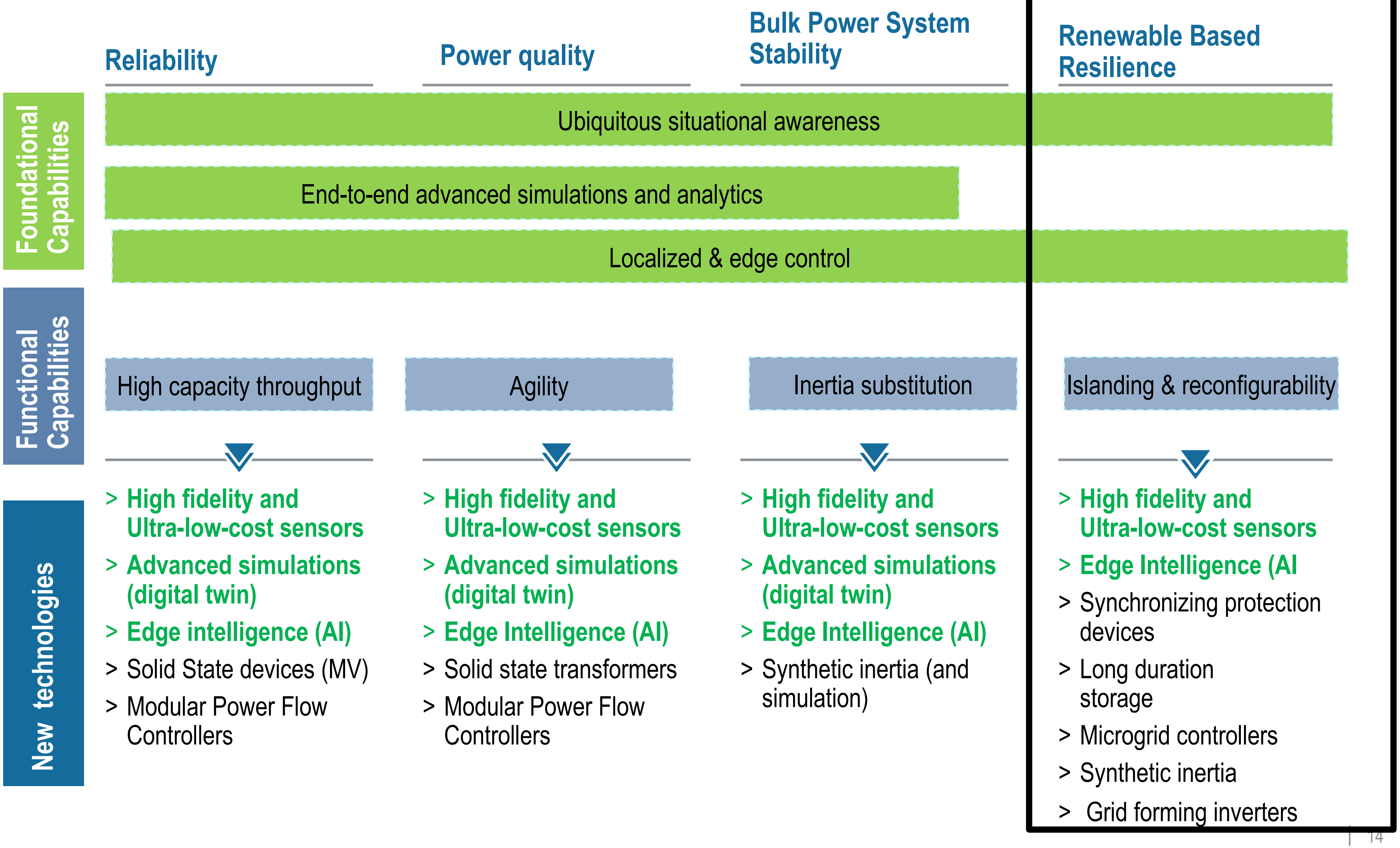
- High fidelity and Ultra-low-cost sensors
- Advanced simulations (digital twin)
- Edge Intelligence (AI)
- Synthetic inertia (and simulation)

Renewable Based Resilience:

- High fidelity and Ultra-low-cost sensors
- Edge Intelligence (AI)
- Synchronizing protection devices
- Long duration storage
- Microgrid controllers
- Synthetic inertia
- Grid forming inverters

New technologies will be needed to enable the capabilities

Examples of capabilities and technologies



	Reliability	Power quality	Bulk Power System Stability	Renewable Based Resilience
Foundational Capabilities	Ubiquitous situational awareness			
	End-to-end advanced simulations and analytics			
	Localized & edge control			
Functional Capabilities	High capacity throughput	Agility	Inertia substitution	Islanding & reconfigurability
New technologies	> **High fidelity and Ultra-low-cost sensors** > **Advanced simulations (digital twin)** > **Edge intelligence (AI)** > Solid State devices (MV) > Modular Power Flow Controllers	> **High fidelity and Ultra-low-cost sensors** > **Advanced simulations (digital twin)** > **Edge Intelligence (AI)** > Solid state transformers > Modular Power Flow Controllers	> **High fidelity and Ultra-low-cost sensors** > **Advanced simulations (digital twin)** > **Edge Intelligence (AI)** > Synthetic inertia (and simulation)	> **High fidelity and Ultra-low-cost sensors** > **Edge Intelligence (AI** > Synchronizing protection devices > Long duration storage > Microgrid controllers > Synthetic inertia > Grid forming inverters

Functional capabilities can be packaged in different architectures to address specific needs

Functional capabilities

Challenges	System Stability Power Quality, Safety	>90% RE Bulk Power Supply	High Density & Magnitude DC Loads	Resilience
High capacity throughput (& protection)		✓	✓	
Islanding & reconfigurability	✓			✓
Energy buffering	✓	✓	✓	✓
Inertia substitution		✓		✓
Seamless grid flexibility	✓	✓	✓	
Customer load flexibility	✓		✓	✓
Bidirectional power flow control	✓		✓	
Grid Architectures	**Distributed Edge Grid**	**Adaptive Grid**	**DC Grid**	**Mini- and micro-grids**

Why it matters now

Renewables without fundamental changes in the grid architecture do not make the grid more resilient against the future changes

What renewables provide alone

Renewables in the bulk power system make the system more resilient against fossil fuel supply chain risks…

…and act as hedges against fossil fuel volatility and carbon taxation or caps

Distributed renewables with storage can provide individual customers with resilience

And provide critical grid services to distribution and bulk power grids

What grid changes are needed for renewables to true resilience

Physical grid design needs to segment the grid into cellular minigrids that have adequate power supply to meet critical and, …

… the capabilities to manage power system stability

Grid needs to dock/undock microgrids seamless, which requires both transparency, control and communications between the parties,…

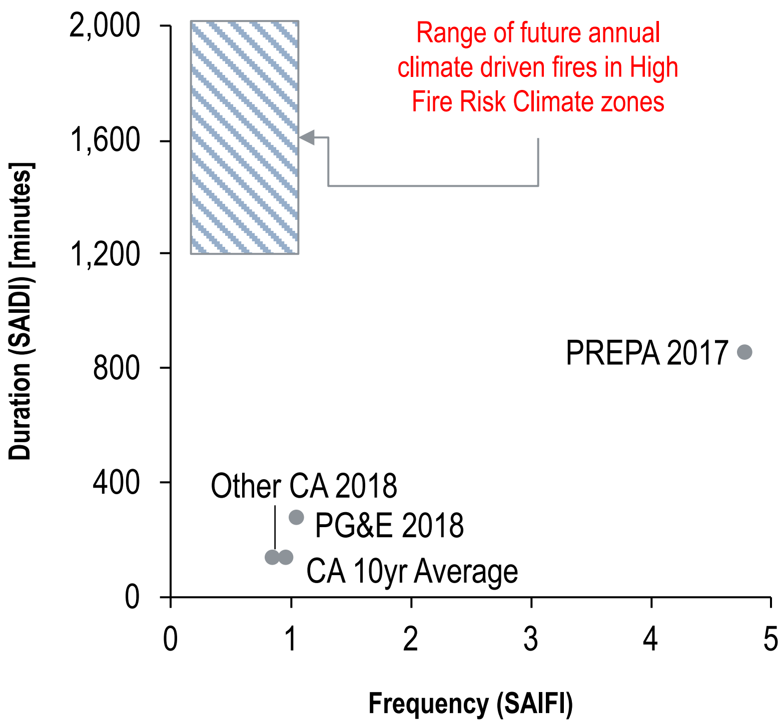
… and new capabilities within the utility

Ultimately, edge intelligence with circuit loop or meshed grid designs will

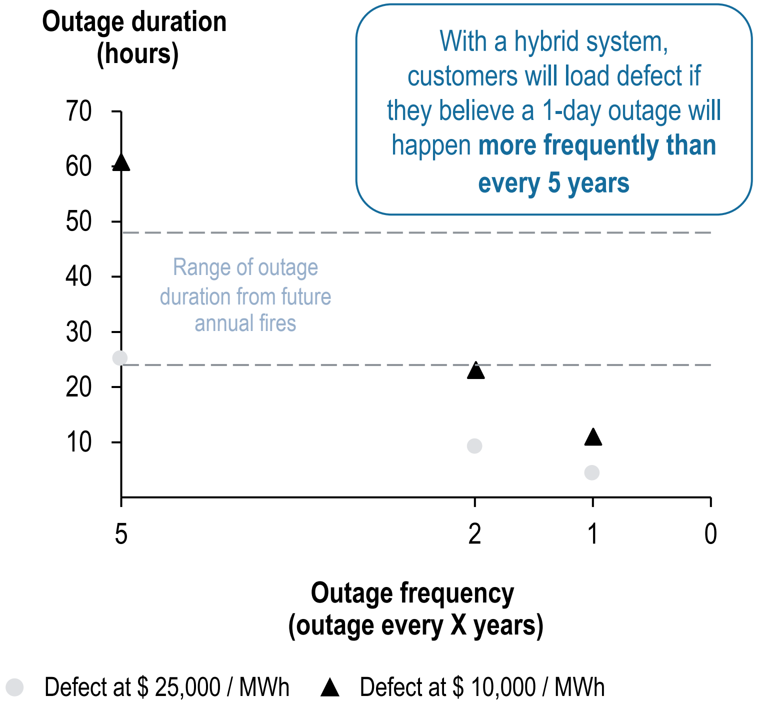
Need for resilience is proportional to customers' expectations of major outage duration and frequency

Customer experience and impact

Customer outage experience + expectations



Hybrid microgrid (PV, BESS, generator) for Large C&I



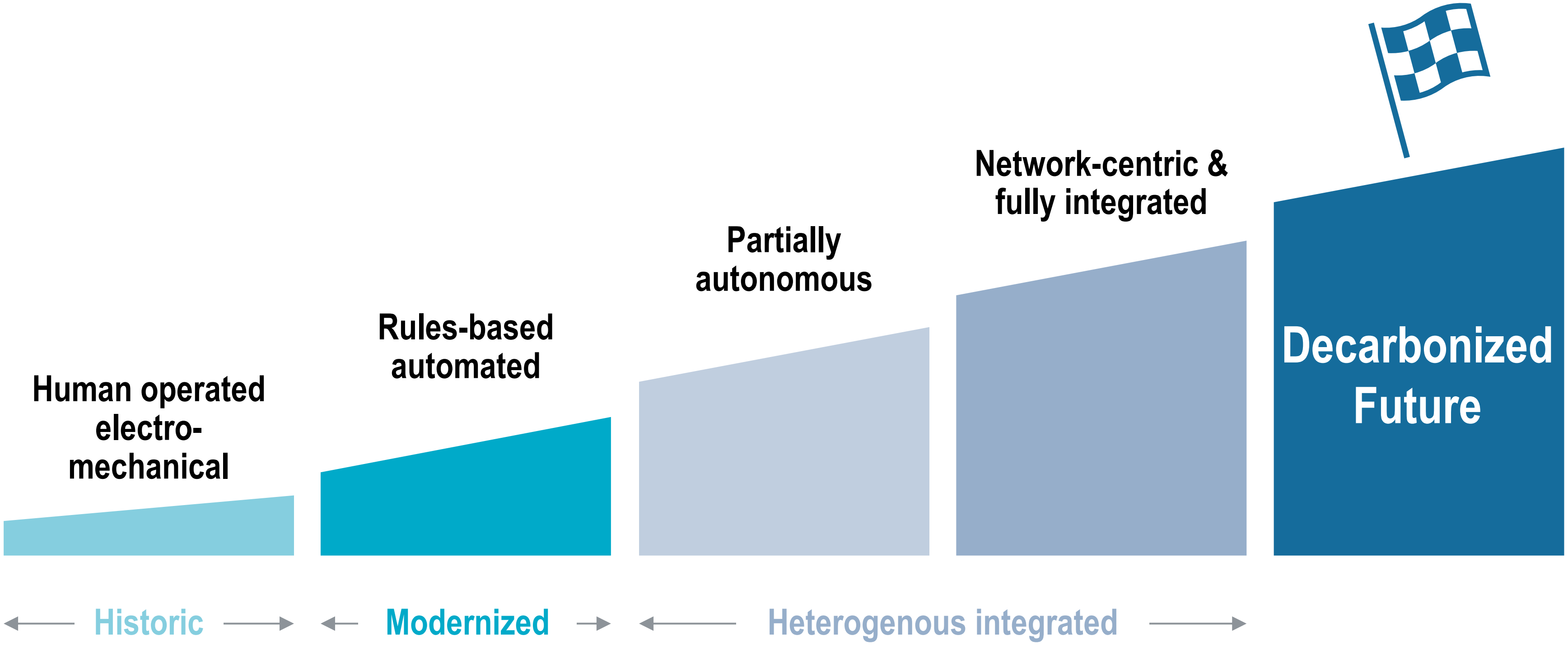
With a hybrid system, customers will load defect if they believe a 1-day outage will happen **more frequently than every 5 years**

When you light a candle you cast a shadow

- The future grid challenges are the inevitable consequence of decarbonization policies combined with the advancement of civilization
- We need to build stakeholder consensus regarding the new challenges the grid will face
- The future grid architectures will be necessary for the system to reliably operate

The journey has just begun: The future grid capabilities will evolve into new paradigms to address future challenges

Grid evolution



Modernized Grid

Separate, homogenous T and D architectures

Heterogenous integrated grid architectures with common digitalized foundation