

UTILITY PERSPECTIVE BRIEFING

Smart Grid

From Increasing Electrical Penetration to the Intelligent Grid

Evolution • Technologies • Protection • Global Progress • The Road Ahead

A reference presentation for utility professionals — with key questions and key perspectives highlighted throughout

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What we'll cover

01

Increasing electrical penetration

Why electrification is the fundamental driver of grid transformation

02

Attributes, drivers & evolution

Core attributes, the seven drivers, and Grid 1.0 → 4.0

03

Maturity & technology stack

Five-stage roadmap and the integrated technology layers

04

Protection systems

Evolution, adaptive/virtualised protection, and the IBR challenge

05

Case study & global progress

The Iberian blackout, plus developed and developing-world progress

06

Road ahead, benefits & roadmap

Emerging technology, value proposition and a transformation roadmap

The electricity grid that evolved through the twentieth century was built around a relatively simple, one-directional paradigm: large, centralised power stations generated electricity, which flowed through transmission and distribution networks to largely passive consumers.

Instrumentation and control were predominantly analogue, much of the distribution network relied on manual operation, and visibility into the network was limited, particularly beyond substations. Utilities could, in many cases, become aware of an outage only after a customer reported it.

KEY QUESTION

What is the Share of Electricity in overall Energy Mix?

Increasing electrical penetration: the fundamental driver

~20%

of global final energy consumption is currently electricity

<40%

electricity share reached by only a handful of countries today

>50%

potential future share as transport, heat & industry electrify

125+ yrs

of grid evolution — yet this next phase is the most fundamental shift

The transition is not simply about replacing conventional generation with renewables — it is about electricity becoming the backbone of the entire energy system, as transport, heat and industry increasingly depend on it.

KEY PERSPECTIVE

The smart grid is not an end in itself — it is the enabling architecture for an economy where electricity's share of final energy could rise from ~20% to over 50%.

Why the grid must become intelligent

Five forces are stretching the century-old, one-way conventional grid beyond its design limits.

600M+

people in Sub-Saharan Africa still without electricity access, underscoring the scale of grid build-out still needed

195M

smart meters installed across the EU27+3 region by end-2024, en route to ~80% penetration by 2029

5

simultaneous pressures: Increased Electrification, renewable integration, ageing assets, rising DERs/EVs, and AT&C loss reduction

10–15 yrs

typical multi-stage journey for a utility moving from digitisation to a mature, DER-integrated grid

Conventional grid vs. smart grid

CONVENTIONAL GRID

- One-way power flow, centralised generation
- Electromechanical / one-way meters
- Manual fault detection & switching
- Little to no visibility beyond the substation
- Passive consumers

INTELLIGENT / SMART GRID

- Two-way power & information flow, distributed generation
- AMI smart meters with real-time two-way data
- Automated fault detection, isolation & self-healing (FLISR)
- End-to-end sensing down to the feeder & consumer
- Active “prosumers” participating in demand response & trading

Defining the smart grid: core attributes

- **Two-way flow**

Electricity & information flow both ways between utility, assets and customer

- **High visibility**

Situational awareness extending to the distribution edge

- **Self-healing**

Automated fault detection, isolation and restoration

- **DER integration**

Centralised and distributed generation, renewables and storage combined

- **Active consumers**

Demand response, flexible loads, generation, storage & EVs

- **Intelligent assets**

Real-time data, analytics and predictive maintenance

- **Reliability & resilience**

Improved power quality; protected against physical & cyber disruption

- **New market services**

Time-of-use tariffs, aggregation, VPPs, transactive energy

KEY QUESTION

Which of these eight attributes does your utility already have — and which represents the biggest gap today?

Seven drivers of the smart grid transformation

- **Electrification**

Transport, heat & industry shifting onto the grid, raising scale and criticality

- **Decarbonisation & IBRs**

Variable, power-electronic-based renewable generation replacing dispatchable plant

- **DERs & bidirectional flow**

Rooftop solar, batteries & EVs turning one-way feeders into two-way networks

- **Flexibility needs**

Generation no longer simply follows demand — storage & demand respond too

- **Ageing infrastructure**

Replacement cycles are a chance to embed sensing & automation, not just swap parts

- **Loss reduction**

Smart metering & monitoring justify investment through AT&C loss reduction

- **Customer expectations**

Consumers expect digital experiences & new energy services

KEY QUESTION

Which driver is creating the most pressure on your network right now: electrification, DERs, or ageing assets?

Evolution of the grid: Grid 1.0 to Grid 4.0

Grid 1.0 *Conventional*

Centralised generation, one-way flow, passive consumers, manual operation

Grid 2.0 *Automated*

SCADA, EMS, digital relays, RTUs, remote control at key locations

Grid 3.0 *Smart*

AMI, DMS, FLISR, DA, DERMS — two-way comms to the grid edge

Grid 4.0 *Intelligent / Autonomous*

AI optimisation, digital twins, edge intelligence, VPPs, V2G, autonomous control

Generation follows load

Generation follows load with automated system control

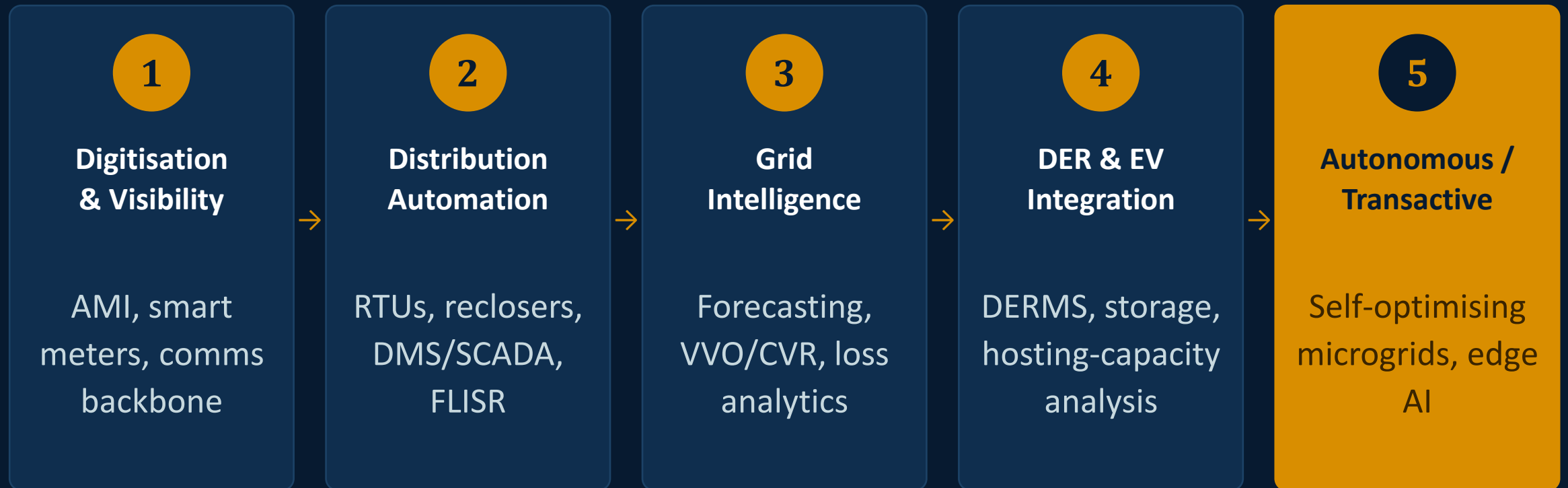
Generation + storage + demand respond to **net load**

System continuously coordinates generation, network, storage and flexible demand.

KEY PERSPECTIVE

Most utilities operate all four generations simultaneously — the real question is which generation each feeder needs to reach, not the network as a whole.

Five stages of smart grid maturity



KEY QUESTION

If you scored your network feeder-by-feeder, what stage would your most advanced feeder be at — and your least advanced?

Stages 1–2: Digitisation & Automation

● STAGE 1

Digitisation & Visibility

- Two-way communicating smart meters (AMI) at consumer, transformer & feeder level
- Establishes the comms backbone: RF mesh, PLC or cellular/NB-IoT
- Enables remote reading, prepayment/ToU billing, theft & tamper detection
- Typically the largest and first capital programme in the journey

● STAGE 2

Distribution Automation

- RTUs, reclosers, sectionalisers and smart relays tied into a DMS/SCADA
- FLISR: automatic Fault Location, Isolation & Service Restoration
- Feeders reroute power around faults in seconds, not hours
- Outage management integrated with AMI “last gasp” alerts

Stages 3–4: Intelligence & DER Integration

● STAGE 3

Grid Intelligence & Analytics

- Load forecasting and predictive asset maintenance
- Voltage/VAR optimisation (CVR) for efficiency gains
- AMI-data analytics to detect non-technical losses
- Demand-response programmes converting data into value

● STAGE 4

DER, Storage & EV Integration

- DERMS gives visibility and control over rooftop solar, storage, EV charging
- Bidirectional protection schemes and hosting-capacity analysis
- Maturing net-metering / net-billing regimes
- Utility-scale batteries deliver peak-shaving & frequency response

Stage 5: Autonomous & transactive grid

The advanced frontier — today, mainly pilots and microgrid deployments

- **Self-optimising microgrids**

Islanding and reconnecting automatically without manual switching

- **Transactive energy markets**

Prosumers trade energy directly; utility shifts toward a platform role

- **AI / edge-computing dispatch**

Minimal human intervention in routine switching and balancing decisions

- **System-of-systems operation**

Utility orchestrates a network of flexible, distributed assets rather than a single centralised source

The smart grid technology stack

- **Sensing & Metering**

AMI, DT/feeder meters, sensors, PMUs, IEDs — granular, near-real-time measurement

- **Communication**

RF mesh, PLC, fibre, cellular/NB-IoT, IEC 61850, 5G/private LTE, TSN

- **Control & Automation**

SCADA, DMS/ADMS, FLISR, smart reclosers, protection relays

- **Data & Analytics**

MDM, AMI analytics, AI/ML forecasting, digital twins

- **DER & Flexibility**

DERMS, VPPs, BESS, EV smart-charging/V2G

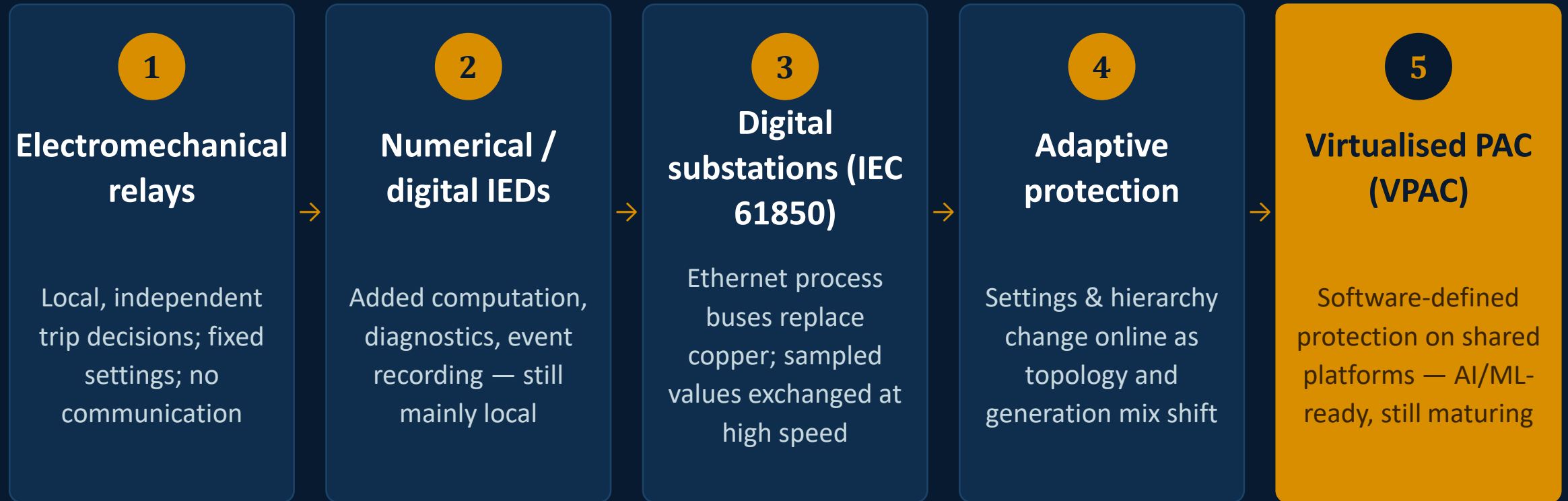
- **Cybersecurity**

Segmentation, encryption, identity/access controls, IEC 62351-aligned controls

KEY PERSPECTIVE

Value only emerges when sensing, communications, control, analytics, DER and cybersecurity operate as one integrated architecture — not six separate projects.

Protection, automation & control: how we got here



KEY PERSPECTIVE

Protection has historically lagged 8–10 years behind metering and communications — and that gap is now the most active risk area in grid modernisation.

Adaptive protection, virtualisation & cybersecurity

● Adaptive Protection

- Relay settings & hierarchy change online with topology and generation mix
- Moves beyond fixed settings calculated for a limited set of operating states

● Virtualised PAC (VPAC)

- Protection logic runs as software-defined functions on shared infrastructure
- Timing precision, redundancy, interoperability & cybersecurity become critical

● Cybersecurity by Design

- Protection now rides on shared Ethernet/IEC 61850 networks, not dedicated wiring
- Must avoid reliance on a single measurement source for centralised decisions

KEY QUESTION

As protection logic moves onto shared IEC 61850 networks, has cybersecurity been designed in from day one — or bolted on afterward?

Why inverter-based resources challenge conventional protection

- **Current-limited faults**

Grid-following inverters cap fault current at $\sim 1.0\text{--}1.2$ p.u. — far below conventional relay design assumptions

- **Software-shaped response**

Fault phase angle & sequence set by inverter control software, not network impedance

- **Cessation risk**

IBRs can enter partial/full current cessation within cycles, affecting protection & directional decisions

- **Grid-forming reduces, doesn't eliminate**

GFM inverters improve disturbance support but still current-limit under severe faults

KEY PERSPECTIVE

Inverter-based resources don't just add capacity — they change the physics that conventional protection was built on.

Emerging protection responses to the IBR challenge

1

Grid-forming inverter control

Hierarchical control spanning device, feeder & system levels

2

Revised distance/directional algorithms

Designed around current-limited, software-shaped fault signatures

3

Negative-sequence injection mandates

Grid codes increasingly require it during unbalanced faults

4

ML-based fault detection

Promising for weak-grid & high-IBR microgrids; needs further field validation

5

Digital substation architectures

Partially centralised protection for renewable plants

KEY QUESTION

Does your grid code yet require negative-sequence injection and grid-forming capability from new renewable connections?

Iberian Peninsula blackout — 28 April 2025

Spain, Portugal

and parts of southern
France affected

Very high

renewable contribution
at the time of the event

12 days

earlier, the same grid ran
on 100% renewables
without incident

No cyberattack

officially confirmed as
the cause

- Official investigation: attributed to a combination of technical and planning factors — not a single cause, and explicitly not a cyberattack.
- Independent analysis: voltage control and reactive-power capability flagged as key considerations as renewable penetration rises and synchronous generation's relative contribution declines.

KEY PERSPECTIVE

High IBR penetration changes system dynamics and places greater demands on voltage control, reactive-power capability, system strength, protection, oscillation management and operational visibility.

Lessons for a high-electrical-penetration grid

- 1 Maintain sufficient dynamic & static voltage-control capability as renewable share rises
- 2 Give operators real-time awareness of reactive-power source limits and voltage vulnerability
- 3 Additional synchronous or grid-forming resources extend the time for protection/load-shedding to act
- 4 Strengthen interconnection capacity with neighbours to reduce cascading severity
- 5 Evolve protection & control alongside the generation mix — don't treat IBRs as conventional generators

KEY QUESTION

Do your operators have real-time visibility of reactive power margin and voltage vulnerability, or only after the fact?

Developed economies: adding intelligence to a mature grid

● Europe

- 195M+ smart meters across EU27+3 by end-2024, ~63% penetration
- Further growth forecast toward ~80% by decade-end

● United States

- Broad AMI coverage among many investor-owned utilities
- Distribution automation, demand response, DER hosting-capacity management maturing

● China

- State Grid: effectively full household smart-meter penetration by early 2020s
- Moving toward V2G-oriented capability enhancements

● Japan & South Korea

- Both completed large-scale smart-meter rollouts
- Continuing to advance grid digitalisation and resilience

KEY PERSPECTIVE

Developed grids are shifting from 'how do we digitise' to 'how do we integrate DERs, storage and EVs at scale.'

India & Sub-Saharan Africa: two developing-world paths

● India — RDSS

- ~7.24 crore smart meters installed nationally as of end-June 2026
- ~5.73 crore under RDSS vs. ~20.33 crore sanctioned
- RDSS sunset date extended to March 2028
- Challenges: procurement, consumer resistance, rural connectivity

● Sub-Saharan Africa

- Story closely linked to basic electrification itself
- Digitally native solar mini-grids deploy smart metering & remote monitoring from day one
- Nigeria, Kenya, Ethiopia & Zambia leading mini-grid programmes
- Serve as test-beds for distributed generation & demand-side management

KEY QUESTION

Is your utility retrofitting intelligence onto an existing grid, or building digitally native from day one — and does your technology choice reflect that?

Common barriers in developing-world deployment

- 1 High upfront capital cost vs. already-strained utility balance sheets
- 2 Financing/procurement complexity (e.g. bundled AMI-as-a-service, DBFOOT)
- 3 Weak underlying comms infrastructure in rural/remote areas
- 4 Consumer resistance to prepayment & perceived billing changes
- 5 Institutional & workforce capacity gaps (cyber, analytics, field ops)
- 6 Regulatory/tariff design not yet rewarding loss reduction or DER integration

KEY QUESTION

Which of these six barriers is the binding constraint for your organisation today?

Emerging technologies and the road ahead

- **AI-driven digital twins**

Real-time simulation, predictive maintenance, load balancing, fault prediction

- **Grid-forming inverters**

Establishing voltage/frequency references rather than simply feeding into the grid

- **Virtualised PAC**

Software-defined protection & analytics on shared computing infrastructure

- **ML for protection & stability**

Oscillation detection, hybrid physics-AI voltage assessment, graph-based contingency analysis

- **Expanding WAMS**

Wider PMU coverage integrated with digital twins & AI — but a growing attack surface

- **Direction of travel**

Sensing → Comms → Visibility
→ Automation → Analytics →
Optimisation → Autonomy

KEY PERSPECTIVE

The objective is not technology for its own sake, but the capability to manage an increasingly electrified, decentralised and interconnected energy system.

Benefits and value proposition

- **Reliability**

Reduced outage duration via automated FLISR

- **Asset utilisation**

Better use of existing network assets

- **Loss reduction**

Lower technical/commercial losses, better revenue assurance

- **Renewable integration**

Greater DER & renewable hosting capacity

- **Power quality**

Improved voltage management

- **Predictive maintenance**

Better forecasting & asset management

- **Flexibility**

Storage, demand response, EVs, aggregated DERs

- **Customer experience**

Improved visibility & new energy services

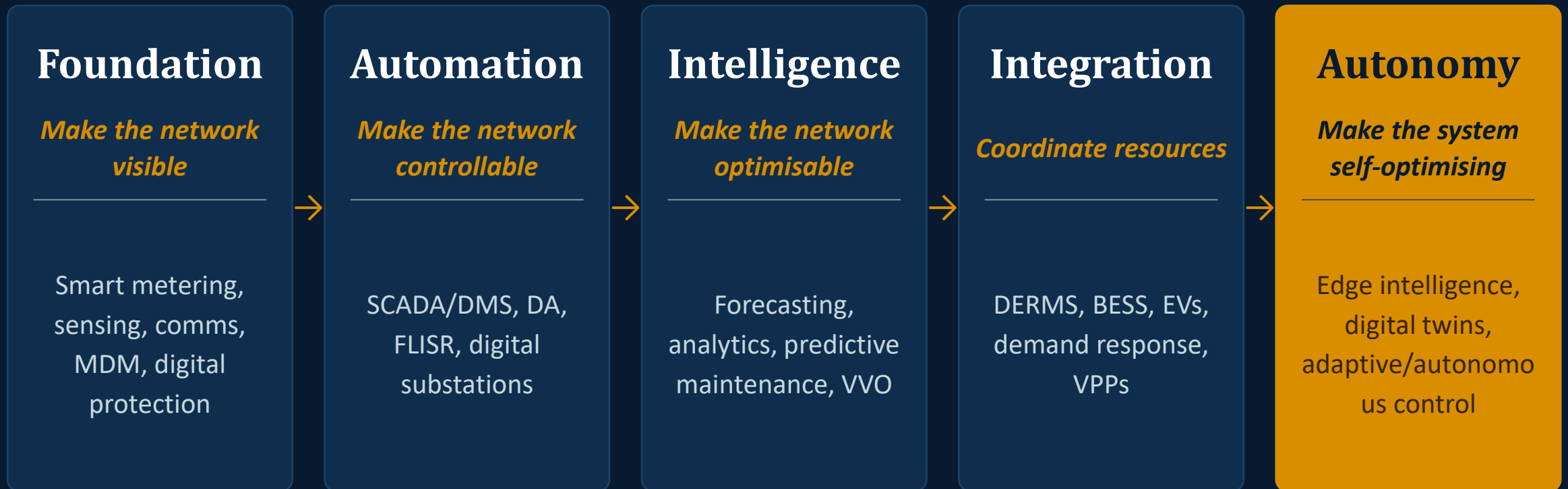
- **Resilience**

Greater protection against physical & cyber-physical threats

KEY QUESTION

Is your business case built around today's most immediate value driver — loss reduction, reliability — or tomorrow's — flexibility, DER orchestration?

A utility transformation roadmap



KEY PERSPECTIVE

Smart grid transformation is a staged capability programme, not a single technology procurement.

Key takeaways

- 1 Electricity is ~20% of global final energy today, but could exceed 50% — this is the strategic context for grid development
- 2 The smart grid is the enabling architecture for a larger, more critical, distributed and interactive electricity system
- 3 Metering, communications, automation and protection evolve at different speeds — protection is now the most active transformation
- 4 High electrical & renewable penetration makes voltage control, reactive power and flexibility as important as energy balancing
- 5 Successful transformation depends on financing, regulation, standards, cybersecurity and workforce — not technology alone

KEY PERSPECTIVE

The objective is not simply a 'smart' grid — it is an electricity system that can sense, communicate, predict, coordinate, adapt and increasingly respond autonomously.

Thank you

Questions & discussion