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Grid codes for renewable powered systems

Presenters:

- Arina Anisie, Analyst Renewable Innovation, IRENA
- Gayathri Nair, Associate Programme Officer RE Grid Integration, IRENA

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IRENA
International Renewable Energy Agency

SPEAKERS

Arina Anisie
Renewable Energy
Innovation, **IRENA**

Gayathri Nair
Associate Programme
Officer RE Grid
Integration, **IRENA**


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A

IRENA Grid Codes Reports

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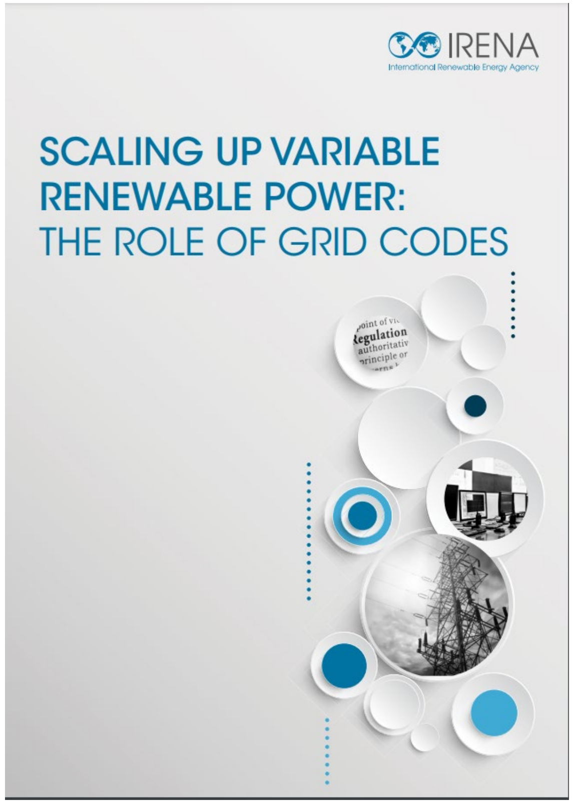

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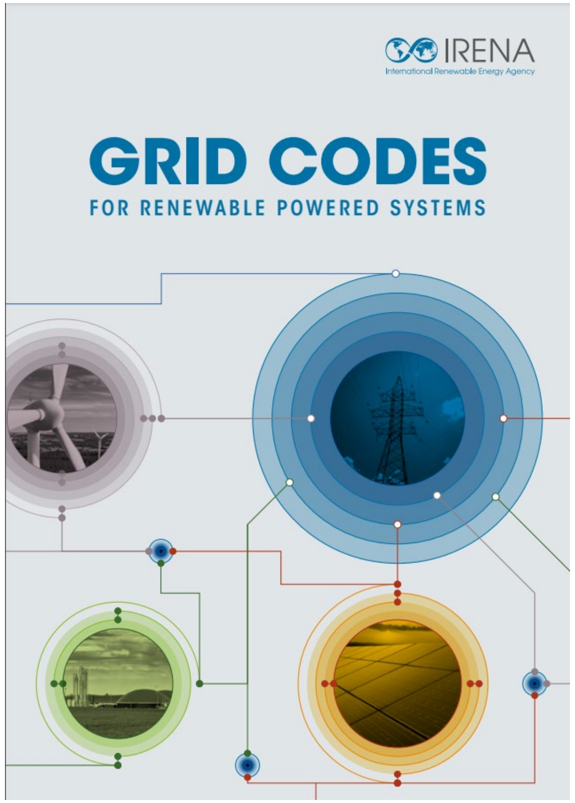

2022

Key contents

1. **Grid code development**
2. **Technical requirements and their evolution**
3. **Ancillary services**
4. **Regional grid codes**
5. **Grid code compliance**
6. **Guidance for designing grid codes**

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Grid Connection Codes

	MARKET CODES	OPERATION CODES	CONNECTION CODES
FUNCTIONALITY	▪ Electricity Balancing ▪ Capacity Allocation ▪ Congestion Management	▪ System Operation ▪ Electricity Emergency and Restoration	▪ **Requirements for Generators** ▪ **Loads Connection** ▪ **HVDC Connection**
MAIN ACTORS	▪ Transmission System Operators ▪ Market Operator	▪ Transmission System Operators ▪ Energy Suppliers	▪ **Transmission System Operators** ▪ **Distribution System Operators** ▪ **Investors** ▪ **Project Developers** ▪ **Technology Providers** ▪ **Energy Suppliers** ▪ **Consumers**

5 Key Messages

1. Grid codes should be technology-neutral and should evolve to meet system needs

2. Grid codes should enable innovations to connect safely to the grid

3. Grid connection code requirements need to be tailored to country/system context

4. Regional grid connection codes is key to facilitate international power trade and ensure competitiveness

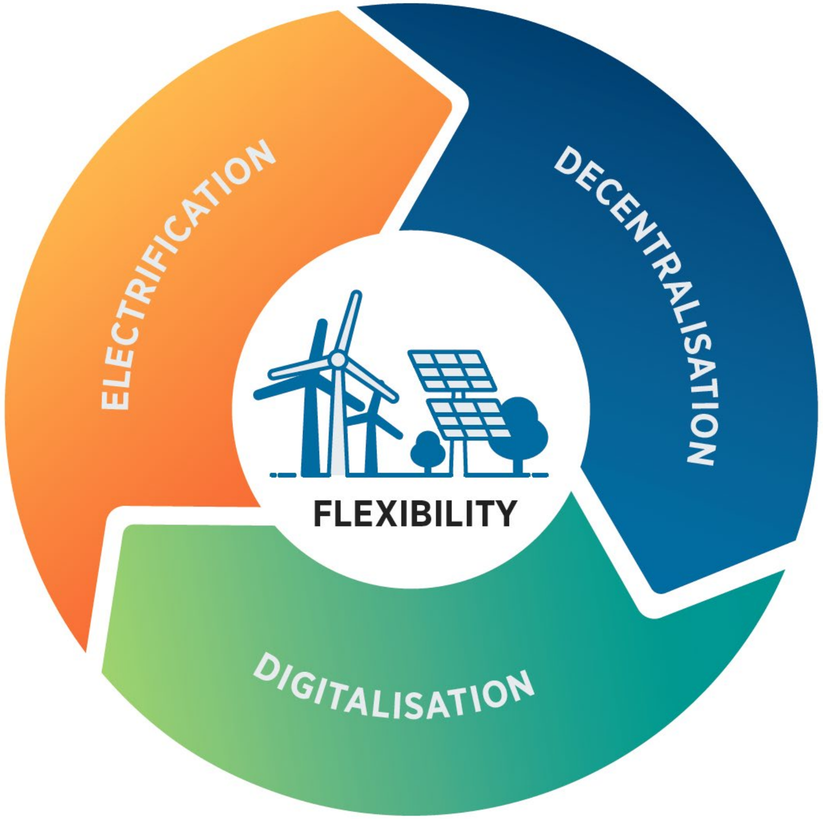
5. An imperfect grid code is, in many cases, better than no grid code at all

1

Grid codes should be technology-neutral and should evolve to meet system needs

Power sector innovations trends

- Electrification of end-use sectors is an emerging solution to **maintain value and avoid curtailment of VRE**, and help decarbonize other sectors



- The increasing deployment of Distributed Energy Resources (DERs) turns the consumer into an active participant, **fostering demand-side management**.

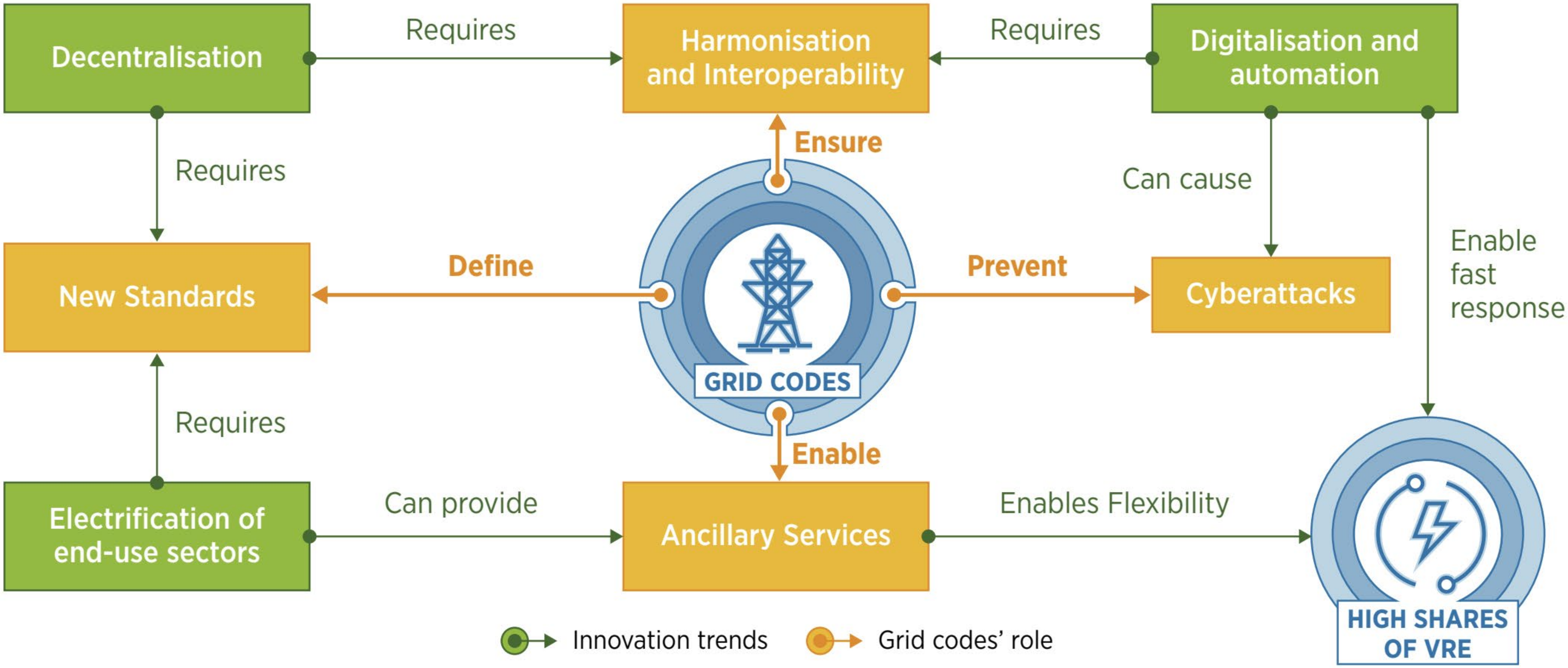
- Digital technologies enable **faster response, better management of assets** by **connecting devices, collecting data, monitor and control**

Power system transformation

ONGOING TRANSFORMATIONS IN THE POWER SYSTEM

Previous state	New state
Regulated fuel influx	Variable Renewable Energy
Synchronous machines	Inverter-based resources
Large-scale power plants	Distributed generation
Flexible generation	Flexible generation, demand and storage
Process automation	Autonomous operation / Digital Smart Grid
Electric light and power	Electric light, power, heating and mobility
Consumers	Prosumers

Grid codes in a transforming power system



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Grid codes should enable innovations to connect safety to the grid

System needs are the main drivers for grid code development

Existing requirements

- **Voltage and frequency operating ranges**
- **Frequency control capability requirements**
- **Requirements for generators to provide reactive power for voltage control**
- **Fault behavior requirements/LVRT**
- **Protection** of customer facilities
- **Controllability** of active and reactive power output
- **Active power controllability requirements**
- **Power quality requirements**
- **RE forecasting requirements**

Grid codes should enable innovations to connect safely to the grid

BEHIND-THE-METER BATTERY

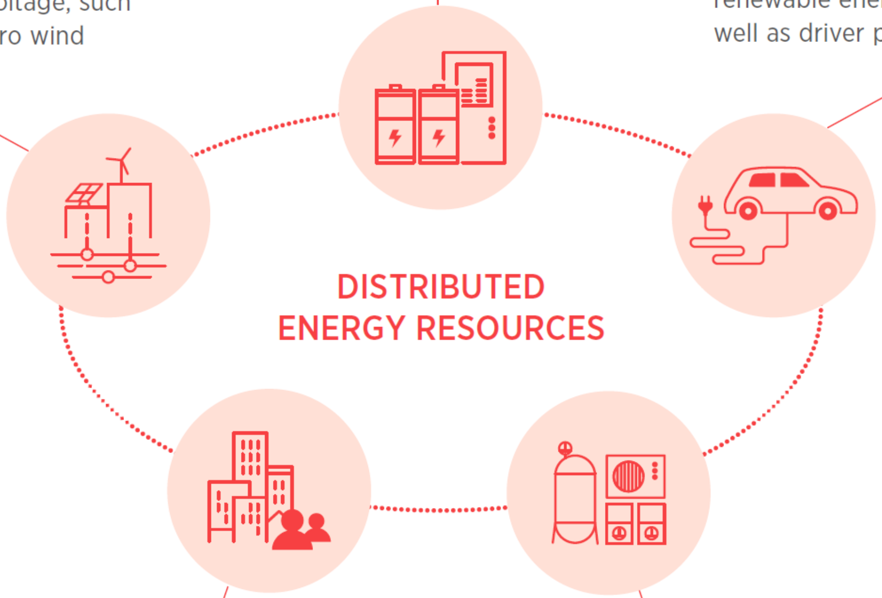
Small batteries that are connected at the consumer end and store electrical energy during periods of surplus generation.

SMART CHARGING ELECTRIC VEHICLES

Optimising the charging cycle of the EVs according to distribution grid constraints and local renewable energy availability, as well as driver preferences.

DISTRIBUTED GENERATION

Generation from plants connected at low and medium voltage, such as solar rooftops, micro wind turbines, etc.



DEMAND RESPONSE

Process that enebles consumers to alter their electricity consumption patterns and provide grid services, individually or through an aggregator.

POWER-TO-HEAT

Thermal boilers, heat pumps, thermal storage, etc. used to provide heat for residential purposes.

The new consumer is also producing, storing, trading energy and managing own load

Source: IRENA (2019) Innovation landscape brief: Market integration of distributed energy resources

Evolving trends in grid connection codes

Current trends of technical requirements

- **Extending application of existing requirements to smaller user**
  - Controllability
  - Communication interfaces and integration
  - LVRT in low-voltage distribution grids
- **Providing requirements for new user types**
  - Storage and consumer-producer combinations
  - Electric vehicle charging
- **Adding requirements for new technical capabilities**
  - High-voltage ride through (HVRT)
  - Grid-forming capabilities of inverters

DER Controllability, LVRT, HVRT and Cybersecurity-Examples

Controllability requirements are increasingly being extended towards applying to rooftop solar PV and other small DER: **Grid codes specify** power reduction capabilities; Minimum power restoration ramps for VRE generation; Upper limits for power injection and minimum power output from VRE under certain conditions (less common)

Example: In Germany for connection to the low voltage grid, new PV facilities with less than 30 kW capacity that cannot be controlled remotely have to limit their output to 70% of rated power. Remote control of active power output at the request of the system operator is required for all DER rated above 100 kW connected to the grid.

Low Voltage ride through (LVRT): for DER connected at low voltage grids; at low voltage there is generally no corresponding requirement to support the voltage by injecting reactive or active current during LVRT events

In Japan, for residential applications of PV, which lowered the threshold of residual low voltage in 2016 from 0.30 per unit to 0.20 per unit for 1 second. In addition, the PV system should recover more than 80% of the power output in 0.2 seconds.

High Voltage ride through (HVRT): keep the VRE functioning during overvoltage and help keep the grid stable

Example: Australia, China and Spain have the most stringent regulations requiring a wind power plant and PV system to withstand a voltage swell of 130% of rated grid voltage.

Communication Interfaces and Integration: Harmonized communication interfaces and control systems; Bidirectional communication; Internet-based communication-Cybersecurity issues;

Example: In Germany, any new DER installation above 7 kW is required to communicate through a smart meter gateway (SMGW), which provides a secure data communication channel to the system operator for energy management.

Grid codes for storage and EV charging-Examples

- **Belgium and Great Britain treats storage as a generation asset** for some requirements, which cover frequency, robustness and low voltage ride through (LVRT), voltage stability, and reactive power capacity.

- **Finland established its own specifications for storage-**The requirements are specific for storage connected through power electronics and include controllability, operating frequency and voltage ranges, RoCoF, FRT, fault behavior, protection, recovery after voltage disturbances, active power control, reactive power capacity, voltage control and reactive power control, commissioning testing, modelling requirements, and the compliance process. They also mention that large storage systems should agree bilaterally with the TSO on the capabilities for black start and anti-islanding.

Grid-following inverters	Grid-forming inverters
Inverter control system measures and synchronises to the grid voltage waveform, adjunting power output to "follow" voltage.	Inverter control system sets an internal voltage waveform reference and adjusts power output to help maintain this voltage.

Example: Great Britain's National Grid ESO undertook a first step in this direction by publishing first drafts of a grid code specification for grid-forming inverters in 2020. When integrated into the grid code, this will be a non-mandatory specification that outlines technical requirements for potentially installed grid-forming inverters but does not generally require the functionality itself.

3 | Grid connection code requirements need to be tailored to country/system context

Grid codes must be based on system characteristics

Definition of grid user classes by:

- Technology (synchronous machine/inverter based resource)
- User type (generator/consumer/hybrid)
- Plant size (rated power, connection voltage level)

Specification and parametrisation of connection requirements per user class

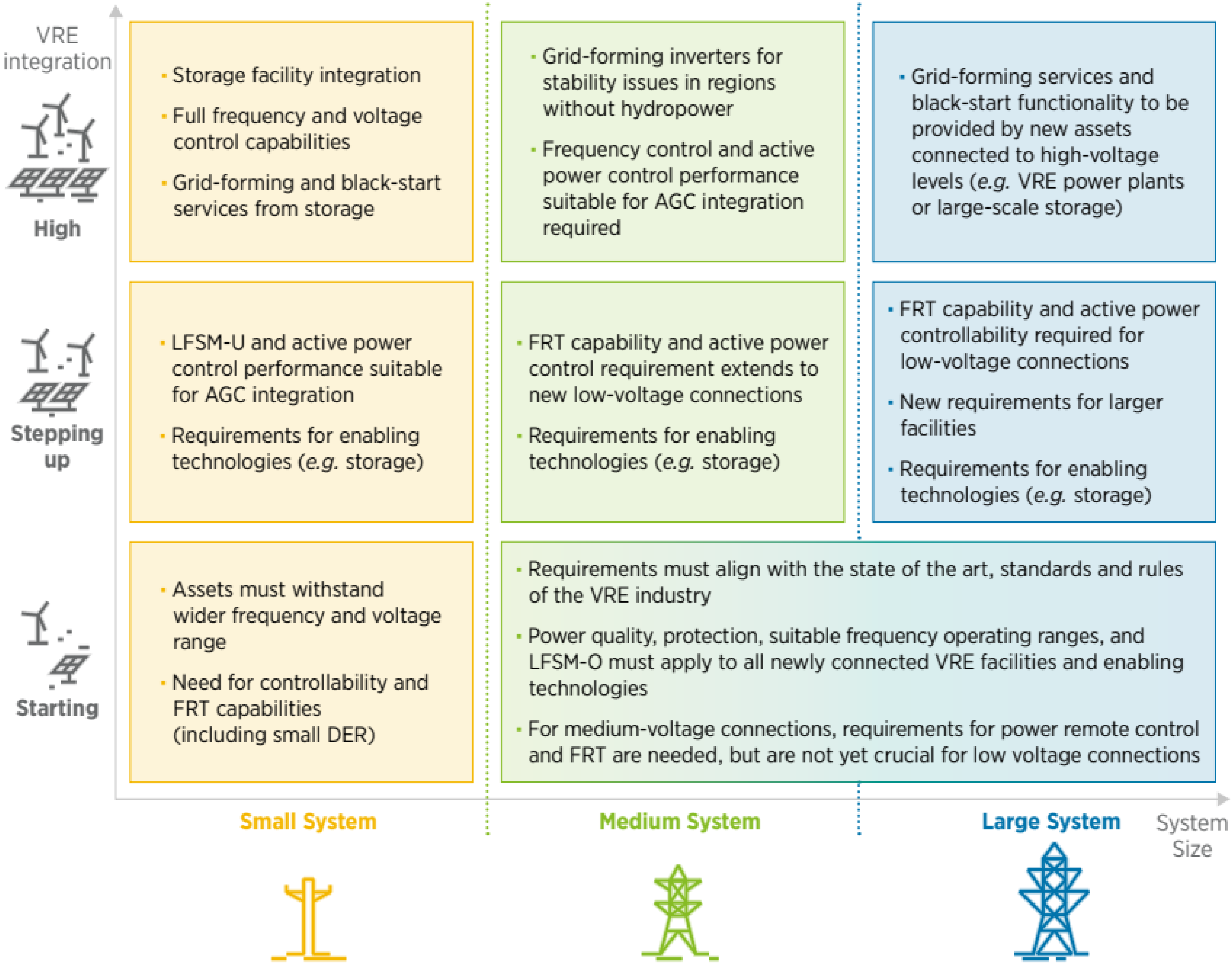
- Protection
- Power Quality
- Simulation/model aspects
- Controllability of active and reactive power output
- Fault behaviour
- Voltage and Frequency operating ranges
- Reactive power and voltage control capability
- System restoration issues
- Frequency control capability

Grid Connection Code

Power system characteristics

- Resources required to maintain system stability and security
- Capacity, location, flexiblity, capabilities of existing resources
- Capacity and resource availability from interconnections to other power systems
- Current and expected/planned situation

Grid code formulation varies according to grid size and VRE integration level



Grid codes refer to IEC and IEEE product specification standards

Standard	Content	Standard	Content
IEC 60034	Rotating electrical machinery	IEC 61215	Terrestrial PV systems
IEC 60044	Instrument transformers	IEC 61400	Wind turbine design
IEC 60045	Steam turbines	IEC 61730	Construction of PV systems
IEC 60076	Power transformers	IEC 61868	Insulating mineral oils
IEC 60143	Series capacitors for power systems	IEC 61869	Instrument transformers
IEC 60044	Voltage and current transformers	IEC 62052	Electricity metering equipment
IEC 60308	Hydraulic turbines	IEC 62548	Solar PV arrays
IEC 60358	Coupling capacitors	IEC 62934	Grid integration of renewable energy generation
IEC 62052	Electricity metering equipment	IEEE 112	Induction motors
IEC 62053	Static meters for AC active energy	IEEE 115	Synchronous machines
IEC 60076	Power transformers	IEEE 421	Synchronous machines
IEC TS 61836	Solar PV energy systems	IEEE 929	Solar PVs

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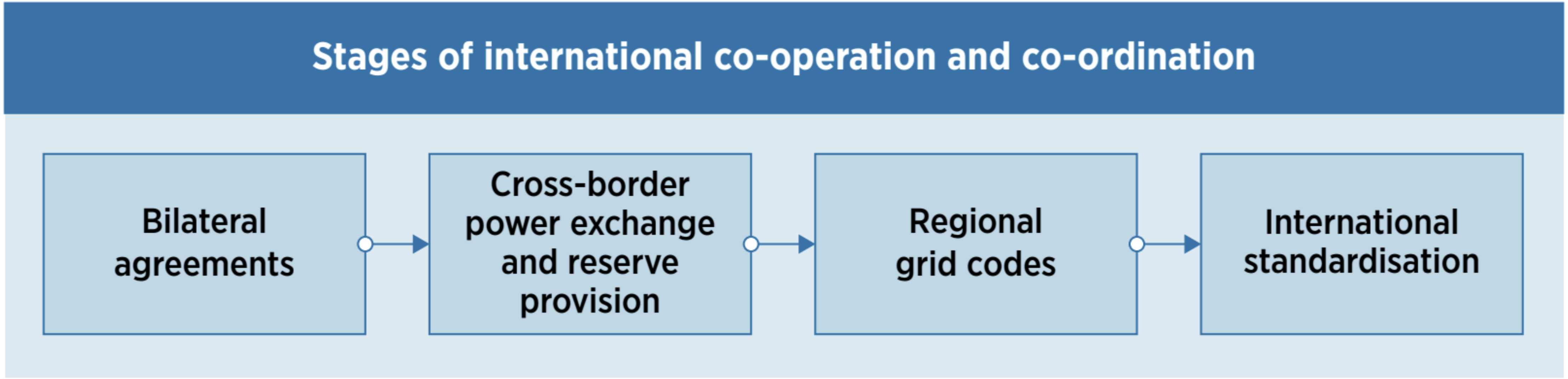
Regional grid connection codes is key to facilitate international power trade and ensure competitiveness

Regional grid codes facilitate sharing flexibility between countries



- Regional grid connection codes ensure competitiveness in regional markets between assets connected to one grid that have the potential to sell their energy and services in neighboring markets.
- EU regional grid code requirements are minimum and non-exhaustive, which means that each TSO could specify additional and/or stricter requirements.
- Regional connection network codes often focus heavily on ensuring operational security but focus somewhat less on actual harmonisation of technical requirements.

5

An imperfect grid code is, in many cases, better than no grid code at all

Grid code development

Policy makers	Lead Institution (TSO, DSO'S etc.)	Working group	Multiple Stakeholders	Regulator or State Administrative Bodies
Policy mandates to write grid codes	Working group formation	Grid code drafting phase	Consultation beyond Working group	Entry into force

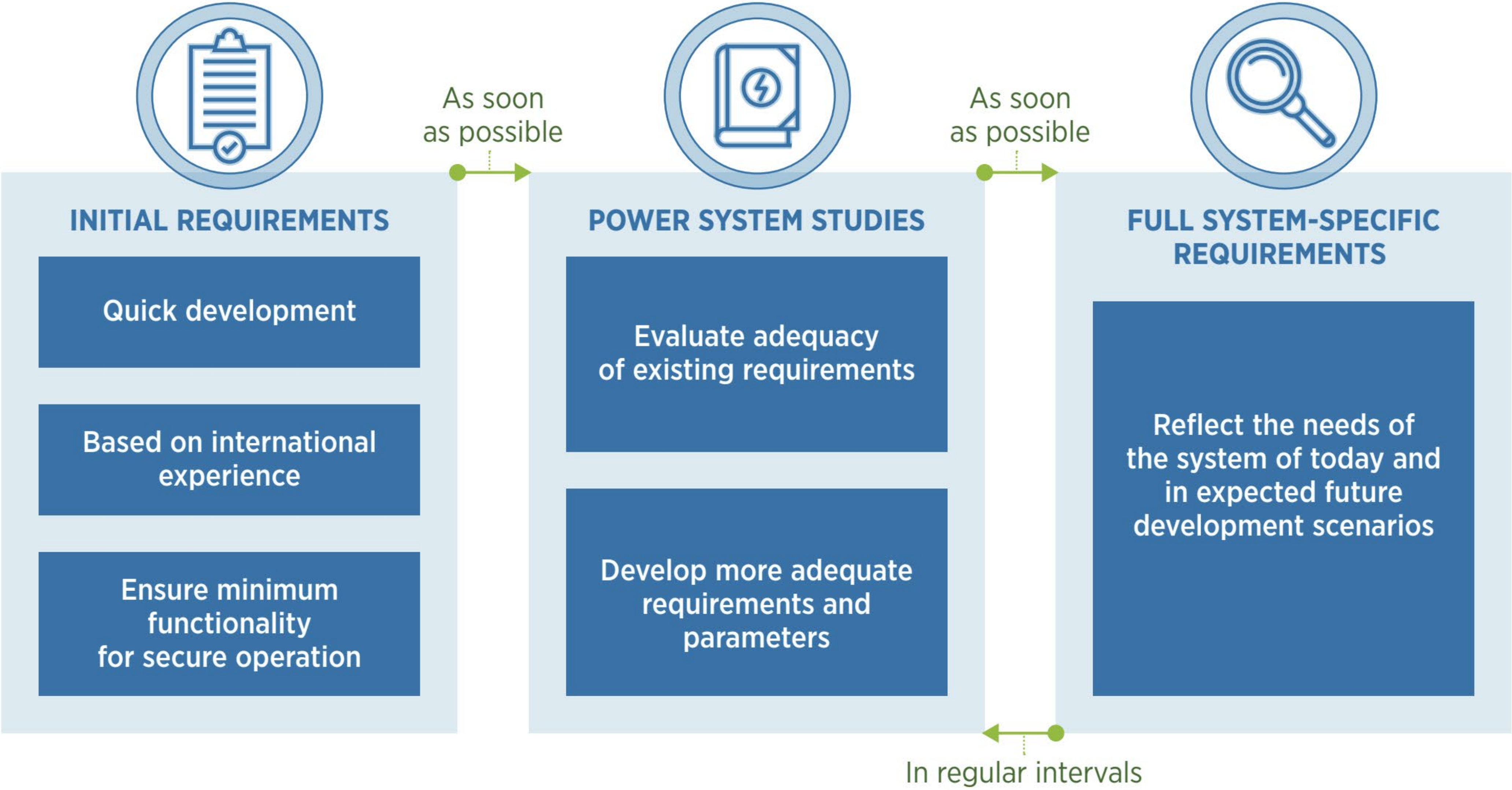
Key recommendations:

- **Install a working group with a diverse set of stakeholder representatives from the very beginning. N**o individual stakeholder has in-depth knowledge of all relevant technical details. Involving all relevant actors early on shortens the feedback loops and leads to a higher-quality draft.

  Grid codes have important role in building trust between different actors

- **Overall co-ordination between various working groups for different grid codes** and some reasonable membership overlap between the working groups are advisable to ensure that the systemic perspective is adequate.

Grid code parameter development and revision process



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