The Role of Grid Codes for VRE Integration

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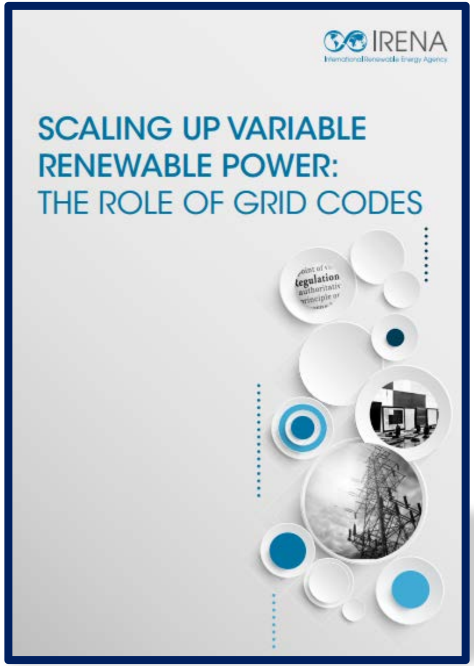
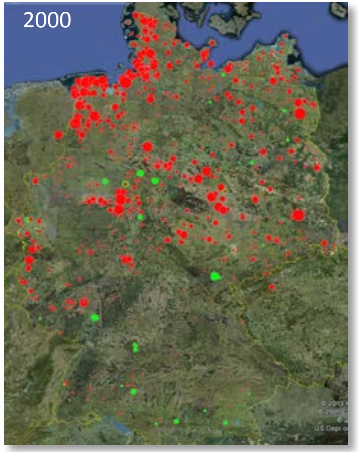
IRENA REPORT



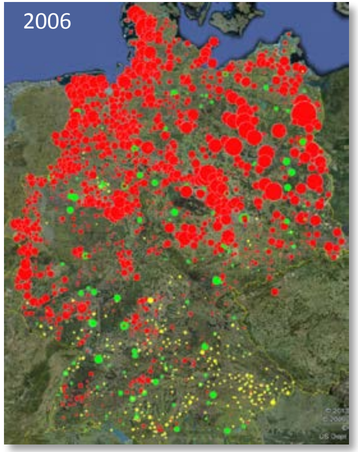
Link http://www.irena.org/DocumentDownloads/Publications/IRENA_Grid_Codes_2016.pdf

(or google “**IRENA Grid Codes**”)

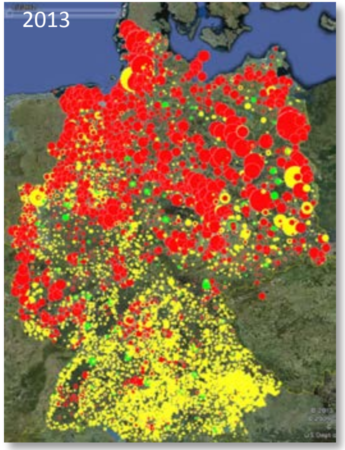
DISTRIBUTED GENERATION
EXAMPLE: DEVELOPMENT IN GERMANY



around 30.000 plants



around 220.000 plants



around 1.500.000 plants

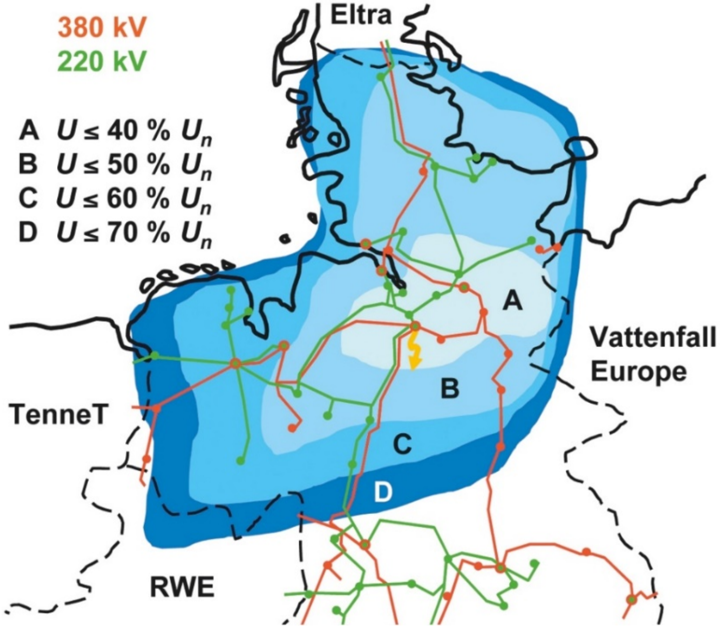
2000 2006 2014

Wind Solar Biomass

Unbundling of power systems and increasing shares of **decentralized generation** are major drivers of grid code development.

SOURCE: 50Hertz, Amprion, TenneT, Transnet BW, Google Earth

LESSONS LEARNED



SOURCE: EON

Grid Code development is an ongoing issue – Signficant onging learning process around the world

- Until a few years ago, there was little electrical power generated from wind, and wind turbines were neglected by system operators
- Turbines were supposed to disconnect in case of faults in the grid
- Installed wind capacity has grown so much that the policy needed to be changed: too much power would be disconnected in case of a wide-area voltage dip – up to several GW
- Danger to system stability, especially frequency stability: Primary control reserve in UCTE network corresponding to worst-case outage of the two largest conventional generation units (= 3 GW)

➔ **Fault ride through capability required!**

IDENTIFYING THE CHALLENGES

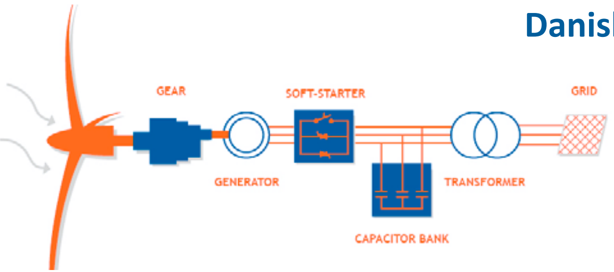
Each of these challenges comes with its own set of technical issues for system planning and operation:

- Variable availability must be incorporated into **system adequacy, dispatch and scheduling, as well as short-time balancing and reserve provision schemes**.
- Distributed generation includes **generator facilities of widely varying scales (power ratings), where also different services are necessary, useful and feasible**.
- Power converter control schemes need to **incorporate response characteristics to voltage and frequency changes**, similar to the inherent characteristics of synchronous machines.

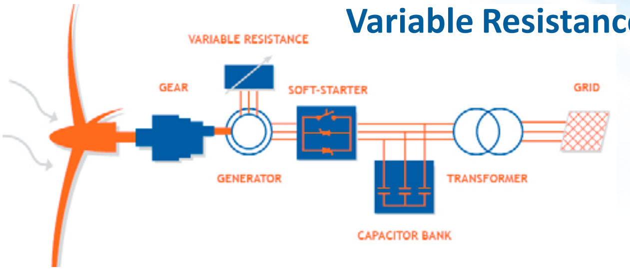
The technical solutions for these issues require research, development, and implementation. The resulting **costs should be optimized**, and the **distribution of costs** should be **agreed on between generator manufacturers, generator owners, and system operators**.

VRE GENERATION TECHNOLOGY
EXAMPLE: CONVERTER-BASED WIND GENERATION

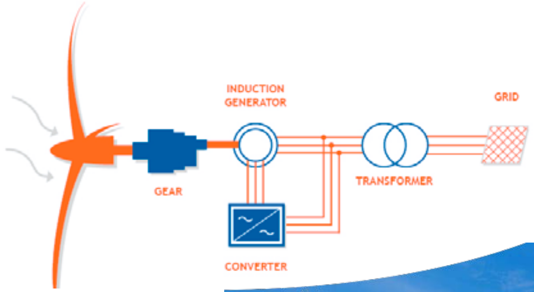
Danish Concept

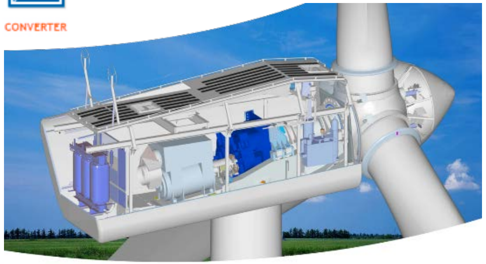


Variable Resistance

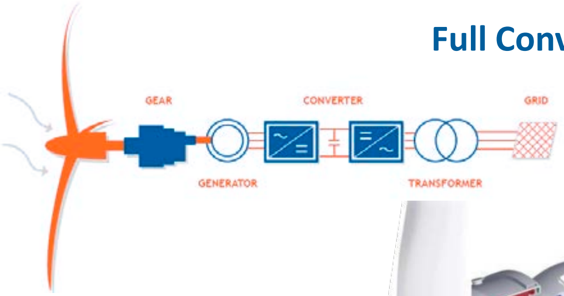


DFIG





Full Converter



CLEAR RULES TO ADDRESS THE CHALLENGES

The technical challenges of VRE integration do not only require technical solutions, but also have operational, economic, and regulatory implications.

Grid codes exist for systems with and without VRE. In case of systems with VRE, the grid codes provide the rules within which the VRE challenges are addressed. Due to the scope of the implications, grid codes also cover a wide range of aspects. These are often divided as follows:

- **Market Codes** govern the rules of the power market, connecting market operation and the technical needs and constraints of system operation.
- **Planning Codes** lay out the principles of network planning and the network-relevant aspects of generator (connection) planning.
- **Connection Codes** specify minimum technical requirements for generators to be connected to the power system. Connection codes may also cover, or exist for, other actors such as demand control facilities, storage, HVDC, etc.
- **Operating Codes** describe operational procedures and requirements concerning data exchange and scheduling, response to operational disturbances, and behaviour in emergency situations.

CLEAR RULES TO ADDRESS THE CHALLENGES

Connection Codes
- Generator Connection Code
- Demand Connection Code
- HVDC Connection Code

This report focuses on VRE Generator Connection Codes

Operating Codes
- Operational Security Code
- Operational Planning and Scheduling Code
- Load Frequency Control and Reserves Code
- Emergency Procedure Code

Planning Codes
- Generator Planning Code
- Network Planning Code

Market Codes
- Market Rules Code
- Network Capacity Allocation and Congestion Management Code
- Balancing Network Code

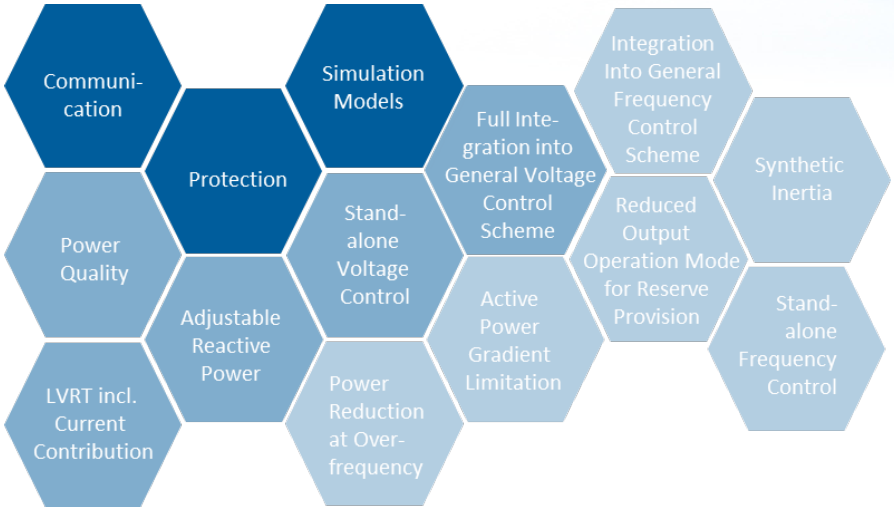
Hence, different types of grid codes facilitate the increasing operational flexibility required and offered by increasing VRE generation with the needs of operational stability, security and quality of supply, and well-functioning wholesale markets.

GRID CONNECTION CODES

The function of a grid connection code is to provide clear rules and technical requirements for generator facilities when connecting to an electricity system.

The technical requirements in grid connection codes are determined by the need to enable a sustainable growth of VRE and to maintain the reliability, security, and quality of the power supply:

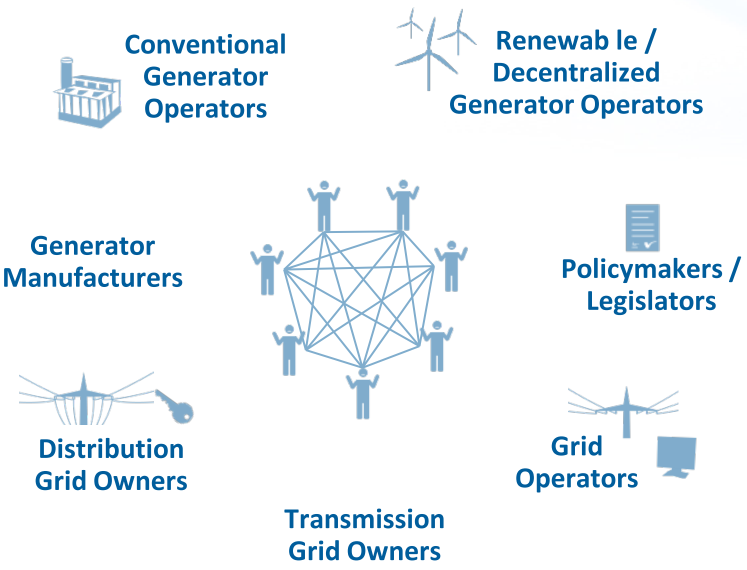
- The electrical power needs of all consumers must be met reliably;
- Voltage and frequency must be maintained within set limits to avoid damaging equipment connected to the grid;
- The system must be able to recover quickly from system disturbances;
- At all times the system must operate without endangering the public or operating personnel.



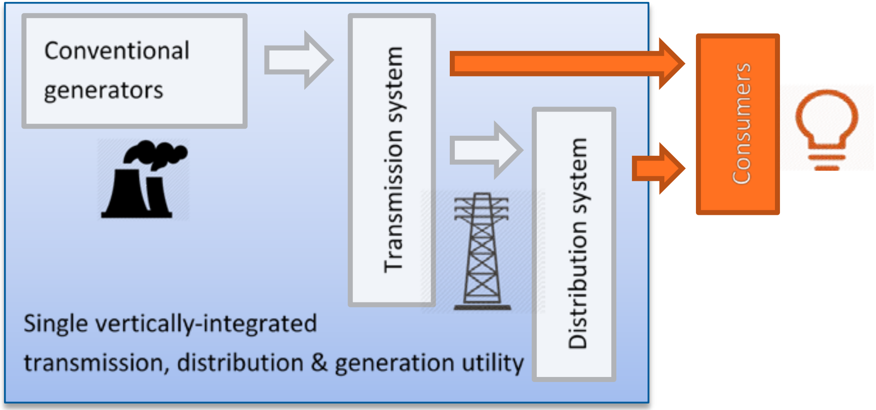
GRID CONNECTION CODES

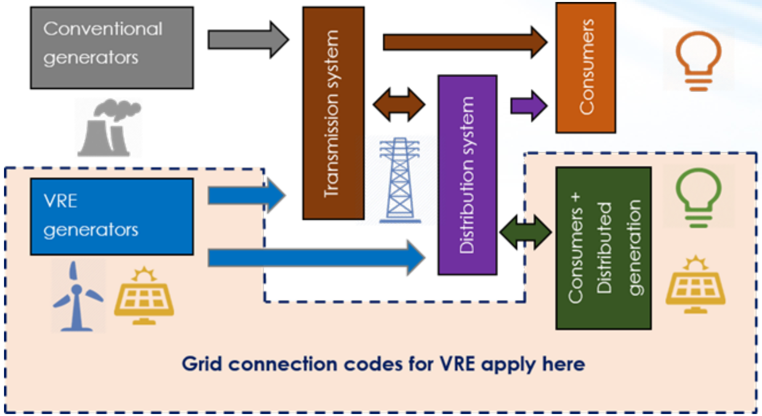
By applying at the boundary between power system and generator facility, technical requirements in grid connection codes affect different stakeholders in unbundled power systems: technology suppliers (generator manufacturers), investors (generator owners), system operators, and often also regulators.

Grid codes are a means to achieve fair and transparent treatment of these system actors and enable efficient coordination.



UNBUNDLING AND THE NEED TO COORDINATE SYSTEM ACTORS





Traditional power system

- Centralized generation
- Utility owns grid and generators
- Internal rules and requirement

Unbundled power system

- Decentralized generation
- Separated ownership
- Need for grid code governance

TECHNICAL REQUIREMENTS DEPEND ON CONTEXT

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Power systems and their requirements for the connection of wind and solar power plants can differ in a number of ways:

- **Size and capacity reserves** of the power system, including generator capacities, transmission capacities, and geographical distances,
- **Voltage levels and system frequency**,
- **Operational practices** such as protection schemes and grounding,
- **Interconnection level** with adjacent systems,
- Current and planned **VRE capacities**,
- **Distribution of** current and planned **VRE resources**,
- **Capabilities of** existing and planned **conventional generators**,
- Institutional **framework**,
- **Market design** and effectiveness,
- **State of the art**: development state of technical and operational procedures

As a result, grid codes usually differ in their requirements.

The process to develop a country VRE grid code should include:

- preparation of technical studies, data collection and assessment of country-specific aspects,
- drafting work of the grid code by experts,
- consultation of the draft with all stakeholders,
- endorsement of the grid code,
- Implementation, and
- future revision based on experience and possible policy changes.

ADEQUATELY STRICT REQUIREMENTS

Requirements **too stringent**: **No VRE** are installed (cost!)

Requirements **too lenient**: **System security** may be compromised.

Grid codes are a **major driver of technology development** as manufacturers have to adjust to new requirements…

… but a bad grid code can also be a major show stopper!

DETERMINING TECHNICAL REQUIREMENTS

The process of **determining** the requirements involves **studies investigating the needs of the power system**. Requirements must consider the capabilities of available generator systems in order not to hinder the process of VRE adoption.

The following studies are usually needed:

- **Load flow study** to investigate the needed reactive power capabilities of generators, consulting manufacturers to identify the capabilities of existing products and evaluate potential cost of extended capabilities,
- **Static and dynamic short circuit studies** for evaluating protection and LVRT requirements,
- **Load frequency control studies** for reserve requirements and gradient limitations, ideally including frequency stability study.

This list only includes studies in the context of VRE grid code parameterization and should be added to the studies that need to be performed for system planning and operation purposes.

TECHNICAL REQUIREMENTS, AND WHEN ARE THEY NEEDED?

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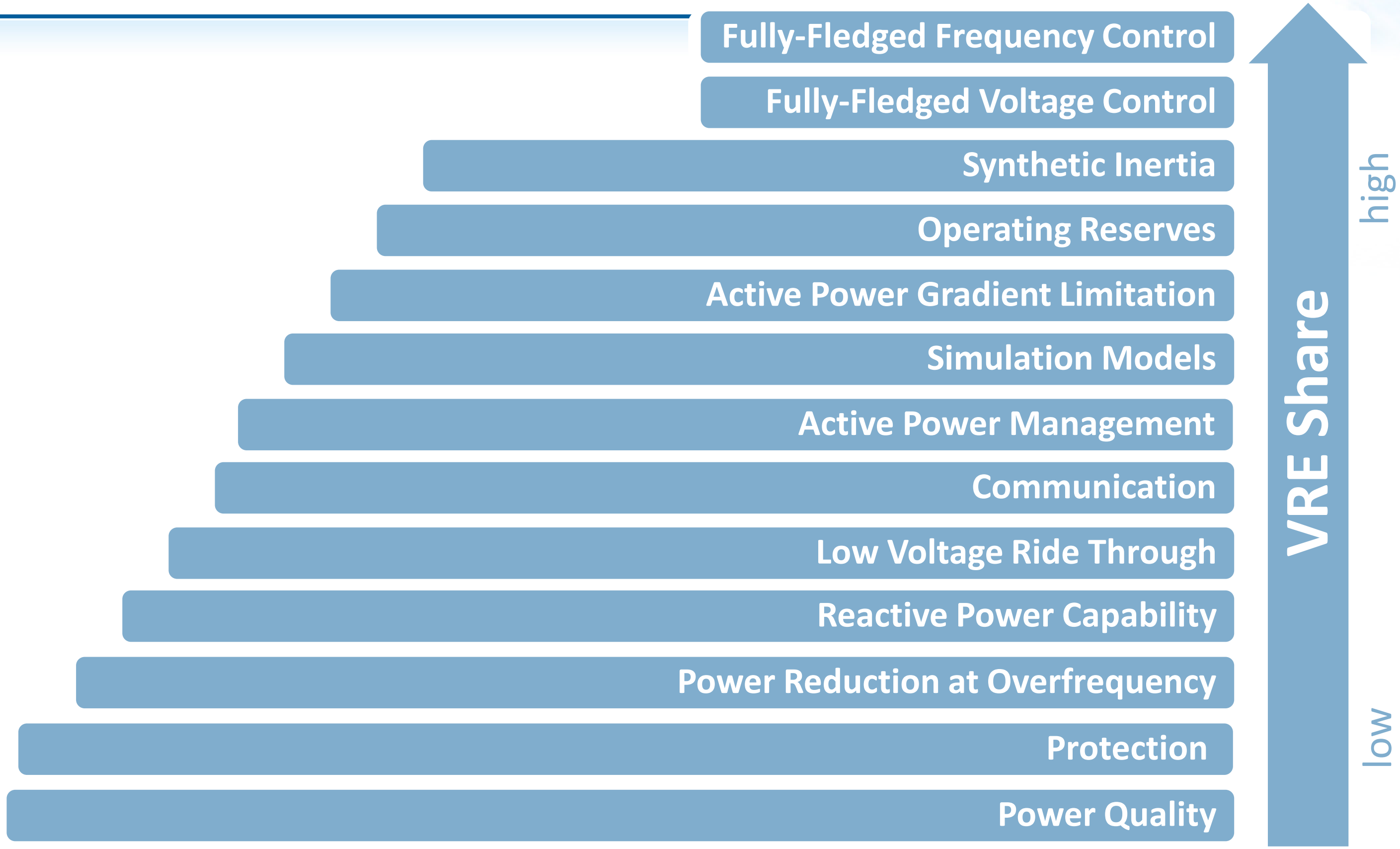
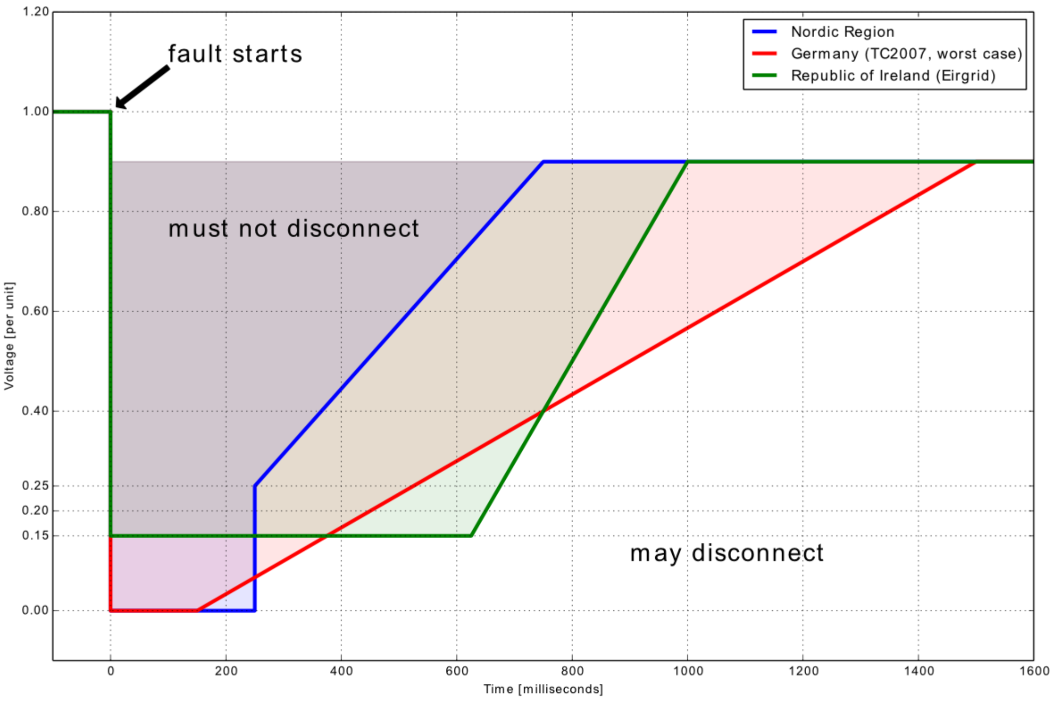


The most important driver for necessity of certain technical requirements for VRE generators is the VRE share in the power system

REQUIREMENT EXAMPLE: LVRT



LVRT requirements from different grid codes

In fault cases that cause a voltage drop, such as short circuits, VRE must support the grid for a certain time without disconnecting.

MAKING USE OF VRE GENERATOR CAPABILITIES

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VRE connection codes govern only the **minimum technical capabilities** VRE generators must provide. Many requirements directly satisfy some operational necessity. However, **certain requirements have a connection to higher-level use cases**. The scale to which extent these capabilities are actually used depends on the scope of the requirement, which in some cases involves legislation, regulation, and market design:

- **System balance and frequency control** is usually procured by the TSO through **reserve power markets.** This use case relates to remote controllability of power control mode and set-point, which is typically enforced on the grid code level for all relevant generators.
- **Reactive power and voltage control** may be obtained by a reactive power market or directly by voltage control requirements in the grid code. Grid Codes usually require the availability of reactive power control modes, and a remote control interface.
- **Active power control** may be required by the grid code, actual participation of VRE in congestion management is **often subject to renewable energy law**.

CERTIFICATION AND VERIFICATION OF TECHNICAL REQUIREMENTS

Enforcing technical requirements in VRE grid codes require mechanisms for verification of compliance with the codes. There are different strategies with differing costs and degrees of feasibility depending on the country context.

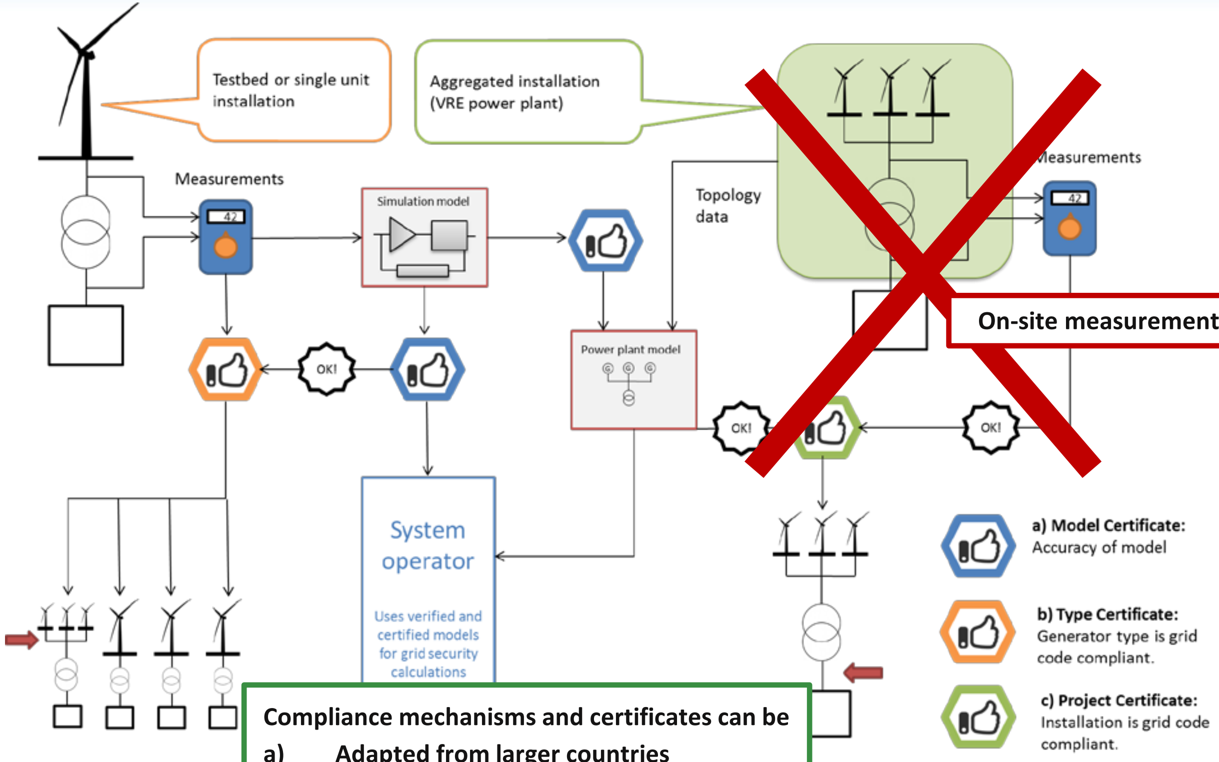
These mechanisms include, for example:

- On-site inspections,
- Use of certification systems,
- Verification of plants instead of units,
- Requiring manufacturer statements of conformance,
- Post-disturbance evaluation of system event recordings and revocation of grid access if non-compliance with grid code requirements is identified for a generator.

An **effective and reliable certification system** may come with the highest level of trust per required effort. However, it is infeasible for small system regulations due to significant organizational overhead.

Harmonization of requirements and resource sharing between countries can make it feasible!

COMPLIANCE



On-site measurements are costly and complicated

Compliance mechanisms and certificates can be
a) Adapted from larger countries
b) Set up regionally, bundling resources

CONCLUSIONS

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Recommendations for stakeholders:

- **Harmonize requirements and share resources!** This makes it easier to use certification systems for verification, and reduces the cost of market access for generator manufacturers.
- **Design a predictable and reliable grid code revision process!** This increases reliability and security by coordinating system change with technical development, and makes system planning significantly easier.
- **Consult with all relevant stakeholders!** VRE integration targets can be reached more easily without sacrificing system security and reliability when the burden of changes is shared fairly between all involved parties.
- **Anticipate requirements of a changed system!** When your targets are reached, the system will work differently than it does today, and has different requirements. System change might even be faster than you expect!
- **Avoid the mistakes from other countries!** Communicate, identify best practices, and consider experiences made by others. Considering that a lot of progress has been made in technical development, many capabilities are now available at low cost that were not available when the pioneering countries started.