# Update on Technical Group High Penetration, ongoing and planned activities

Ioannis Theologitis, ENTSO-E

**16th Grid Connection European Stakeholder Committee Meeting**

12 December 2019, Brussels

# Technical Group on High Penetration

# Members of Technical Group High Penetration - TG HP

Wind Manufacturing Industry:
Peter Christensen, Vestas, Denmark / substituted recently by Gert Karmisholt Andersen
Matthias Seidel, Senvion, Germany / substituted recently by Sigrid Bolik
Sönke Engelken, Enercon, Germany,
Thyge Knueppel, SiemensGamesa, Denmark,
HVDC Manufacturing Industry:
Athanasios Krontiris, ABB, Germany,
Klaus Wuerflinger, Siemens, Germany,
PV Manufacturing Industry:
Thorsten Bülo, SMA, Germany,
Power System Analysis tool providers/Consultants:
Bernd Weise, DIgSILENT, Germany,
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Academia:
Agusti Egea, University of Strathclyde, UK,
Prof. Jens Fortmann, HTW Berlin, Germany,
System Operators (on behalf of ENTSO-E):
Jőrg Jahn, TenneT TSO, Germany / substituted by Mario Ndreko
Saeed Salehi, 50Hertz Transmission, Germany,
Ioannis Theologitis, ENTSO-E, Belgium

# Final technical report

- Contains conclusion of the work of the cross industry Technical Group

- Contains **considerations beyond the guidance in IGD HPoPEIPS issued in 2017** – material (61 pages) for more formal code / market developments to facilitate secure operation even in ultimate 100% penetration

- There has also been **good interactions with a separate group in GB** working on the same topics, the VSM Expert Group associated with Grid Code Consultation GC0100, which has recently published a draft non-mandatory Grid Code extension and initiated a two stage market based tendering process for deliveries starting in 2020 and 2023 respectively.

- The **report has been shared** with the European Stakeholder Committee and other relevant European associations for comments and comments have been implemented. Sept 2019 Useful comments received from:
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# Main changes made to draft report and Recent developments, facilitating further references in report

The report has been extensively updated in response to positive comments received, including adding many references. Additionally, the following developments has allowed additions:

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  - GFC was on focus, mentioned on the closing session, has received attention
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  - focus on high penetration aspects
  - GFC on focus
- Draft Grid Code and market elements on GB – been added on the report

# Structure of the report

**PPM**: Power Park Module
**HCS:** HVDC Converter Stations
**LFDD:** Low Frequency Demand Disconnection



Final report ~61 pages

# GFC considerations linked to satisfying the system needs
# TG HP focus on seven challenge / characteristics during high penetration

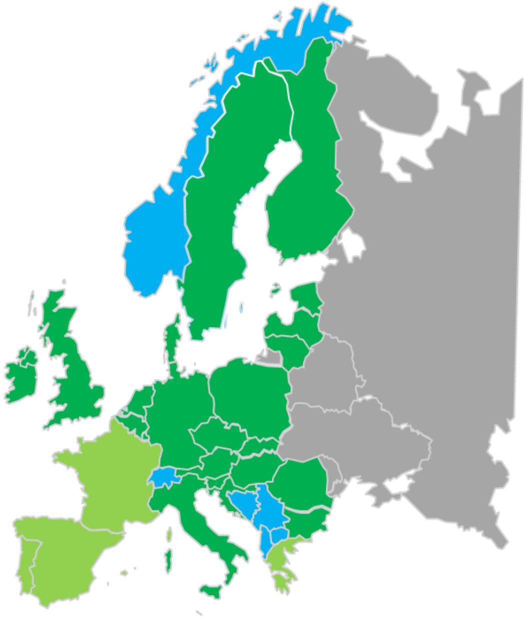
**The focus of the TG HP regarding GF capabilities has been exhausted on:**

1. Creating system voltage (does not rely on being provided with firm clean voltage)
2. Contributing to Fault Level (PPS & NPS within first cycle)
3. Contributing to Total System Inertia (limited by energy storage capacity)
4. Supporting system survival to allow effective operation of Low Frequency Demand Disconnection (LFDD) for rare system splits.
5. Controls acting to prevent adverse control system interactions
6. Acting as a sink to counter harmonics & inter-harmonics in system voltage
7. Acting as a sink to counter unbalance in system voltage

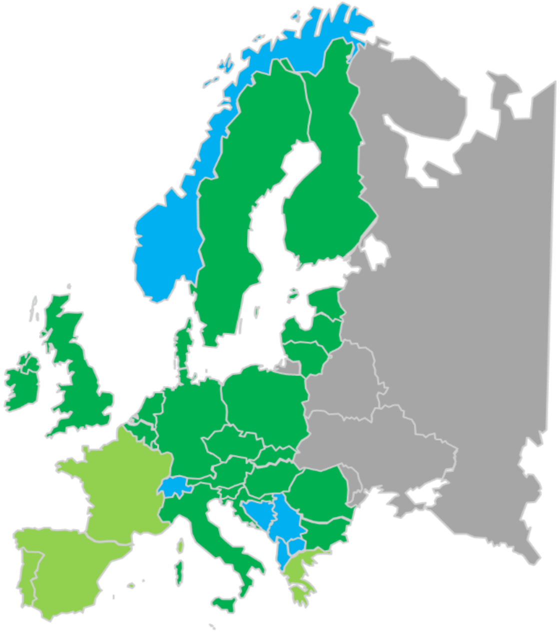
# CNC Implementation Monitoring

# CNC Implementation Monitoring – November 2019

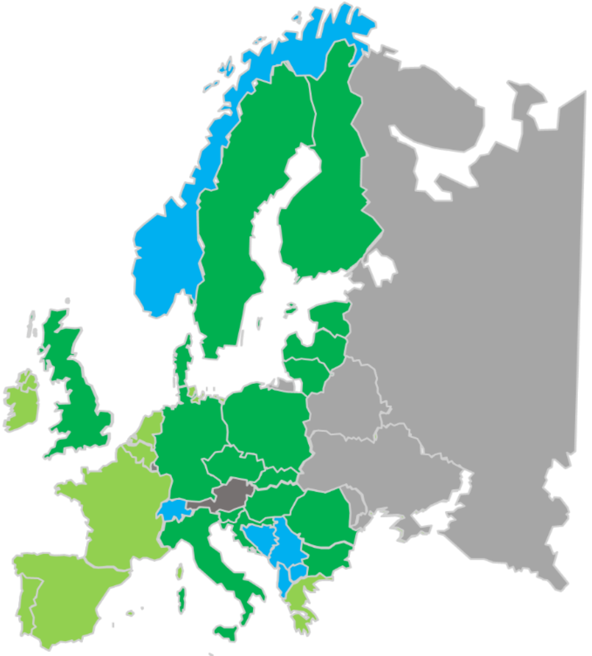
RfG NC



DC NC



HVDC NC



- In some countries there is partial approval e.g. thresholds approved but not all values of non-exhaustive requirements

Approved/binding
Submitted for approval
Non EU MS - implementation under different framework
No proposals

More details on the proposals and approved values in each Member State can be found in the monitoring file part of the Active Library here

Ongoing consistency check with the first edition of the CNC Implementation Monitoring report

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# Legal framework and background

CNC Implementation Monitoring report 2019

- An ENTSO-E obligation of monitoring the implementation of the European Connection Network Codes has been established in each connection code (NC RfG, NC DCC and NC HVDC) in accordance with Article 8(8) of Regulation (EC) No 714/2009.

  - According to the relevant articles of these CNCs the monitoring shall cover in particular
    - identifications of any divergences in the national implementation; and
    - assessment of whether the choice of values and ranges in the requirements of these CNCs continues to be valid

      - ENTSO-E has been collecting the proposals for the national specifications of relevant non-exhaustive requirements since the beginning of the implementation process. The implementation monitoring report has analyzed the national specifications of the non-exhaustive requirements of general application (i.e. those requirements that shall apply uniformly at national level), that are mandatory for the relevant system users.

        - NCLPs have been the main source of information – requested to update the monitoring excel file, provide additional information following the approved (by SDC) data collection process, considering that CNC implementation should be finalized in all Member States.

# Introduction of EU Regulations related to connection network codes



- ❑ An identification of any divergences in the national implementation means:
  - finding the national variations in the CNC implementation among the countries and the synchronous areas

- ❑ The assessment process is focused on the analysis of the current stated values and ranges in the CNC

- ❑ The results of the assessment process shall conclude whether the current stated values and ranges in the requirements applicable to facilities under CNC continues to be valid or if they need to be updated

- ❑ Some examples of requirements to be assessed:
  - Frequency ranges, LFSM-O/U, FSM, FRT, voltage ranges, reactive power capability -> RfG
  - Frequency ranges, voltage ranges, reactive power capability -> DCC
  - Frequency ranges, LFSM-O/U, FSM, FRT, voltage ranges, reactive power capability -> HVDC

- ❑ However, the assessment has been suspended for this first implementation monitoring report, because national implementations have not been approved yet in all Member States

# Summary and conclusions

CNC Implementation Monitoring report 2019

- ❑ The analysis of the implementation data has been carried out based on the data provided by the country representative member (NCLP)
- ❑ The results of the implementation data analysis can be considered for an assessment of the specific requirements of the capabilities in the CNCs
- ❑ The specification of the requirements that are significantly related to the each synchronous area has been recommended by ENTSO-E in the IGDs
- ❑ Divergences among Member States and consequently within the synchronous areas could be given by the different system characteristics ( e.g. given by different generation mix, by different voltage levels, maximum / minimum demand levels …) that require slightly different capabilities of the facilities connected to the system (e.g. power plants, demand units and distribution systems, HVDC systems, …)

# Summary and conclusions

CNC Implementation Monitoring report 2019

- CNC implementation required to consider following aspects at each country:
  - RfG required to consider the generation mix and voltage levels operated at each country for specification of MW thresholds and general specific requirements
  - DCC required to consider the voltage level of the TS/DS or TS/DF and the influence of the facilities related to the relevant connection points
  - HVDC required to consider specification of RfG and DCC requirements to meet the HVDC position in the system (i.e. to be the strongest element in the power system)
- The synchronous area specificities have been considered during the national implementation of these CNCs (e.g. size of the synchronous area, inertia, development of the system)
- Detail overview of the CNC implementation monitoring will be published in the dedicated monitoring report

TS – transmission system; DS - distribution system; DF – demand facility

# CNC Active Library

## CNC Active Library

**Implementation Guidance Documents**

Go to IGDs

**Monitoring**

Download monitoring file

**NC News**

All Announcements

ENTSO-E, for reasons of transparency, has been monitoring the implementation process in the European countries reporting all the necessary and publicly available information. This is an ongoing activity until Maybe 2018 for RfG NC and until September for DCC and HVDC NC. Available information, documents, websites, contacts can be found below.

In addition, a **monitoring file** (please check the Monitoring box on the left) can be downloaded which summarizes all the proposals for non-exhaustive requirements for all Connection Network Codes and their status for all the countries under the scope.

Choose a country in order to track the progress of **Connection Network Code implementation.**

Please, see below the implementation maps

**Countries**

Austria → Archive
Belgium
Bosnia and Herzegovina
Bulgaria
Croatia
Cyprus
Czech Republic
Denmark
Estonia

**The new AL will provide easy access to:**

- Final approved documents (national documentation) when available – organized by CNC
- National sites (update the current ones when required)
- Contact people (already incorporated in the old version)
- Any archived material shared during the national implementation process

**In each country in the current AL:**

- Already available documents from the implementation time remain
- Already available tasks from the implementation time remain

**Outstanding!** ENTSO-E will verify and update the information of the Active Library. Currently links to websites and documents are included in the monitoring excel file (those that are available).

**Note!** The quality of information per country differs significantly due to the differences of the national implementation. For more details, one can consult national websites or the national contacts when those exist.

# Overview of planning

# Currently planned activities for 2020 (high level)

- Workshop on January 30 around high penetration issues and grid forming aspects (discussions on the report)

- Continuation with the existing Expert Groups during the first half of 2020

- Initiate the new (approved) Expert Groups – possibility to kick off at least one of them in March if EG PSH concludes then

- Final setting of the Active Library and the monitoring excel file (Q1 2020)

- Preparations for the CNC Implementation Monitoring report 2020 and other monitoring activities

- Assessment of IGD list with possible updates

# GC ESC EGs – phase 2

**Expert Group on Pump Storage Hydro**
- **Meetings:**
  - 07/11/2019 webinar
  - 19/11/2019 webinar
  - 11/12/2019 webinar
  - Arrangements for 2020 meetings ongoing

**Expert Group on Identification of storage devices**
- **Meetings:**
  - 08/11/2019 webinar
  - 19/11/2019 physical meeting
  - 10/12/2019 ad-hoc webinar
  - 16/12/2019 webinar
  - Arrangements for 2020 meetings ongoing

**Expert Group on Mixed Customer Sites**
- **Meetings:**
  - 31/10/2019 webinar
  - 20/11/2019 physical meeting
  - 06/12/2019 webinar
  - Arrangements for 2020 meetings ongoing

# Back-up slides

# Performance Aspects of Grid Forming Converters

## High Penetration of Power Electronic Interfaced Power Sources Technical Group

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Klaus Wuerflinger, Siemens, Germany,
PV Manufacturing Industry:
Thorsten Bülo, SMA, Germany,
Power System Analysis tool providers/Consultants:
Bernd Weise, DIgSILENT, Germany,
Helge Urdal, Urdal Power Solutions, UK,
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Final report ~61 pages

# Grid Forming Converters – one answer to the 100% challenges

**The report defines 3 levels of converter capabilities:**

- Class 1 Power Park Modules (PPMs) - basic (survival) level of grid-connected converter functionality
- Class 2 PPM / HVDC Converter Systems (HCSs) – advanced controls reflecting present highest code reqm
- Class 3 PPMs and HCSs – perceived future capabilities for some – in order to allow up to 100% penetration

Class 3 PPMs or HCSs shall in addition to capabilities of Class 2 be:

- **capable of supporting the operation of the ac power system (from EHV to LV) under normal, alert and emergency states without having to rely on services from synchronous generators.**
- This shall include the capabilities for stable operation for the extreme operating case of supplying the complete demand from 100% converter based power sources.
- The support services expected are limited by boundaries of defined capabilities (such as short term current carrying capacity and stored energy). Transient change to defensive converter control strategy is allowed (if it is not possible to defend the boundaries), but immediate return is required.

Description of **one practical implementation:** The control strategy of **Grid Forming PPMs or HCSs** provide an inherent performance resulting from presenting to the system at the Connection Point **a voltage behind an impedance, in effect a true voltage source.**

# GFC considerations linked to satisfying the system needs
# TG HP focus on seven challenge / characteristics during high penetration

**Issues / challenges potentially remaining** even with Class 2 converter capabilities
**if PEIPS penetration moves beyond 60% towards 100% of instantaneous power demand**

**Therefore the focus of the TG HP regarding GF capabilities has been exhausted on:**

1. Creating system voltage (does not rely on being provided with firm clean voltage)
2. Contributing to Fault Level (PPS & NPS within first cycle)
3. Contributing to Total System Inertia (limited by energy storage capacity)
4. Supporting system survival to allow effective operation of Low Frequency Demand Disconnection (LFDD) for rare system splits.
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# GFC considerations linked to satisfying the system needs

Challenge: **Create system voltage**

The PPM or HSC provides a three-phase voltage.

- Within the capability of the source, the voltage is maintained in amplitude, frequency and phase angle independently from a load connected to the source.
- **Does not rely on being provided with firm clean voltage**

**Dynamic Capability:**

- Ride through and **maintain synchronism during transient events** like grid faults and load steps in the system
- Capability to supply linear and nonlinear loads of active and reactive power with a supply voltage of commonly accepted quality (specify e.g. THD_U at given THD_I) stationary
- Transient active and reactive power need / demand resulting from load steps can be fulfilled
- The capability to **limit and control the rate of change of voltage angle** in transient conditions in order to ensure overall system stability, e.g. following system splits

# GFC considerations linked to satisfying the system needs

Challenge: **Contribute to fault level**

- Limiting the impact of a grid fault (e.g. short circuit on transmission level) on generators and consumers in the wider area of the fault.
- In addition, the functionality of protection equipment in the grid has to be ensured.
  - **Contributes to Fault Level (Positive/Negative Phase Sequence within first cycle)**
  - Without NPS contribution, performance of transmission distance protection may be suspect
- The voltage source characteristics of a GFC means that it would contribute to the system strength of the power system.
  - **The grid forming converter control regardless of the technology implementation, behaves as a Thevenin source,** controlled in frequency and in amplitude.
- If current limitation is necessary during voltage drops in the network, two options will be available:
  a) switch over to current control during the fault period in order to limit the current to below the rated current capacity of the converter
  b) implement some current clipping features (done either by hardware or software depending on converter technology)

# GFC considerations linked to satisfying the system needs

Challenge: Sink for harmonics and unbalances

In the absence of synchronous machines which provide a low impedance to harmonics and unbalance, **GFC can provide a passive, damping response in the harmonic frequency range using harmonic current flow with the effect of improved voltage quality at point of connection.** The characteristic could be:

- inductive, similar to a synchronous machine

or

- inductive-resistive, providing superior performance to a synchronous machine

**Consideration is needed to:**

- Sharing of current headroom:
  - Power quality prioritized in steady-state
  - Under dynamic disturbances, giving it lower priority than FRT or frequency support
- Frequency range needs to be defined
  - Reduce voltage harmonic content at POC by providing a current path for non-fundamental frequencies up to a limit of e.g. 2 kHz.
- Performance stands **in contrast to grid code requirements to-date**
  - These typically **focus on** harmonic content rather than on **voltage harmonics.**

# GFC considerations linked to satisfying the system needs

Challenge: Contribution to inertia

The main benefit of inertia from synchronous machines is, that their rotating mass provides inherently stored energy that – in combination with the voltage source characteristic of a synchronous machine

- counteracts voltage angle, amplitude and frequency perturbations
  - therefore reduces  the rate of change of frequency in case of load steps
  - helps to limit voltage steps by providing a source of active power if needed

TG HP worked on **definitions of inertia, synchronous machines inertial response, synthetic inertia and fast frequency response**

**Inertia provided by GFCs could be:**

- **specified / designed to be similar to synchronous machines**
- **chosen (by the TSO) to be substantially different by giving greater emphasis on damping**

**From the manufacturers point of view**

- important for a **generic inertial characteristic to emerge that can be fine-tuned for specific system needs.**
- in future it could be possible to **vary the inertial and damping gains based on varying grid needs.**

# GFC considerations linked to satisfying the system needs

Challenge: System survival to allow effective LFDD

This part deals with the challenges of extremely **rare situations assuming last resort (LFDD) is called upon**

So far LFDD (also called Under Frequency Load Shedding) has been effective, to contain major sudden generation – demand unbalances, e.g. **stage 1 (of many) has been enough for recovery for two cases**

- CE three way split 4 Nov 2006
- In GB 8 August 2019 near simultaneous loss of two large generation sources + embedded LOM trips

- In 1981 in GB **6 stages of LFDD just avoided system collapse** following a system split (hit 47.3Hz)
- In 2003 the Italy split from CE was **not rescued by all stages of LFDD** - a rare case when the **system collapsed** when tripping more demand (>30%) than lost in split (25%)

With the possibility of operation close to 100% PEIPS with no synchronous generators and therefore in principle very limited system strength, **preliminary analysis shows a risk of near instant system collapse (say <200ms), prior to LFDD operation.**

- Studies have shown that even when operating a system close to 100% PEIPS and experiencing system splits with very large % imbalance, the system can **avoid collapse, if system strength is delivered by applying adequate volume of well designed GFCs (order of 25%).**

# GFC considerations linked to satisfying the system needs

Challenge: Prevent adverse control interactions

When a power converter is connected to the electrical grid, the **overall network resonances vary** because of

- (i) the connection of the converter passive components and
- (ii) the impact of the converter’s active behaviour

- **The stability phenomenon relate to small signal disturbances in a wide frequency range. The terms “harmonic stability” or “super synchronous instability” are sometimes used.**
- **In addition, sub-synchronous control interactions need to be similarly considered.**

One view in terms of managing the challenges is:

1. A general specification, which avoids control interaction and resulting harmonic over-voltages in any situation, might be very conservative and impossible to fulfil.
2. **A TSO contrary view is advocating a frequency band (5 to 1000 Hz) to be avoided for active GFC controls in order to ensure stability** for varying network topology over time and varying short term connection of generation.

# Operational boundaries for GFC performance and the need to define key quantities linked to storage and dynamic current rating

- The **performance of a GFC** during a grid event, is **dependent** on the grid forming characteristics being supported by the converter hardware in terms of **headroom for the additional current and availability of the requested active power** in context of the actual operating conditions.

- If the **converter has no headroom for the requested current**, the control system must adapt into a protective mode to avoid damaging the power hardware, which means rejecting the exchange of active and/or reactive power that the grid event initiated.

- For grid events involving active power there is additionally the consideration that the power converter must be able to source or sink the energy as requested by the grid event.

- The **hardware requirements for a GFC are given as a function of desired grid forming performance** and the system boundaries within which the grid forming characteristics should be operational. The characteristics of the worst-case events and if the requested or required inertial characteristics are known, the **hardware for converter and the energy source can be designed accordingly**:

    1. sufficient current window in the converter on top of its pre-event operating point, and
    2. the energy source that is delivering the inertial power

# GFC cost considerations for wind, PV, Batteries and HVDC

**Grid forming converter control is fundamentally different** from the control that is commonly employed today and will, considering the general maturity level anno 2019, **require a significant R&D effort from converter manufacturers to develop their technology readiness level to today's level for current control.**

**This includes:**

- control stability and interaction
- hardware development and re-dimensioning
- development and validation of client user models
- grid compliance testing and certification
- assessment of the wider impact on equipment design
- quantifying any impact to equipment capability across the entire operational envelope
- concept maturing and runtime

# Maturity of GFC implementation

**Experience with GFC to date is limited**, but rapidly expanding:

- From a few MW, so far up to **a 30MW installation in South Australia.**
- So far the most **common adoption of GFC control is associated with BESS facilities** mainly linked to PV installations.
- For wind, the reported installations so far are limited to one 3MW WTG on test.
  - Presented here is a **23 turbine 69MW wind farm on test with GFC for 8 weeks with H up to 8s**
- GFC has so far been established in applications (mainly in microgrids) where it is required to ensure stable system operation already today **GFC has not yet been driven by future proofing large systems with approaching 100% PEIPS penetration.**
- The R&D associated with GFC is rapidly expanding and widening in its coverage with an extensive set of publications being delivered in the second half of 2019.
- **GFCs have not yet been established by the major manufacturers in their mass market converter products.**

# Challenges of a possible transition to GFC for equipment suppliers operating in an increasingly competitive markets

- Delivering new capabilities **requires R&D resources** and hence incurs expenditure and time.
- Introducing GFC is a **major change.**
- Ensuring that the **desirable characteristics embedded in existing designs** developed over decades **are not lost** is essential.
- **Added capital cost** in mass manufacture is likely
  - mainly focused on **energy storage and increased converter rating.**

- Offering GFC as well as existing products adds complexity and cost.

- **Manufacturers need commercial incentives to proceed with GFCs,** implying willingness on the part of developers to pay a premium for the new capabilities.
  - Currently, such incentives do not exist (except in some microgrid contexts). They could arise from:
    - Mandatory requirements, such as those in grid codes.
    - Opportunities for additional revenue streams, e.g. ancillary services markets.
      - Compared to existing AS markets, services to deal with the range of issues (e.g. the seven here) arising from weak networks with potential low system strength appear more complicated
  - Negative incentives for non-compliant equipment, e.g. uncompensated constraining off.
  - In **GB the Stability Pathfinder process is in progress, may deliver cost / Effective MVA for alternatives**

# Outstanding questions

- **What proportion** of the converter interfaced equipment need to have the seven characteristics in question?
- **Where and when** will the capabilities need to be **available**?
  - **Different urgencies** between small SAs (e.g. GB now) and countries in large SAs (e.g. CE later)
  - **Wind Europe suggest manufacturers need 5 years to prepare even after full spec / codes delivered**
- Are some types of converter interfaced equipment better suited to deliver GFC with these characteristics cheaper and more effective than others?
  - small embedded units versus larger units connected at higher voltages?
  - If a market driven approach is adopted, questions arise as to the **market design.**
  - Would available **capability or utilisation be remunerated**?
  - Would payments have to be **location-based**?
  - Could the **entire required range of services (seven covered here) be obtained on the market**?