Activities of the Joint Working Group CIGRE C4/C6.35/CIRED: Modelling and Dynamic Performance of Inverter Based Generation in Power System Transmission and Distribution Studies

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On behalf of: JWG CIGRE C4/C6.35/CIRED

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Overview of CIGRE JWG C4-C6.35/CIRED

WG Composition:

- WG Co-Conveners: Koji Yamashita and Herwig Renner
- Number of full members: 45
- Number of corresponding members: 21
    - Number of countries represented: 23
    - Number of members from industry: 38
    - Number of members from university/R&D: 28

WG Timeline:

- Start date: 2013/10
- End of WG activities: 2017/03

Overview of CIGRE JWG C4-C6.35/CIRED

Recent Activities:

- CIRED Tutorial was held in Glasgow, Scotland on 2017/06.
- IEEE Powertech 2017 Special Session was held in Manchester, United Kingdom on 2017/06
- Extra meeting for U.S. members was held in Chicago on 2017/07 (during IEEE GM 2017).
- Native language check of the technical brochure has finished in 2017/08.
- 2 TBs are expected to be submitted to CIGRE/CIRED by the end of 2017.

Other Items:

- 2 TBs will be published by no later than end of Jan. 2018.

1. Comparison with Synchronous Generators

~ + AVR + GOV

Assumed to be replaced by IBG

≠

With minimum functionalities

Before interconnection requirements are evolved

15 Characteristics which SGs have that IBGs do not

With minimum functionalities

- Major differences between IBG and SG are:
  - Contribution to Inertia
  - Fault Current Provision
  - Synchronization Capability
  - Constant Internal Voltage Source (grid forming capability)

These capabilities are very hard to achieve with IBGs in an equivalent way as a SG.

- To emulate this capability the IBG needs to increase or decrease the active power output.
- Decreasing P is easy.

- PVs can easily change the output as there is no such limitation of the "limited frequency sensitive mode" for PVs.

- Synthetic inertia cannot be considered completely equivalent to the inertia provided by SG.
- Measuring devices and control introduce delays.

	...vanced capability / Advanced ...sibility of IBG
Rotating mass/iner...	..., depending on: Prime mover, ...rating point, storage device and ...ction of frequency deviation
Frequenc... response... capabilit...	...s, depending on: Prime mover, ...erating point, storage device, ...ection of frequency deviation
Limited f... sensitive...	...s (prime mover dependent)

	Conventional SG	IBG with minimum functionalities	Advanced capability / Advanced feasibility of IBG
Constant voltage source			… but in order to have a …ant voltage following … oversizing of the inverter …essary
Grid voltage support (Steady state)			…arge-scale IBGs only) …eactive power …ensators (shunt …itor, SVC ,...)
Reactive power support (V-Q steady state)			…ccording to PQ capability
Reactive power support (reactive current control during incidents)			…usually during faults IBGs …e able to provide a …ctive current injection with some delay.

- The IBGs themselves can change the reactive power output through the oversized inverter and/or through the reduction of active power output.

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	Conventional SG	IBG with minimum functionalities	Advanced capability / Advanced feasibility of IBG
Synchronization (torque) capability	Yes	No	Yes (but almost infeasible)
Damping torque capability (power oscillation damping capability)	Yes, damper		…es, POD functionality
FRT capability			…prime mover dependent)

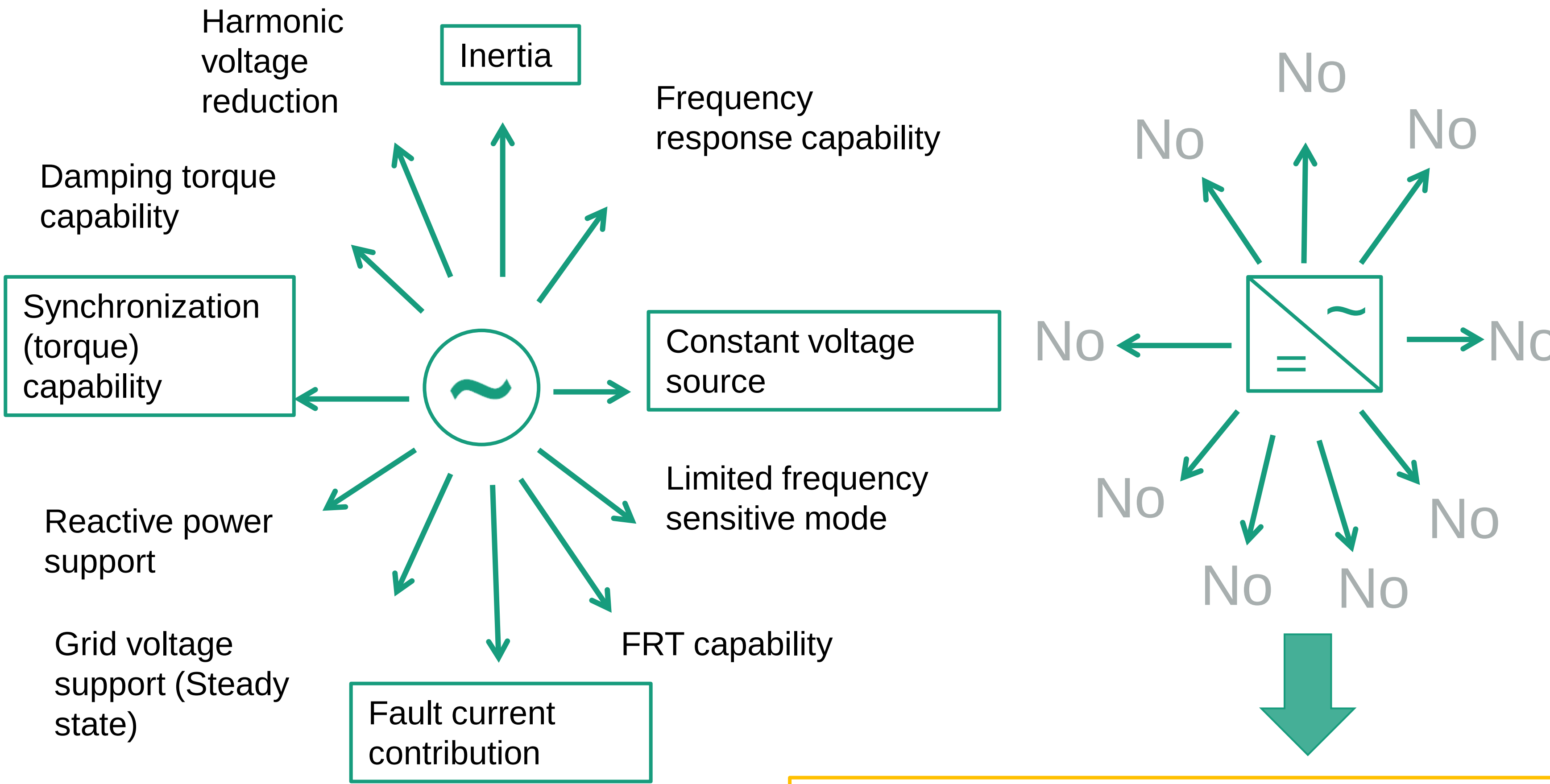
- The IBGs might be required to have the synchronizing torque capability in the future.
- It is very difficult to achieve because the angle difference needs to be observed without time delay.

- The IBGs could contribute to mitigating Power Swing Oscillations.

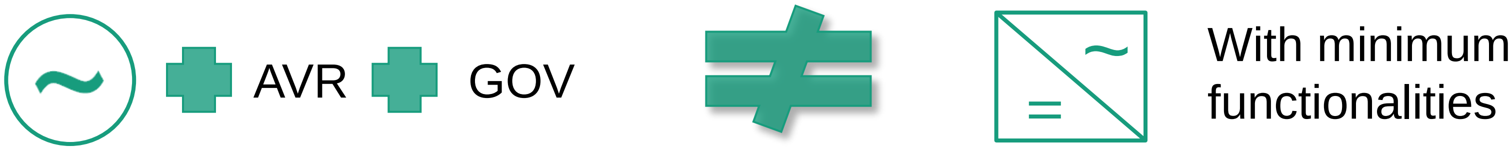
	Conventional SG	IBG with minimum functionalities	Advanced capability / Advanced feasibility of IBG
Harmonic emission	No	Yes, supra-harmonics	-
Harmonic voltage reduction	Yes, for low order harmonics	No	Yes, if active filter algorithms are implemented
Fault current contribution	Yes	N	Yes, but contribution is limited to around 1 p.u.
Control response capability			erter itself fast, possible limitations due to measurement delay
Overload capability (up to few seconds)			but significant oversized IBGs are required.

- SGs provide a rather low impedance path for harmonic currents and thus tend to reduce harmonic voltages.
- IBGs equipped with algorithms in the control system are able to act as active filter, reducing (low order) harmonic current and therefore, voltages.

Inherent Characteristics



A set of ancillary functions is required



- SGs may be replaced by IBGs. Hence, functionalities which the SGs have, will be lost and the system stability may be affected.
- In order to cope with this, such functionalities have been required by the IBGs through updating of Grid Codes.

2. Ancillary functions

- Because of the flexibility of the inverter control design, IBGs may be required either, from the technical Standards and/or from Grid Codes, to provide some additional capabilities for grid support.
- The following tables show the most relevant requirements of capabilities for IBGs from:
  - European commission - EU Regulation 2016/631 establishing network code requirements for grid connection of generators (NC-RfG).
  - The IEEE 1547 - Standard for Interconnecting Distributed Resources with Electric Power Systems .

2. Ancillary functions

Requirement	EU 2016/631	IEEE 1547	IEEE 1547 (Future)
P(f) (over/under)	x		x
Voltage Control by means of Reactive Power (Q(V))	x	(x)	x
Voltage Control by means of Active Power (P(V))			x
Synthetic Inertia	(x)		
ROCOF Immunity	x		x
Voltage phase angle jump immunity			x
LVRT & HVRT	x (LVRT only)	(x)	x
Anti-islanding Detection Methods	x (ROCOF)	x	x

x means one or more classes/categories of the IBGs that are required.
( ) denotes a non-mandatory requirement.

2. Ancillary functions

Requirement	EU 2016/631	IEEE 1547	IEEE 1547 (Future)
Dynamic Voltage Support during faults and voltage dips	(x)		(x)
Power Oscillation Damping	(x)		
Black Start Capability	(x)		(x)
Capability of Islanding Operation	x		(x)
Automatic Disconnection with Abnormal Voltage	x	x	x
Automatic Connection with Active Power Recovery Speed	x		x
Constant Power at Low Voltage	x		x
Constant Power at Low Frequency	x		x

x means one or more classes/categories of the IBGs that are required.
( ) denotes a non-mandatory requirement.

3. Inverter protection

- Inverter Protection may be distinguished into
  - Internal Protection (DC Protection)
  - Internal Protection (AC Protection)
  - Internal Protection (Protection Purpose Control)
  - External Protection (Interface Protection Systems)

"Limitation of inverter current's

Required to serve a different purpose and consider the network. Monitoring the network, not the inverter.
Loss of Mains Protection (LOM)
UFR/OFR, UVR/OVR

Compared to the synchronous generators, IBGs are more likely to be disconnected due to the high sensitivity inverter protections.

Because the operation of the inverter protection could result in the disconnection of the IBG, the inverter protection models play an important role for most of the dynamic stability analysis.

1	Reduction of maximum in... limit
2	Limitation of inverter curr...
3	Limitation of current
4	DC Overvoltage Protectio...
5	Overvoltage/Undervoltage...
6	Overfrequency/Underfrequency Pr...
7	Protection for Detecting Balan...
8	Protection for Detecting U...alanced Short-Circuit Fault
9	Protection for Detecting Single-line-to-ground Fault
10	ROCOF tripping: monitoring the power frequency variation rate and disconnecting the inverter when it reaches a certain limit [Hz/s]
11	Vector jump
12	Transfer trip
13	Anti-islanding active detection method

3. Conclusions

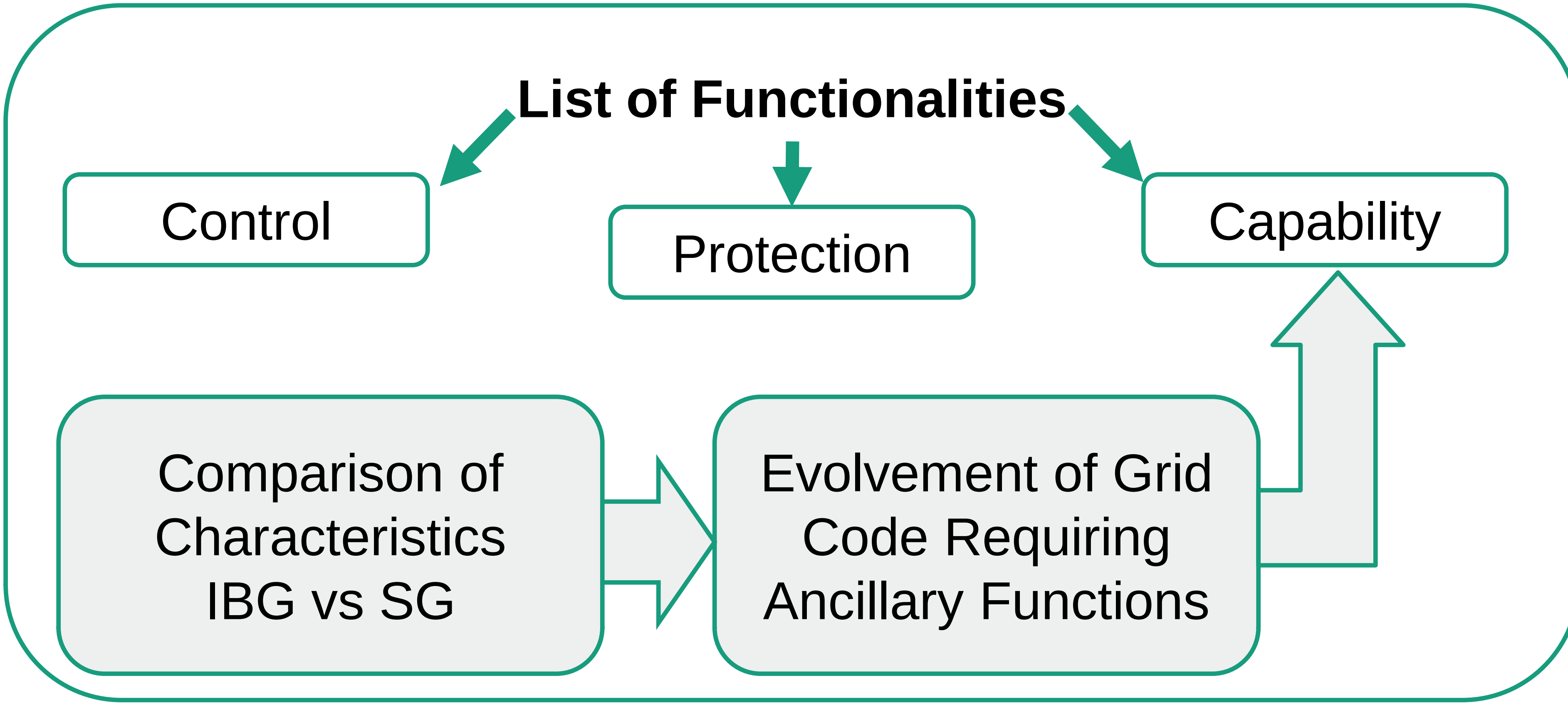
- The major differences between conventional SGs and IBGs are:
  - The inertia
  - The fault current provision
  - The synchronization capability
  - The fixed internal voltage source.

- Those four characteristics are provided by synchronous generators. However, they are not easily provided by IBGs.

3. Conclusions

- On the other hand, many of the characteristics such as the frequency control capability and the reactive power control capability can be provided by IBGs.
- Compared to the synchronous generators, IBGs are more likely to be disconnected due to the high sensitivity inverter protections.
- Because the operation of the inverter protection could result in the disconnection of the IBG, the inverter protection models play an important role for most of the dynamic stability analysis.

3. Conclusions



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Fraunhofer IWES - Business Field Grid Planning and Operation

- Techno-economic studies for analyzing, planning, operation, control, stability of power systems
- Automated Planning Tools (e.g. pandapower http://www.uni-kassel.de/go/pandapower)
- Operational Tools (algorithms for ancillary services, hardware/software platform for pilot systems)
- (Co-Simulation) Test Platforms for operational solutions (www.opsim.net)
- Multi-Energy System Planning and Operation (Power, Heat, Gas)
- Microgrid/ Hybrid System Test Bench and PHiL Tests

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Department Energy Management and Power System Operation - e²n

- Development of models, methods, algorithms and tools for analysis, operation and control, and design of the future decentralized power system with high share of renewable energies. e.g. pandapower
- Multi-Objective/Perspective/Level Optimisation of the power system
- Simulation of the power system over time scales and system levels.
- Resilient Control Design incl. power system stability, network restoration, microgrid structures