ENERGY

RoCoF Alternative Solutions

Technology Assessment

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SAFER, SMARTER, GREENER

Introduction

1. Scope of Works, Phase 1, RoCoF alternative solutions –a high level assessment-
2. FFR type device definition
3. Inertia: Synchronous and Non-synchronous
4. Frequency measurement technology and reliable RoCoF detection
5. FFR type technologies and Ranking
6. FFR type technology faceplates (explanation of 2 examples)
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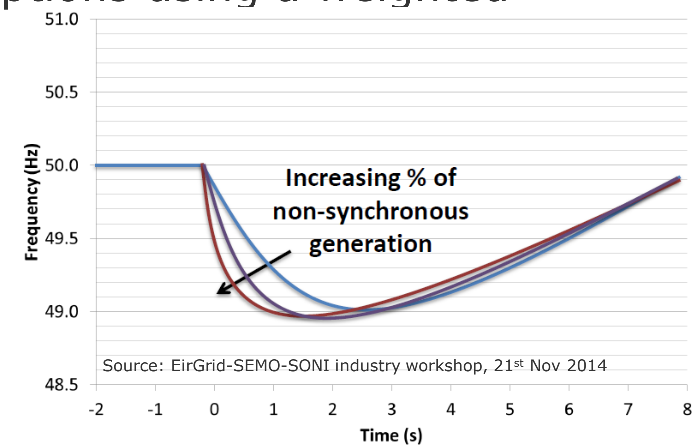
RoCoF alternative solutions, Phase 1, -a high level assessment-

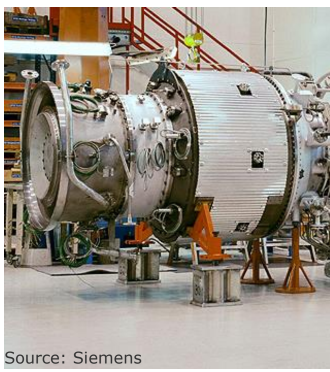
- **Phase 1:** (initial phase => Shortlist viable options for Phase 2)
  - A review of potential alternatives to changing the RoCoF standard from 0.5 Hz/s to 1 Hz/s; and
  - Qualitative high level assessment of theoretical options using a weighted scoring.



- **Phase 2:** (detailed review of shortlisted options)
  - Technical and economic analysis on the aspects of each option, which shall include:
    - Dynamic simulations
    - Techno-economic studies to assess economic benefit

FFR type device definition (Synchronous/ Synthetic)

- Fast Frequency Response (FFR) type devices refers to technologies that can be applied to help prevent large RoCoF events in the island power system.
- Synthetic FFR type devices refers to non-synchronous technologies that connect to the grid by means of power electronics which can be applied to help prevent large RoCoF events in the island power system.


Source: Siemens


Source: Alstom


Source: stoRE (290 MW Island of Ireland)


Source: REDT

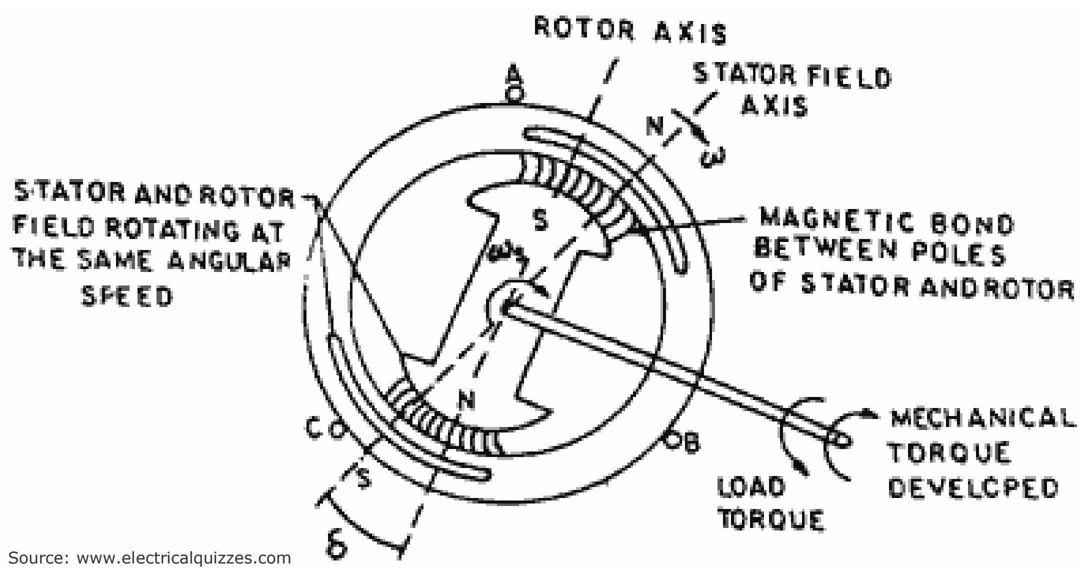

Source: Beacon Power (Hazle Township, PA)


Source: www.constructionireland.ie)

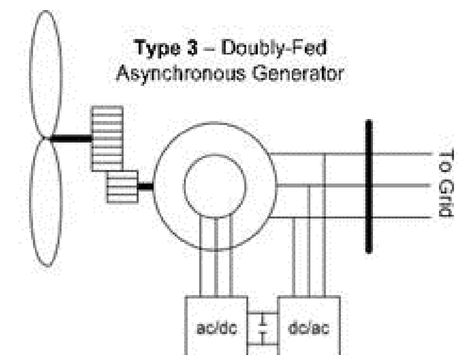
Inertia: <u>Synchronous</u> and Non-synchronous

Synchronous inertia is provided by all machines physically connected to the electricity Grid via its electromagnetic field, and hence its prime-mover are also directly connected.

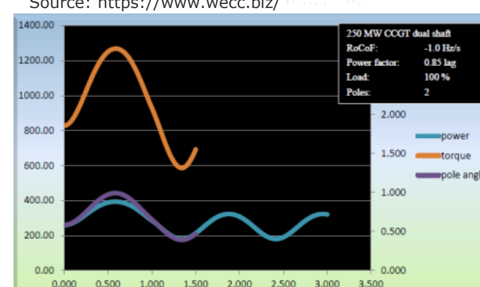
- Motors: For a motor, the electrical energy induces a magnetic field in the stator (rotating field) and rotor (static field). The two magnetic fields interact, creating a rotation and mechanical force.
- Generators: For a generator this process is reversed. The machine is rotated by a mechanical force. The rotor (with its static magnetic field) induces a changing magnetic force in the stator which induces electrical energy.



Source: www.electricalquizzes.com

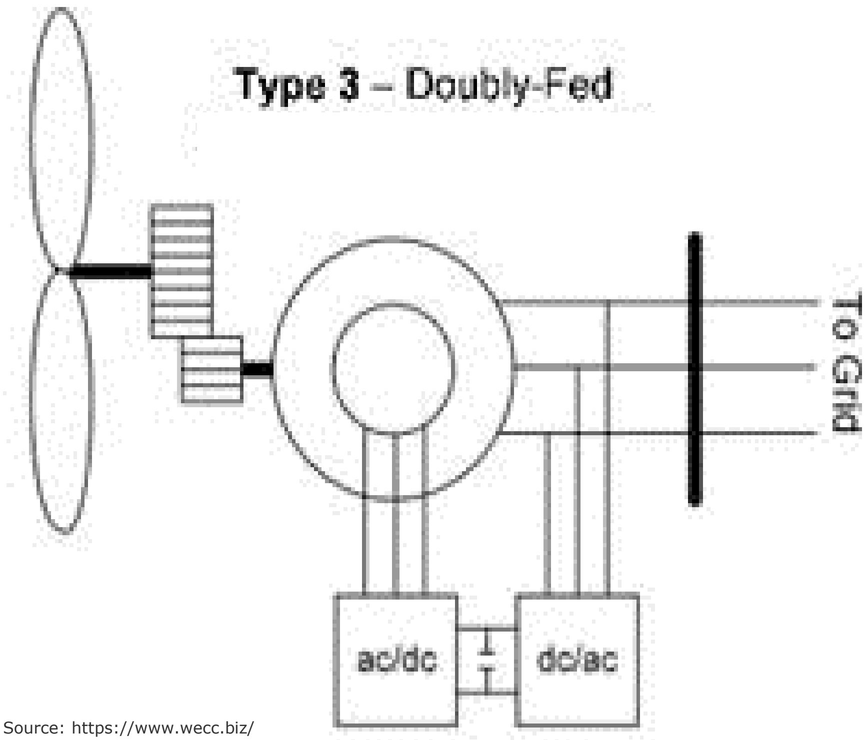


Source: https://www.wecc.biz/



Source: DNV KEMA, RoCoF report 16010927, 8th Feb 2013

Inertia: <u>Synchronous</u> and Non-synchronous



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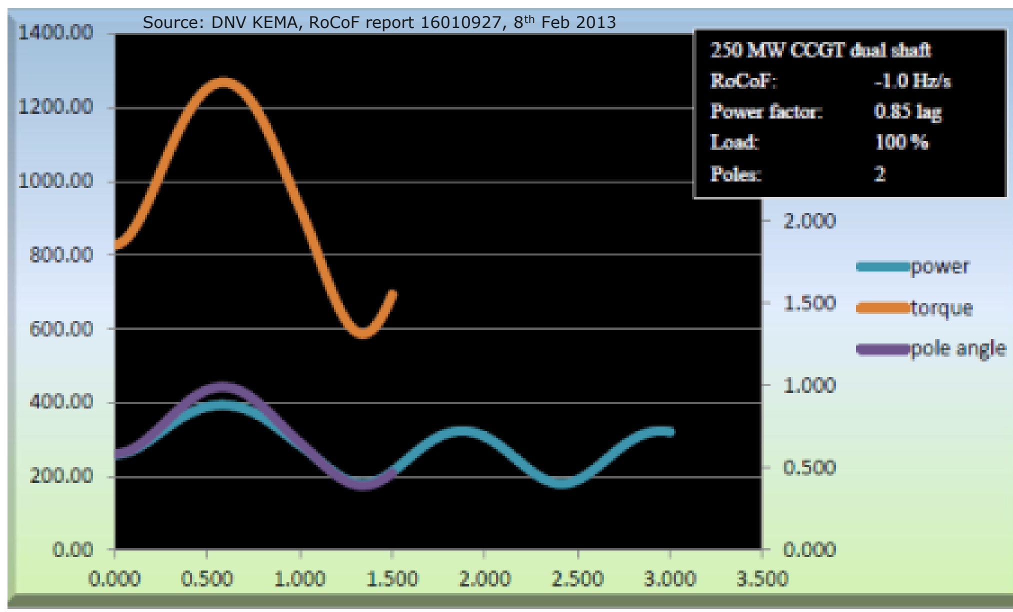
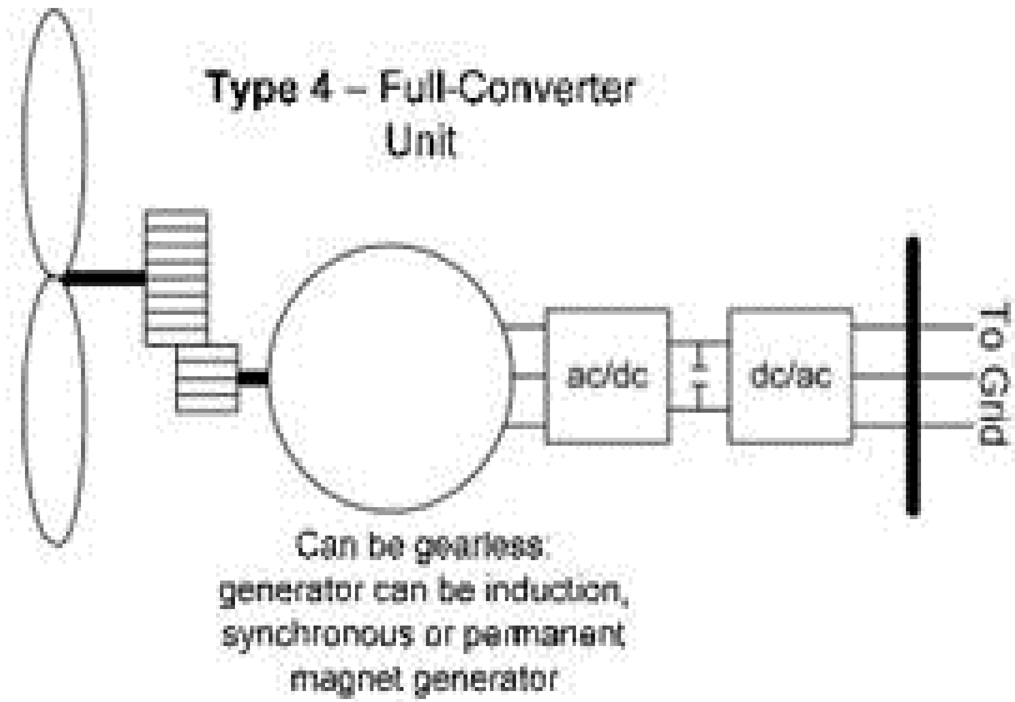


Source: www.electricalquizzes.com

Inertia: Synchronous and **Non-synchronous**

Non-synchronous inertia (synthetic inertia) is provided by all machines which are connected to the electricity Grid by separation of power electronics with the result that there is no direct electromagnetic connection between the Grid and technology.

- Devices connected non-synchronously through power electronics can only provide synthetic inertia in principle, but not synchronous inertia.

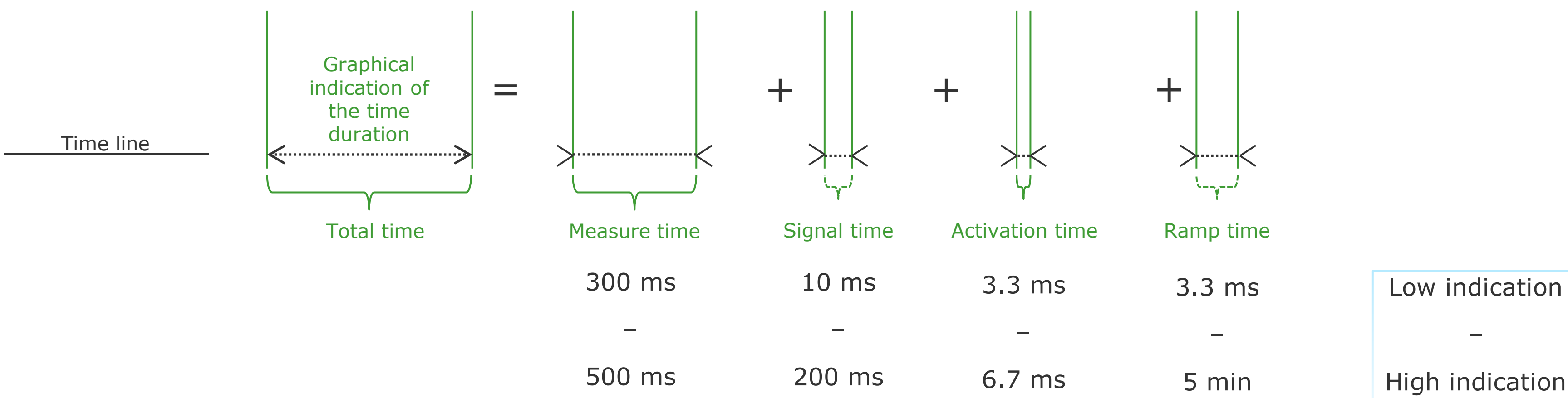


Source: https://www.wecc.biz/

Frequency measurement for RoCoF detection

- Response time elements for non-synchronous technologies (synthetic inertia):
  - Measurement time, $T_{measurement}$
  - Signal time, T_{signal}
  - Activation time, $T_{activation}$
  - Ramping time, T_{ramp}

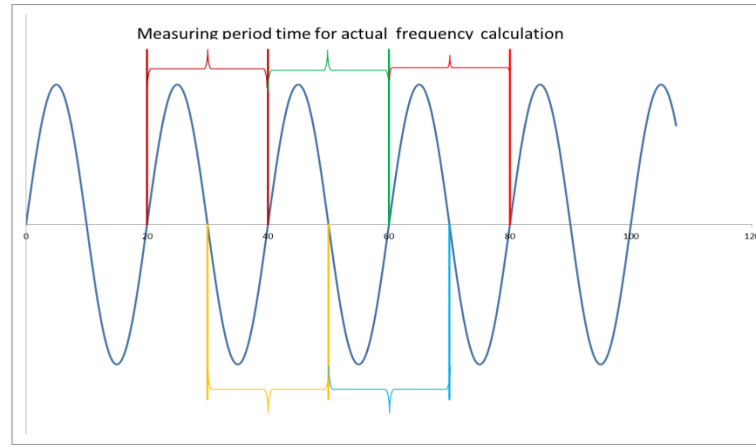
$$T_{response} = T_{measurement} + T_{signal} + T_{activation} + T_{ramp}$$



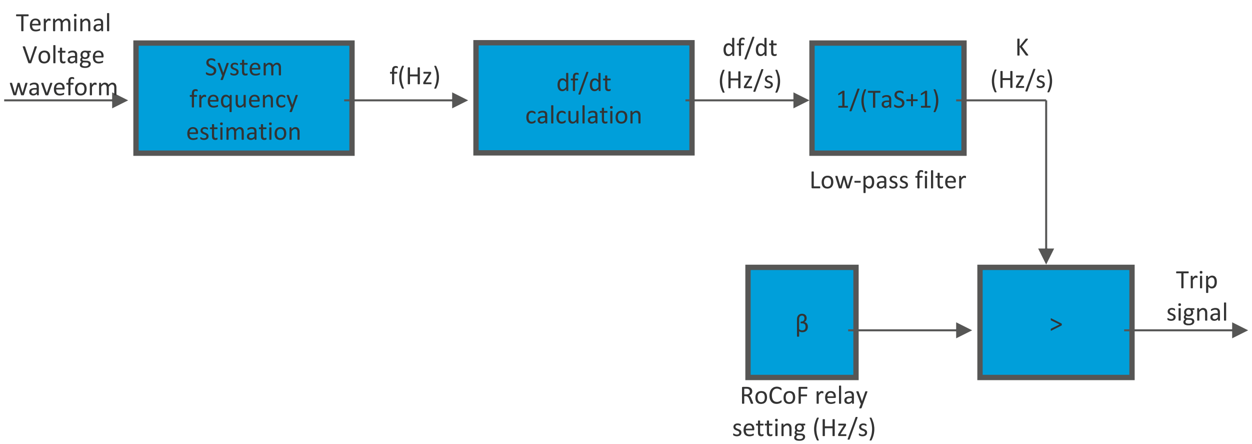
Frequency measurement for RoCoF detection

- Common technologies of frequency measurements:
  - Zero crossings
  - Angular velocity of voltage phasor
  - Fast Fourier Transformation

Sine wave of 1 phase



Simplified RoCoF protection diagram

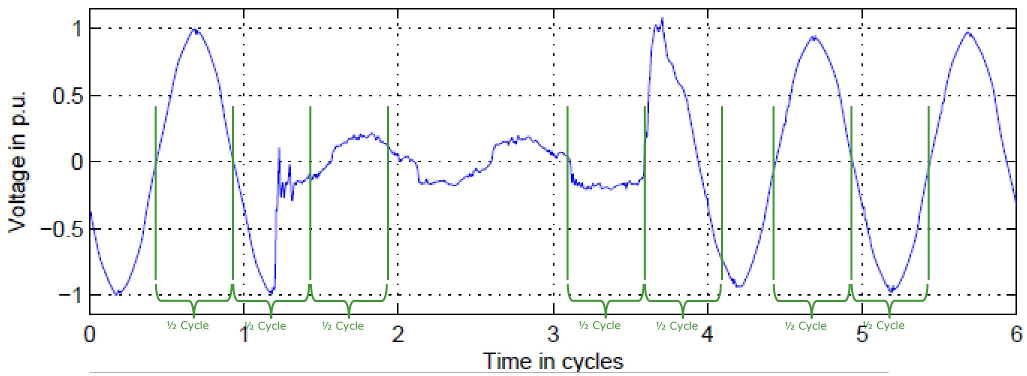


Source: Bohan Liu, University of Nottingham; Advanced ROCOF Protection of distribution systems, March 2012

Frequency measurement for RoCoF detection

- RoCoF detection challenges
  - Governor actions can result in damped frequency swings in the early cycles
  - Transients in the sine wave of the system voltage during an event
  - Response time need to be shorter than 0.5 seconds

Disturbed sine wave



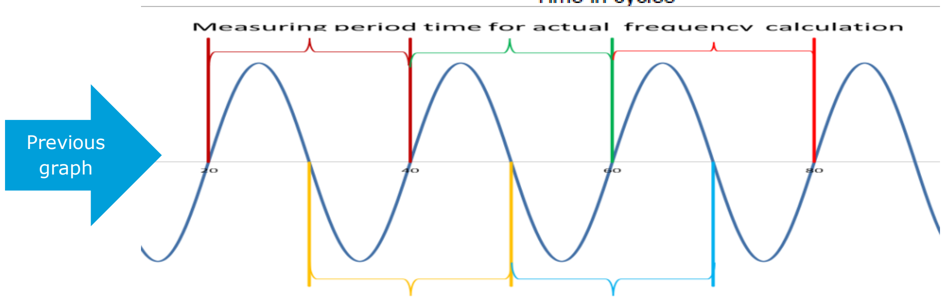
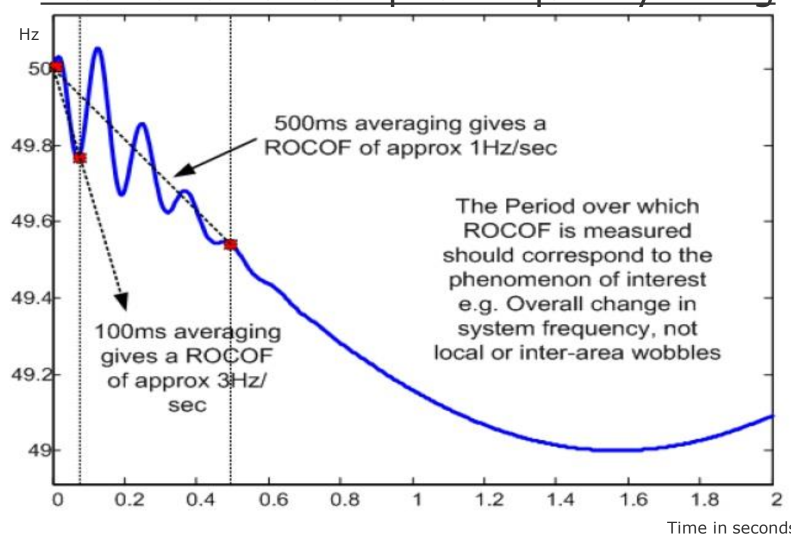


Illustration of damped frequency swing



Source: EirGrid-SONI report RoCoF “Modification Proposal–TSOs Recommendations”

FFR type technologies and Ranking

- Five characteristics used for a weighted ranking:

Characteristics	Weighting factor
Technical application (Effectiveness)	4
Geographical flexibility (suitable location for inertia device)	1
Technology maturity with regards to help prevent large RoCoF events	3
Lead time	3
Additional system services benefits	2

  - Effectiveness: Delivery/consumption capability and power quantity
  - Geographical flexibility: No mesh with other synchronous systems, and therefore the FFR type device shall be suitably located close to demand
  - Technology maturity: Successful employment elsewhere/ proven system
  - Lead time: Informs whether a technology could be applied in a timely fashion
  - Additional system services: Multiple system services can tap into regulated revenue streams and are therefore likely more commercially attractive.

FFR type technologies and Ranking

- Preliminary suitability characteristic scoring (with regards to help prevent large RoCoF events)

Nr.	Technology	Effectiveness	Geographical flexibility	Technology Maturity	Lead time	Additional system services	Total
	Factor	4	1	3	3	2	
1	Synchronous compensators	5	4	5	4	3	57
2	HVDC interconnectors;	3	1	4	3	4	42
3a	Battery technology - Flow battery	3	4	2	3	4	39
3b	Battery technology - Lead Acid	3	5	4	4	3	47
3c	Battery technology - Li-ion based	3	5	3	4	4	46
3d	Battery technology - Nickel based	2	5	3	4	3	40
3e	Battery technology - Sodium-Sulfur	3	5	3	3	4	43
4	Flywheels (high speed)	3	5	3	4	4	46
5	Rotating stabilisers	5	4	4	4	4	56
6	Wind turbines;	3	3	3	4	4	44
7	Pumped hydro	5	1	5	2	5	52
8	CAES	5	1	3	2	5	46
9	Construction of AC interconnectors	4	1	3	2	2	36
10	"Parking"	5	4	3	4	1	47
11	Reduction in the minimum MW generation	5	4	4	4	4	56
12	Demand Side Management (DSM)	3	5	2	3	3	38
13	Flexible thermal power plant.	4	3	4	4	4	51

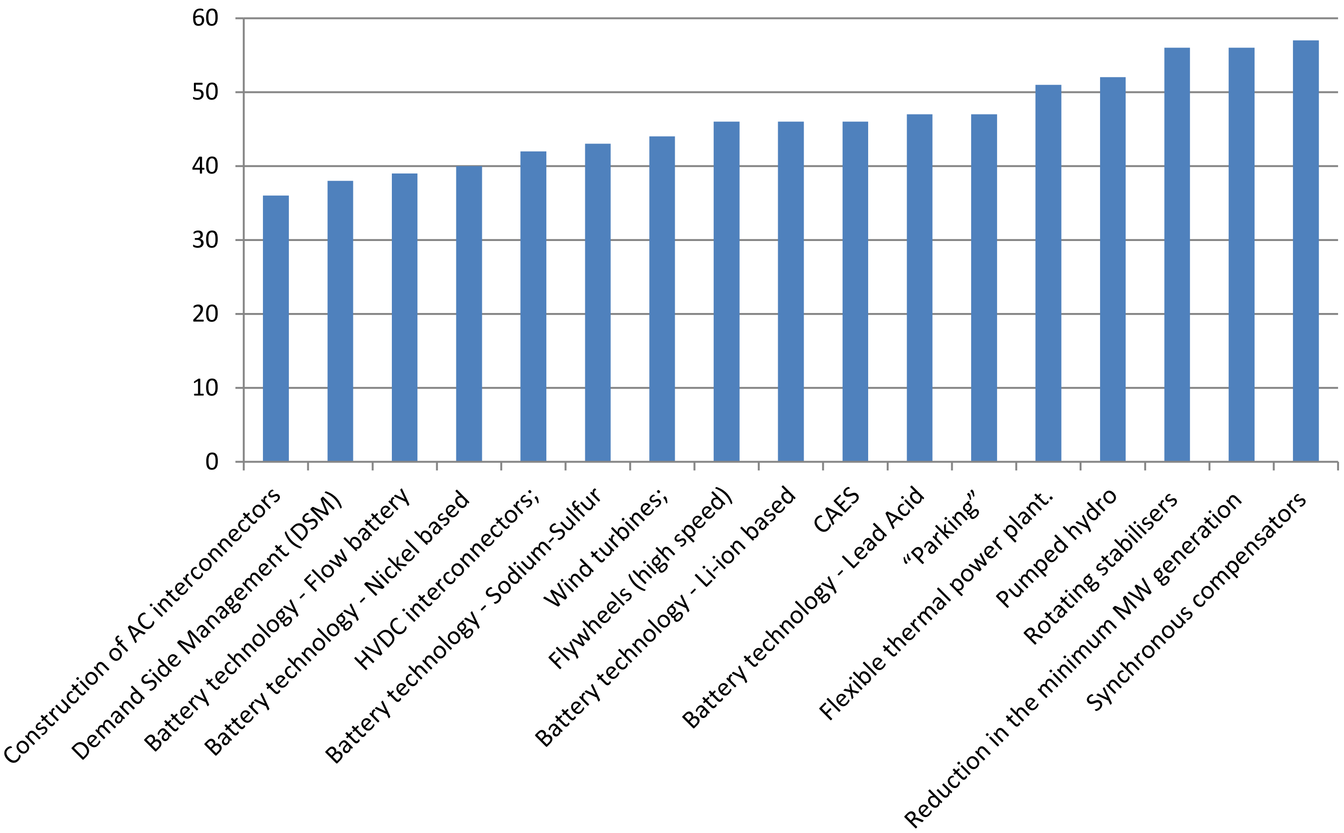
Score	Explanation
• 1	Poor
• 2	Unsatisfactory
• 3	Moderate
• 4	Satisfactory
• 5	Good

Maximum score 65 with a weighting factor for each of the 5 criteria

FFR type technologies and Ranking

(Assessments of the technologies are with regards to the purposes of helping prevent large RoCoF events)

- Preliminary suitability ranking of the 13 technologies



1. Synchronous compensators ;
2. Reduction min. MW generation;
3. Rotating stabilisers;
4. Pumped hydro;
5. Flexible thermal power plant;
6. "Parking"
7. Battery technology;
8. CAES;
9. Flywheels;
10. Wind turbines;
11. HVDC interconnector;
12. Demand Side Management (DSM);
13. AC interconnectors.

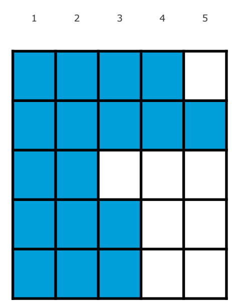
FFR type technology faceplates selected example for illustration

- Synchronous FFR type device

13) Fast responding gas turbines (Flexible thermal power plant)

ID	Items	Value	
1	Suitable to help prevent RoCoF events	Techno- / Economic	[traffic light]
2	Type of Frequency response	Bi-directional (High, Low)	
3	Inertia Constant H	5.5	[seconds]
4	Energy to Power (E/P) ratio (for storage)	-	[seconds]
5	Typical power capacity	Up to 500 MW	[MW]
6	Typical Energy content (for storage)	-	[MWh]
7	Charging time (for storage)	not applicable	[time]
8	Ramp-time	5 – 8 minutes	[time]
9	Efficiency	35 – 42 %	[%]
10	Expected lifetime	30 years	[years]
11	Capital expenditure	-	[EUR]

		Comment	Score
12	Economy of scale		
13	Technology matureness		
14	Future development potential		
15	Capital expenditure per MW		
16	Expenditure development after 2020		



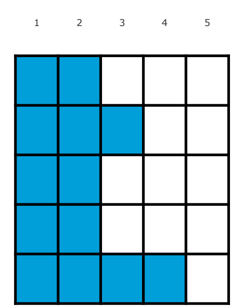
FFR type technology faceplates selected example for illustration

- Non-synchronous FFR type device

4) Flywheel (high frequency)

ID	Items	Value	
1	Suitable to help prevent RoCoF events	Techno- / Economic	[traffic light]
2	Type of Frequency response	Bi-directional (High, Low)	
3	Inertia Constant H	-	[seconds]
4	Energy to Power (E/P) ratio (for storage)	> 1 minute	[time]
5	Typical power capacity	Up to 10 MW	[MW]
6	Typical Energy content (for storage)	Up to 1 MWh	[MWh]
7	Charging time (for storage)	1 minute to 1 hour	[time]
8	Ramp-time	instant	[time]
9	Energy Consumption	10 %	[%]
10	Expected lifetime	25 years, ∞ cycles	[years]
11	Capital expenditure	15,328,000.00	[EUR]

		Comment	Score
12	Economy of scale		
13	Technology matureness		
14	Future development potential		
15	Capital expenditure per MW		
16	Expenditure development after 2020		



Observations and high level conclusions

- The technology analysis indicates that all 13, listed by EirGrid-SONI, have the capability, in principle, to help prevent high RoCoF events.
- The first top 6 technologies are all providing synchronous inertia, using rotating mass directly connected to the grid without being separated by electronic converters. As a result, the response is immediate without the need for frequency measurement and RoCoF detection.
- The total response time is the largest obstacle for providing effective “synthetic” inertia. Within this total response time, the most challenging aspect is the period required to robustly detect a RoCoF event.
- To prevent a RoCoF event of 1 Hz/s measured over a time window of 500ms, the reliable response time should be, at most, 0.5 seconds, and in reality much shorter.
- At this moment there is no proven track record for accurate RoCoF detection for the purpose of mitigation of RoCoF events as opposed to anti islanding disconnection protection measurement.

Observations and high level conclusions

- Different aspects of the challenge to utilise “synthetic” inertia FFR type devices to mitigate RoCoF events need to be analysed in more detail. In particular, the combination of measurement methodologies used and the likely electricity networks characteristics with regards to damped frequency swing durations
- The resulting weighted scoring system presents the following technologies:
  1. Synchronous compensators ;
  2. Reduction in the minimum MW generation;
  3. Rotating stabilisers;
  4. Pumped hydro;
  5. Flexible thermal power plant;
  6. “Parking”
  7. Battery technology;
  8. CAES;
  9. Flywheels;
  10. Wind turbines;
  11. HVDC interconnector;
  12. Demand Side Management (DSM);
  13. AC interconnectors.

Thank you for your attention

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