QualyGridS

Qualifying tests of electrolysers for grid services

Finalized testing protocol

www.qualygrids.eu

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Revisions

Version	Changes

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Abbreviation	Explanation
RES	Renewable Energy Sources
PEM	Polymer Electrolyte Membrane
TSO	Transmission System Operator
DSO	Distribution System Operator
AWE	Alkaline Water Electrolyser
ISO	International Standardization Organisation
ENTSOE	European Network of Transmission System Operators for Electricity
JRC	Joint Research Centre
FCR	Frequency Control Reserve
FRR	Frequency Restoration Reserve
RR	Replacement Reserve
DSR	Demand Side Response
KPI	Key Performance Indicator
SOEC	Solid Oxide Electrolyser Cell
AC	Alternating current
HV	High voltage
PtH	Power to Hydrogen

Table 1 List of Abbreviations

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1 Summary

This report provides the project's finalized draft of testing protocols for water electrolysers providing electricity grid services. It is prepared according the format of international standards that shall allow easy adaptation and submission to international standardisation institutions at the end of the project. The draft is based on published prequalification procedures for electricity grid services in Europe (status August 2019) as well as the project partners' own knowledge. The grid services which are deemed the most probable to be applied by electrolysers and which are applied in more than one country of the European Union were considered. Within the QualyGridS project, the testing protocols were applied on several alkaline and PEM electrolysers and the applicability of the tests were verified, as well as findings from the tests reported for improvement of the testing protocols.

Alkaline and PEM water electrolysers are given priority and focus in this document's protocols due to the fact that they are the only ones available in Megawatt size in industrial standard in the current era. However, an adaptation to other electrolyser techniques like SOEC should be possible with a few changes.

The purpose of the protocols is to determine whether an electrolyser is in principle capable of providing electricity grid services. This document shall be used by manufacturers of electrolyser systems to determine the capability of their products and to allow them to provide reliable information to their customers who want to use an electrolyser for grid services.

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03.07.2020

Testing protocols for electrolyser systems performing electricity grid services

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ELECTROLYSER TECHNOLOGIES –

Testing protocols for electrolyser systems performing electricity grid services

INTRODUCTION

This document describes testing protocols for water electrolyser systems, focusing on alkaline and PEM water electrolysers. The purpose of these protocols is to determine if an electrolyser has the basic capabilities of providing electricity grid services. As a basis for these tests, the European TSOs' and DSOs' requirements as published by August 2019 are taken. Apart from the requirements specified in these protocols, further requirements might apply that have to be fulfilled before an on-site prequalification of the electrolyser can be performed. This document is to be used by manufacturers of electrolyser systems to determine the capability of their products and to be able to provide reliable information to their customers that want to use an electrolyser for grid services as well as by any owner of an electrolyser that wants to evaluate its capability.
Users of this document may selectively execute test items suitable for their purposes from those described in this document. This document is not intended to exclude any other methods.

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ELECTROLYSER TECHNOLOGIES –

Testing protocols for electrolyser systems performing electricity grid services

1.1 Scope

This document reviews electrolyser systems, includes test apparatus, measuring instruments and measuring methods, establishes performance test methods, and evaluates test reports for PEM and alkaline electrolyser system.

This document is applicable to entities evaluating the performance of PEM and alkaline electrolyser systems with respect to performing electricity grid services.

1.2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies. Other references are provided in the bibliography.

INTERNATIONAL STANDARD ISO 22734:2019-09 Hydrogen generators using water electrolysis process — Industrial, commercial, and residential applications

1.3 Terms and definitions

For the purposes of this document, the following terms and definitions apply. Most of these terms are based on the definitions in the document "Water Electrolysis Terminology" published by JRC Joint Reseach Center in January 2018 (http://fch.europa.eu/sites/default/files/TERMINOLOGY_JRC_FINAL_GT.PDF), here cited as [JRC2018]. Terms on electricity grid systems are in line with the ENTSO-E terminology [https://www.entsoe.eu/data/data-portal/glossary/], here cited as [ENTSO-E glossary].

1.3.1 Polymer electrolyte membrane water electrolyser (PEMWE) system

A **PEMWE system**, whose typical scheme is depicted in Figure 1, is an assembly incorporating various number of components designed to operate the electrochemical conversion system(s) (also called stack) at the intended operating conditions (temperature, pressure, water, supply of electrolyte and gas purity) [JRC2018]

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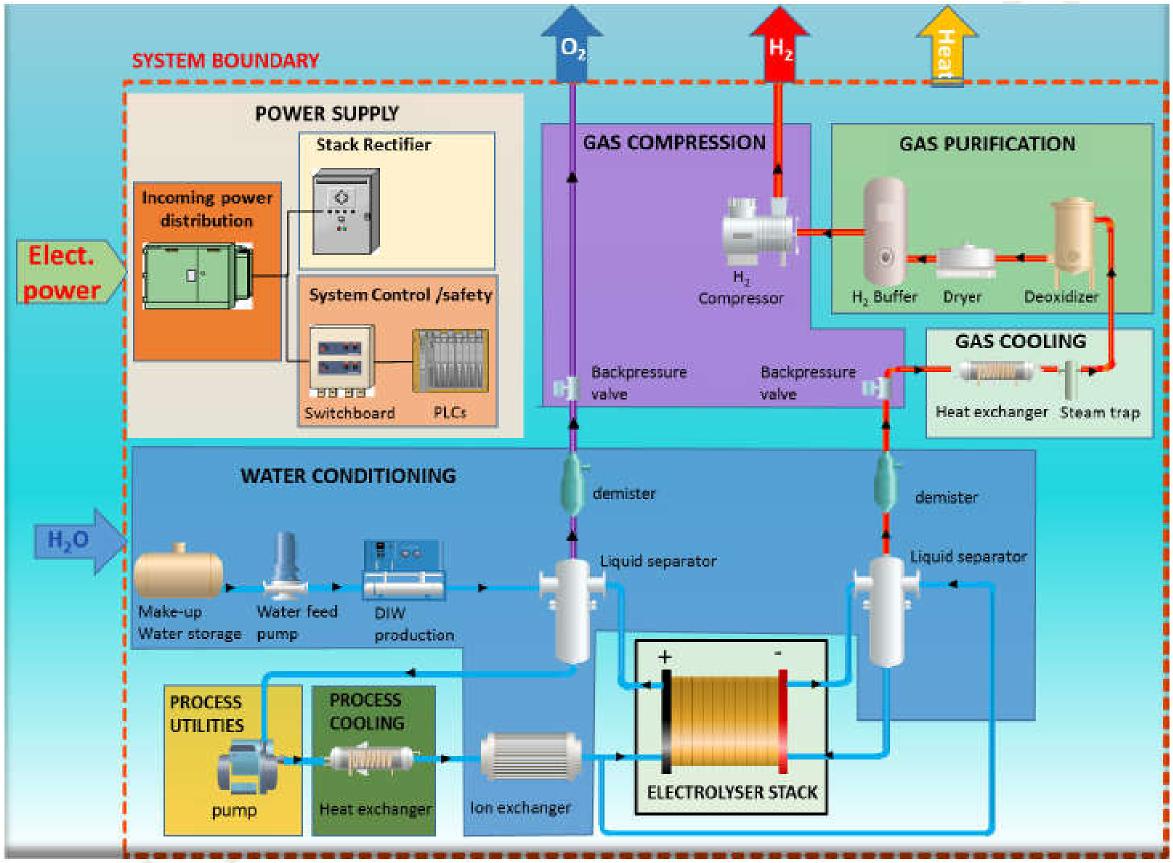

Figure 1: **Schematic representation of the components of a PEMWE system [JRC2018].**

1.3.1.1 PEMWE Components

The typical **components** of a **PEMWE** system are as follows:

 POWER SUPPLY which includes:

o **Incoming power distribution** that consists of the grid connection and transformer to adjust the electricity from the transportation or distribution network to the operational requirements,

o **Rectifier for stack operation**,

o **System control board** for other auxiliary components of the electrolysis system including automatic control system to operate the system according to manufacturer's specification. It includes safety sensors, process parameter measuring devices, piping and valves, control devices, data I/O, PC.

 WATER CONDITIONING for the necessary treatment of the water supplied and recovered that is composed by:

o Make-up water tank

o Water feed pump

o De-Ionized Water production system (DIW)

o Anodic circulation loop consisting of:

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 Water purification system – mostly an ion exchange resin bed – used to keep the water quality at the desired level, to minimize the risk of chemical contamination of the stack;
 Oxygen / water separator vessel used for a first separation of residual liquid water in the gases outlet stream;
 Demisters used for further removal of small liquid water droplets from the gas outlet stream.
o Cathodic circulation loop consisting at least of:
 a hydrogen / water separator vessel and subsequent demister and sometimes an additional circulation pump for defined thermal management of the cathode side.
 ELECTROLYSER STACK that is the core of the system where water is electrochemically converted into hydrogen and oxygen by means of a DC current. It comprises one or more PEMWE stack(s) connected either in series or parallel mode.
 PROCESS UTILITIES consisting of the elements using power for the operation like the water recirculation pump enabling a continuous flow of water into the stack for the electrochemical reaction itself and for the thermal management of the stack; process value measuring devices (i.e. pressure sensor, flow meter, gas sensors)
 PROCESS COOLING consisting of heat exchanger(s) for the thermal management of the pumped water to remove heat out of the circulation loop and to keep the stack at the proper temperature range.
 GAS COOLING consisting of heat exchanger(s) for the thermal management of the gases produced during the electrolysis process.
 GAS PURIFICATION to clean the hydrogen product stream to the desired level of quality consisting of:
o De-oxidation stage, to recombine catalytically residual traces of oxygen that could be present due to cross-over effects;
o Gas dryer to remove residual moisture down to the ppm level;
o Buffer tank for compensation of variable hydrogen production.
 GAS COMPRESSION composed of:
o Pressure control valve for hydrogen and oxygen to operate the EL system at the desired pressure level (either pressure balanced or differential pressure).
o Compressor, to bring the gas pressure at the specified value.
o High pressure storage tank(s) for the final storage of the gas produced by the electrolyser.
[JRC2018]

1.3.2 Alkaline Water electrolysis (AWE) system

The principle layout of an **AWE system** is shown in Figure 2. The utmost noticeable difference compared to PEMWE systems is that in this case the electrolyte is an aqueous alkaline solution formed by KOH with a concentration of approx. 20-30% in deionized water called Lye. The anode and cathode electrodes are immersed in this solution separated by a diaphragm. This solution is caustic and this shall be taken into consideration for the selection of the proper material for the components that are or may get in contact with Lye solution.

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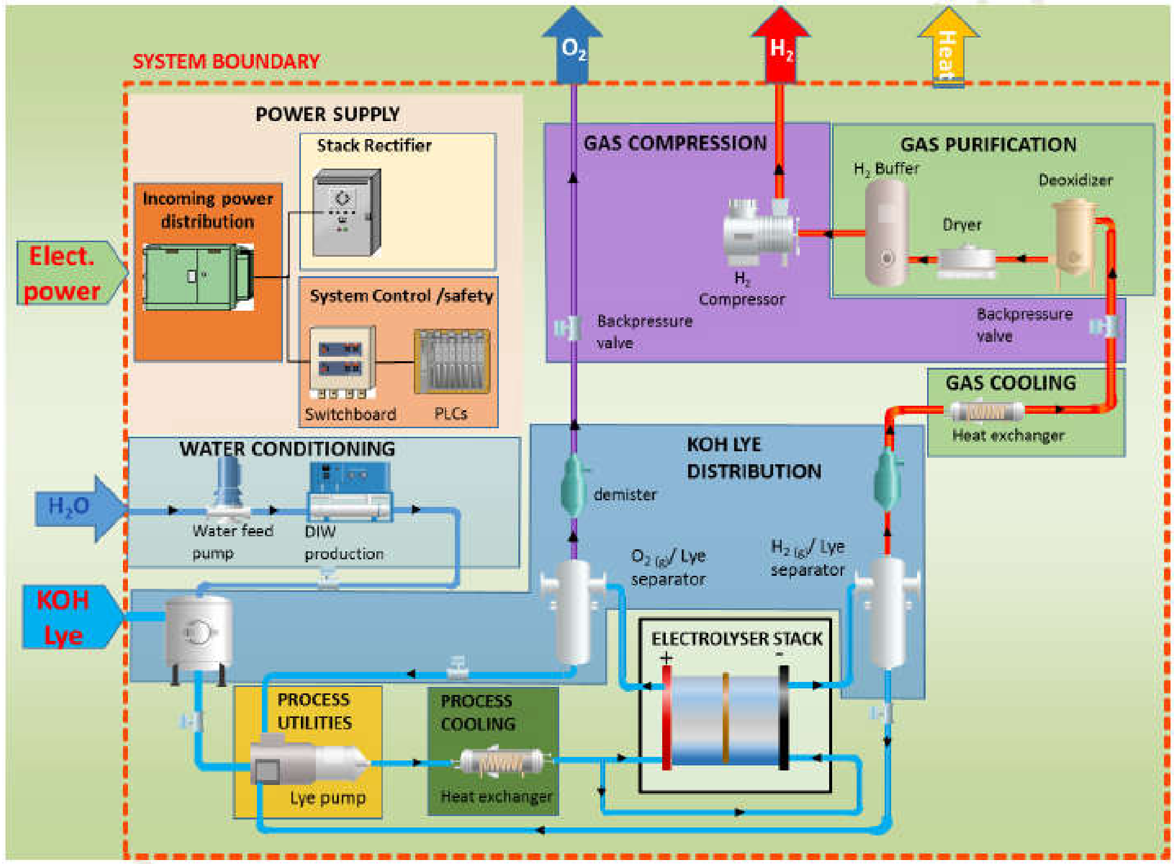

Figure 2: **Schematic representation of the components of an AWE system [JRC2018]**

1.3.2.1 AWE Components

The typical **AWE components** include the following items:
 POWER SUPPLY, see 2.5.1

 WATER CONDITIONING

 Alkaline electrolysis stack

 Lye supply/recirculation system is used to provide a continuous electrolyte flow into the stack for the electrochemical reaction and thermal management. The main components are:

o Lye recirculation pump

o Lye heat exchanger

 Gas/lye separator, used for a first separation of residual liquid in the produced gases outlet stream.

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 Demisters and scrubbers are devices for further removal of water and lye aerosols from the gases outlet stream.

 ELECTROLYSER STACK, see 2.5.1

 PROCESS UTILITIES, see 2.5.1

 PROCESS COOLING, see 2.5.1

 GAS COOLING, see 2.5.1

 GAS PURIFICATION, see 2.5.1

 GAS COMPRESSION, see 2.5.1
[JRC2018]

1.3.3 Nominal Current

Electric current value associated to the nominal design point as specified by the manufacturer. [JRC 2018]

1.3.4 Electrical Power Input Rated or Nominal

Electrical power input value associated to the nominal design point and the nominal operating conditions as specified by the manufacturer. [JRC 2018]

1.3.5 Nominal or Rated Power

Value stated on the device nameplate. It is the power to be provided at the input terminals of a component or piece of equipment that is operated in compliance with the manufacturer's performance specifications. [adapted from JRC2018]

1.3.6 Connection Point

Interface at which the power-generating module, demand facility, distribution system is connected to a transmission system, offshore network, distribution system, including closed distribution systems, as identified in the connection agreement between relevant system operator and either power-generating or demand facility owner.

[Source: ENTSOE glossary]

1.3.7 Frequency Containment Reserves (FCR)

Active power reserves available to contain the system frequency after the occurrence of an imbalance.
[Source: ENTSOE glossary]

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1.3.8 Frequency Restoration Reserves (FRR)

Active Power Reserves available to restore System Frequency to the Nominal Frequency, and for Synchronous Area consisting of more than one Load Frequency Control (LFC) Area to restore power balance to the scheduled value.

[Source: ENTSOE glossary]

1.3.9 Automatic Frequency Restoration Reserves, aFRR

FRR that can be activated by an automatic control device.

[Source: ENTSOE glossary]

1.3.10 Manual Frequency Restoration Reserves, mFRR

FRR that can be activated manually

1.3.11 Replacement Reserves (RR)

Active power reserves available to restore or support the required level of FRR to be prepared for additional system imbalances, including operating reserves.

[Source: ENTSOE glossary]

1.3.12 Demand Side Response (DSR)

Demand offered for the purposes of, but not restricted to, providing Active or Reactive Power management, Voltage and Frequency regulation and System Reserve.

[Source: ENTSOE glossary]

1.3.13 Frequency Response Deadband

An interval used intentionally to make the frequency control unresponsive.
[Source: ENTSOE glossary]

1.3.14 Full Activation Time

Time period between the activation request by TSO and the corresponding full activation of the concerned product.
[Source: ENTSOE glossary]
Usually will be composed of preparation time (with no power change) and ramping period .

1.3.15 Heating Value

Value of the heat of combustion of a fuel defined by the heat supplied to a thermal system by the entire reaction enthalpy of the exothermal combustion reaction at standard conditions (25°C, 105Pa) [kJ mol^{-1}]

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NOTE – The heating value is thus the negative reaction enthalpy of the combustion reaction.
Lower (LHV): value of the heat of combustion of a fuel as measured by allowing all products of combustion to remain in the gaseous state. This method of measure does not take into account the heat energy put into the vaporisation of water (heat of vaporisation).

Higher Heating Value (HHV): value of the heat of combustion of a fuel as measured by reducing all of the products of combustion back to their original temperature and condensing all water vapour formed by combustion. This value takes into account the heat of vaporisation of water.

[JRC2018]

1.3.16 Hydrogen Production Rate

Amount of H2 produced by an electrolysis cell/stack/system during a specified time interval at a rated power with a defined purity [Systems: kg/h or, kg/day].
[JRC2018]

1.3.17 Key Performance Indicator (KPI)

Metric parameter used to quantify the relevant process parameters for a specific task/project.
[JRC2018]

1.3.18 Operating Conditions

Test or standardized operating conditions that have been predetermined to be the basis of the test in order to have reproducible, comparable sets of test data.
[JRC 2018]

1.3.19 Nominal Operational Mode

Operation of the device using the parameter setting defined to obtain the nominal performances as defined in the technical specification.
[JRC2018]

1.3.20 Shutdown

Sequence of operations that occurs to stop the system and all its reactions in a controlled safe manner.
[JRC2018]

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1.3.21 Emergency Shutdown

Control system actions, based on process parameters, or manually activated, taken to stop the system and all its reactions immediately to avoid equipment damage and/or personnel hazards.
[JRC2018]

1.3.22 Standby State

State without hydrogen/oxygen output that allows fast re-starting of the system by keeping some parameters at or close to the nominal operating parameters.
[JRC2018]

1.3.23 Cold Standby State

Non-operating state of equipment turned off and ready for immediate start.
[JRC2018]

1.3.24 Warm Standby State

Operating state of equipment powered and warmed up at a temperature lower than the one needed for service operation.
[JRC2018]

1.3.25 Initial Response Time

Time needed after a set-point change of a parameter to begin changing the output.
[JRC2018]

1.3.26 Total Response Time

Time needed after a set-point change of a parameter for reaching a new value.
Compare “Full Activation Time”, 1.3.14.
[JRC2018]

1.3.27 Overload Capability

Ability of electrolysis system to operate beyond the nominal operating and design point for a limited period of time, typically in the range of few minutes to less than one hour. Mostly the overload capability is used to provide a larger flexibility in different grid service applications (e.g. secondary control reserve).
[JRC2018]

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1.3.28 System Minimum Power

Minimum power for which the system is designed, as a percentage of nominal power (%).
[JRC2018]

1.3.29 Warm Start Time to Nominal Power

Time required reaching nominal power when starting the device from warm standby mode.
[JRC2018]

1.3.30 Operating Pressure

Pressure at which the electrolyser (stack) operates.
[JRC2018]

1.3.31 Purity of Gases

Measure to indicate the amount of other gases in a particular gas. It is expressed as the molar or volumetric percentage of the gas which is equal to 100 percent minus the sum of the other gas impurities. There are different ways to express purity, as percentage e.g. 99.99 % or with grade, e.g. N4.0 for 99.990%.
The first digit of the grade classification indicates the 'number of nines' purity, e.g. N4.0 = 99.99% purity.
The second digit is the number following the last nine, e.g. N4.6 oxygen has a guaranteed minimum purity level of 99.996%.
[JRC2018]

1.3.32 Hydrogen Purity

Allowable or tolerated amount of specific impurities (e.g. nitrogen) to define the hydrogen purity depends by the scope of use of the hydrogen produced. For fuel cell operation the hydrogen quality is defined in ISO FUEL QUALITY 14687-2:2012a .
[JRC2018]

1.3.33 Reliability

Ability of an item to perform a required function under stated conditions for a stated period of time.
[JRC2018]

1.3.34 Response Time

Time required for a power system to transfer from one defined state to another.
[JRC2018]

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1.3.35 Overall System Efficiency

At system level (Stack + BoP), it is necessary to take into account the energy consumption of all the necessary ancillary equipment. System efficiency for the HHV is defined as the ratio between the flow rate of the produced hydrogen, $\dot{n}_{H2}$ expressed in mole per second multiplied by the HHV expressed in $J.mol^{-1}$, and the **total thermal and electric power** supplied to the system, for the operation of all ancillary equipment, expressed in Watt. It is expressed in percentage as

$$\eta_{system}^{HHV} = \frac{HHV}{P_{system\ extern}} \cdot \dot{n}_{H_2}$$

with higher heating value of hydrogen HHV = 285.84 10^3 J mol^{-1} **,** Volumetric flow rate $\dot{n}$ in mol s^{-1}.
[JRC2018]

1.4 General Safety Considerations

An operating electrolyser produces oxidizing and reducing combustible gases. Typically, these gases are stored in high-pressure containers. The electrolyser itself may or may not be operated at pressures greater than atmospheric pressure.
Those who carry out electrolyser testing shall be trained and experienced in the operation of electrolyser systems and specifically in safety procedures involving electrical equipment and reactive, compressed gases. Safely operating an electrolyser test station requires appropriate technical training and experience as well as safe facilities and equipment, all of which are outside the scope of this document.
Consider the recommendations and requirements in the ISO standards
INTERNATIONAL STANDARD 22734:2019-09 Hydrogen generators using water electrolysis process — Industrial, commercial, and residential applications

The electrolyser system control shall monitor if the “critical parameters” remain in their limit. Safety-relevant parameters of the system shall be monitored to avoid injury of the operator. Also parameters relevant for the state of health of the system shall be monitored. These are, depending on the system, e.g.

- hydrogen in oxygen content
- oxygen in hydrogen content
- cell temperature
- differential pressure anode-cathode
- differential pressure before – after the cell
- cell voltage.

When the system leaves the allowed parameter range defined by the manufacturer safety measures must apply. When approaching a critical

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parameter the first step shall be a reduction of the stack current to minimum value. When leaving the allowed parameter range a controlled shutdown procedure to a safe state shall be applied. This shutdown procedure is implemented and defined by the manufacturer of the electrolyser system and might be to reduce the stack current to zero, vent the anode and cathode gases in a controlled manner and to flush the anode and cathode with nitrogen gas and to set an alarm.

The electrolyser system may not be run without a safety system installed that controls all parameters that might cause situations dangerous for the operator or the electrolyser system. Dangerous parameters can be e.g. high oxygen in hydrogen content, high hydrogen in oxygen content, pressure differences within the system and between system and ambience exceeding the specifications, overheating, high cell voltage, malfunctioning/failure of BOP components, high hydrogen content in ambient air, too low oxygen content in ambient air, freezing temperatures in water system. The safety system must be installed by the system manufacturer.

1.5 Environmental conditions

The tests shall be carried out in the following environment:

a. A temperature of 15°C to 35°C;

b. A relative humidity within the limits by the manufacturer without exceeding 75%;

c. An atmospheric pressure of 75 kPa to 106 kPa;

d. No hoarfrost, dew, percolating water, rain, strong solar irradiation, etc.

To be sure that the system can perform the grid services it would in the case that the system transfers heat to the environment be useful to test the full range of ambient temperature. This is because the cooling electrical power needed will vary with the ambient temperature and makes up a major part of the BOP power. Therefore it might especially have impact on the stability criterion. If testing at various ambient temperatures cannot be done some simulations or considerations on the impact of ambient temperature on the relevant parameters of the system should be done.

1.6 Electrolyser system components

Detailed description in 1.3.1 and 1.3.2.

The power to be considered as the primary parameter of these tests is the electrical power at the grid connection point, usually connected to high voltage grid. Normally this includes all power needed to supply the electrolyser stack, rectifier, control system, balance of plant components (e.g. heating, cooling, provision of compressed air, water pre-treatment, gas purification); however the heat exchange with atmosphere is not considered.

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In case the system is tested in a test bench setup, not including all BOP components as they will be included in an application setup, and if it is intended to perform grid services with the total electrolyser system, then in addition to all electrical power input also all heat input into and output from the tested setup must be measured and reported as well as the flows and compositions of all material input and output at the boundaries of the tested system.

Alternatively to considering the total power there is also the option to connect the rectifier input power to one grid connection point, usually connected to the high voltage grid, and all other electrical power input into the system (BOP) to another grid connection point. In case that the BOP connection point power is much smaller than the rectifier input power then only the rectifier power can be used for grid services. If such a setup is foreseen the tests must measure the rectifier input power and documentation of the average and maximum value of the BOP input power should be provided.

1.7 System initial installation and preparation

- Installation according to the manufacturer's instructions.
- Connect to test bench and interfaces.
- Verify the functions, especially the safety of the system.
- Run initialization and conditioning of the system as indicated by the manufacturer.
- Only use a stably running system for these tests.

If the system is tested in a test-bench setup, the H_2 outlet should preferentially be at the same pressure level it is in normal applications. This can be realized by e.g. using a pressure vessel at the H_2 outlet. Alternatively, H_2 can be vented to atmospheric pressure; however it should be considered that it might influence the operational characteristics of the subject.

1.8 Test ensemble setup

1.8.1 Minimum equipment requirement

A test setup for the electrolyser is required that provides the water and power input and the removal of the produced hydrogen/gas mixtures as well as removal of heat. Further interfaces as required by the manufacturer must be set up and monitored.

Minimum interface requirements:

a) Water of tap water quality or quality as defined by the manufacturer with the maximum flow as defined by the manufacturer
b) Electrical power input at high voltage or low voltage three-phase alternating current level with the maximum power as defined by the manufacturer
c) Waste hydrogen/gas mixture removal to the ambient or a waste gas removal connection as defined by the manufacturer

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d) Useable hydrogen gas removal to a connection to hydrogen use. For purely testing purposes this hydrogen flow can also be vented to atmosphere (considering safety).
e) Waste oxygen removal to the ambient or an oxygen removal connection as defined by the manufacturer
f) Heat removal to the ambient atmosphere or to a heat sink

The minimum test equipment functionality in order to meet the intention of the electrolyser system test procedure includes the following test parameters:

a) Power control as indicated in the testing protocols must be included in the electrolyser system or as an external control from the test station communicating with the built-in electrolyser control. An interface to set the required power must be provided. For FCR tests the power vs. time request respectively the simulated grid frequency value vs. time input to the system must come from outside and not be set up within the system's control. Also start points triggering the ramps in aFRR, mFRR and RR must come from outside the system. Data registration of total system power.
b) Monitoring of power to electrolyser system input and optional power to rectifier input or alternatively power to rectifier input and optional electrolyser system BOP power, data registration
c) Optional monitoring of energy content of any further input or output of the system, e.g. liquid cooling
   Or
   Required monitoring of energy content of any further input or output of the system, e.g. liquid cooling if the system is tested in a configuration different from the configuration that will be used in a real application and if the total system power is foreseen for grid services.
d) Measurement of ambient temperature
e) Optional monitoring of stack voltage and current
f) Optional monitoring of stack temperature
g) Optional monitoring of hydrogen output flow and gas quality
h) Optional monitoring of system hydrogen pressure

The optional data monitoring is not necessary to determine the electrolyser's capability of performing grid services. However it is useful information necessary to evaluate a planned business model and to see the basic functions of the electrolyser.

All input- and output parameters registered must be time-synchonized.

Materials used for all components which will be in contact with humidified gas or water shall be compatible with the gas or water to prevent the elution of impurities in the material. Example materials include stainless steel and fluoro-plastics.

1.9 Schematic diagram

Detailed description in 1.3.1 and 1.3.2.

Variations to this configuration are acceptable providing that the functional requirements of this document are met. They shall be reported in the test reports.

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1.10 Maximum variation in test station controls (inputs to test)

The electrolyser test station shall have the following recommended maximum variation in its controls:

Calibration should be verified and stated in the protocol.

- Current control ±1% relative to nominal set point
- Voltage control ±1% relative to nominal set point
- Power set point input value control ±1%relative to nominal power
- Stack temperature control ±5°C at nominal set point (at steady state)
- Flow rate control ±5% relative to nominal set point
- Pressure control ±3% relative to nominal set point

1.11 Measurement

1.11.1 Instrument uncertainty

The maximum instrument uncertainty for the measurements (test outputs) in the tests shall be as follows:

- Current ±1% of maximum expected value
- Voltage ±0.5% of maximum expected value
- Power ±1% of maximum expected value
- Temperature ±1°C of maximum expected value
- Flow rate ±2% of maximum expected value
- Pressure ±3% of maximum expected value
- Gas composition ±10% of maximum expected value
- Humidity ±10% of maximum expected value

NOTE. At low current, voltage and flow rates, the uncertainties may be very large with respect to the measured values.

1.11.1 Measurement systems

Table 2 identifies the parameters and their measurement systems for the tests.

Table 2 -- Parameters and units

Parameter	Unit
Input power	W
Current	A

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Voltage	V
Temperature	°C
Hydrogen/gas mixture pressures	kPa****
Hydrogen/gas mixture flow rates (NTP*)	$cm^3\ min^{-1}$, $cm^3\ s^{-1}$
Hydrogen gas quality	Ppm or (mol) mol^{-1}

*STP = standard temperature and pressure: 0°C and 101,325 kPa (absolute)
****ISO recommends using absolute pressure (kPa), if possible. If gauge pressure is used, it should be noted as such and be given in kPa (G)

1.11.2 Measuring instruments and measuring methods

1.11.2.1 General

Measuring instruments shall be selected in accordance with the range of values to be measured. The instruments shall be calibrated regularly in order to maintain the level of accuracy described in 1.11.1. All measuring devices must be calibrated to traceable standards.

1.11.2.2 Power

Measuring the total electrical power input to the system P_{system} is a mandatory measurement in case that the total system power is foreseen for grid service. The position for the measurement is symbolized by the arrow “electrical power” passing the red marked system boundary in Fig. 1 and Fig. 2. Due to varying system architectures an exact specification for the point of measurement cannot be given in this document but must be described in the measurement protocol. Measuring the total electrical power input to the system can be done either with a meter reporting the power or individual measurement of current and voltage calculating power. In addition an optional but recommended measurement is the input power to the rectifier (which then provides the DC current for the stack) to be able to separate the contributions of stack and balance of plant to the total power.
Alternatively, if the rectifier input power is foreseen for grid service measuring the electrical power input to the rectifier $P_{rect,\ input}$ (usually AC and often HV) is a mandatory measurement. Due to varying system architectures an exact specification for the point of measurement cannot be given in this document but must be described in the measurement protocol. Measuring the rectifier input electrical power can be done either with a meter reporting the power or individual measurement of current and voltage calculating power. In addition an optional but recommended measurement is the input power to the BOP to be able to separate the contributions of stack and balance of plant to the total power. Appropriate measuring devices are required for either AC 3 phases power input or high voltage power. The root mean square value of electrical power must be given.

1.11.2.3 DC Voltage

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An optional voltage meter shall be connected to the stack end plates or current collectors, minimizing the influence of electrical contact resistances. The electrical contact resistances between the connections of the voltage meter, either anode and cathode flow plates or output terminals of anode and cathode current collectors shall be measured and reported, if not negligible.

1.11.2.4 DC Current

A current measuring device shall optionally be located in the current-carrying circuit of the stack. The current may also be measured by non-contact current probe. The current-measuring device may also consist of an appropriate low-impedance ammeter or a calibrated shunt resistor, which develops a precisely known voltage reflecting the current flowing.

1.11.2.5 Hydrogen/gas mixture flow rates

Hydrogen/gas mixture flow rates shall optionally be measured by means of a volumetric meter, a mass flow meter, or a turbine-type flow meter. If such a method is not practical, flow measurement by a nozzle, orifices, or venturi meter is recommended. The location of a flow meter shall be downstream of the stack.

If the flow meter requires pressure compensation, a static pressure measuring port shall be located immediately upstream of the flow meter to be corrected.

1.11.2.6 Stack temperature

The optional sensor for direct temperature measurement can be a thermocouple, resistance thermometer with a transducer or a thermistor.

The temperature sensor should be located preferentially within the stack. Alternatively the temperature of the anode liquid flow upstream as close as possible to the inlet of the stack or the liquid cooling flow upstream as close as possible to the inlet of the stack can be taken as a measure of the stack temperature[9]. As additional information the temperature of the anode liquid flow downstream close to the stack or the cooling flow downstream close to the stack can provide valuable information about the stack average temperature.

[9] Definition in line with JRC “EU harmonized test protocols for low temperature water electrolysis for energy storage application”, Ver. 2020.02.28

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1.11.2.7 Hydrogen gas quality

The optional sensor for hydrogen gas quality should be located in the gas stream of usable hydrogen gas or take samples or a defined gas flow out of the usable hydrogen gas flow. This can be an electrochemical sensor or a gas chromatograph or any other sensor achieving the required accuracy. Preferentially the gas composition should be monitored continuously; if not possible discontinuous measurement at low time intervals can be realized.

1.11.2.8 Hydrogen/gas mixture pressure

For optionally measuring hydrogen/gas mixture pressure, calibrated pressure transducers are the preferred method. Other acceptable methods include calibrated manometers, dead-weight gauges, bourdon tubes or other elastic type gauges.

A static pressure measuring port shall be located immediately upstream of the hydrogen exit valve in the usable hydrogen gas exit.

Connecting piping shall be checked to verify that it is leak-free under working conditions in advance of the performance tests. Liquid water in the usable hydrogen gas exit piping has to be avoided.

If pressure fluctuations occur, a suitable means of damping shall be installed in an effective position.

Pressures shall be measured as static pressures with the effect of velocity considered and eliminated.

1.11.2.9 Energy content of liquid cooling external to the system

If the system is tested in a test station providing liquid cooling to the electrolyser system the energy content of liquid cooling should be specified because in an final installation of the electrolyser this cooling will have to be realized also consuming electrical power. The flow, input and output temperature of the cooling liquid should be measured and the energy (heat) input/output of the system through this interface calculated and indicated.

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1.12 Test Preparation

1.12.1 Frequency of measurement

1.12.1.1 Frequency

The data sampling rate is 1 per second. For FCR testing the total system power should be sampled with a sampling rate 10 Hz.

1.12.1.2 Power Setpoint

Input power series must be checked if it is aligned with the required time series within one second (for FCR test faster) and then examine the reaction of the electrolyser system.

1.12.1.3 Repeatability and Reproducibility

For reliable measurement results usually the entire test should be measured three times. If this is not possible for practical reasons the fact that the testing procedures of this document usually run sequences of similar profiles with more than one repetition can be used to investigate the repeatability and reproducibility of the tests by comparing the ramps within one test. If within the test no reproducibility is observed repeating the entire test is highly recommended.

1.12.1.4 Maximum permissible variation in measured values

Values for three or more measurements of the test input and output parameters shall be within the range of ±5% of their average.

1.12.1.5 Initial conditioning and stable state check

Before starting the tests the system function and safety is to be verified.

It is to be verified that the initial fast conditioning processes of the electrolyser system are settled before these tests are started in order to achieve reproducible test results.

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1.13 Overview

Category	No.	Description	Related parameters	Pre-condition	Estimated Duration
FCR	1.14.2 / 1.14.2.3	Step changes of power level	P_{up}, P_{med}, P_{low}	P_{med} for 1 hour (part of test)	~3.5 h
	1.14.2 / 1.14.1.4	Frequency vs time profile	f; P_{up}, P_{med}, P_{low}	P_{med} for 1 hour (before test)	~4 h
aFRR	1.14.3.2 (*)	Negative control power, Upward ramp protocol	P_{up}, P_{low}	P_{low} for 1 hour (part of test)	~6 h
	1.14.3.3 (*)	Positive control power, Downward ramp protocol	P_{up}, P_{low}	P_{up} for 1 hour (part of test)	~6 h
mFRR	1.14.4.2 (**)	Negative control power, Upward ramp protocol	P_{up}, P_{low}	P_{low} for 1 hour (part of test)	~5 h
	1.14.4.3 (**)	Positive control power, Downward ramp protocol	P_{up}, P_{low}	P_{up} for 1 hour (part of test)	~5 h
RR	1.14.5.2 (***)	Negative control power, Upward ramp protocol	P_{up}, P_{low}	P_{low} for 1 hour (part of test)	~5.5 h
	1.14.5.3 (***)	Positive control power, Downward ramp protocol	P_{up}, P_{low}	P_{up} for 1 hour (part of test)	~5.5 h
Aggregated tests	1.14.7.3. (*)	aFRR aggregated test	P_{up}, P_{low}	P_{low} for 30 mins (part of test)	~6.4 h
	1.14.7.3 (**)	mFRR aggregated test	P_{up}, P_{low}	P_{up} for 30 mins (part of test)	~ 5.5 h
	1.14.7.3 (***)	RR aggregated test	P_{up}, P_{low}	P_{low} for 15 mins (part of test)	~ 6 h
	1.14.7.3 (***)	aFRR and mFRR aggregated test	P_{up}, P_{low}	P_{low} for 30 mins (part of test)	~ 11.6 h

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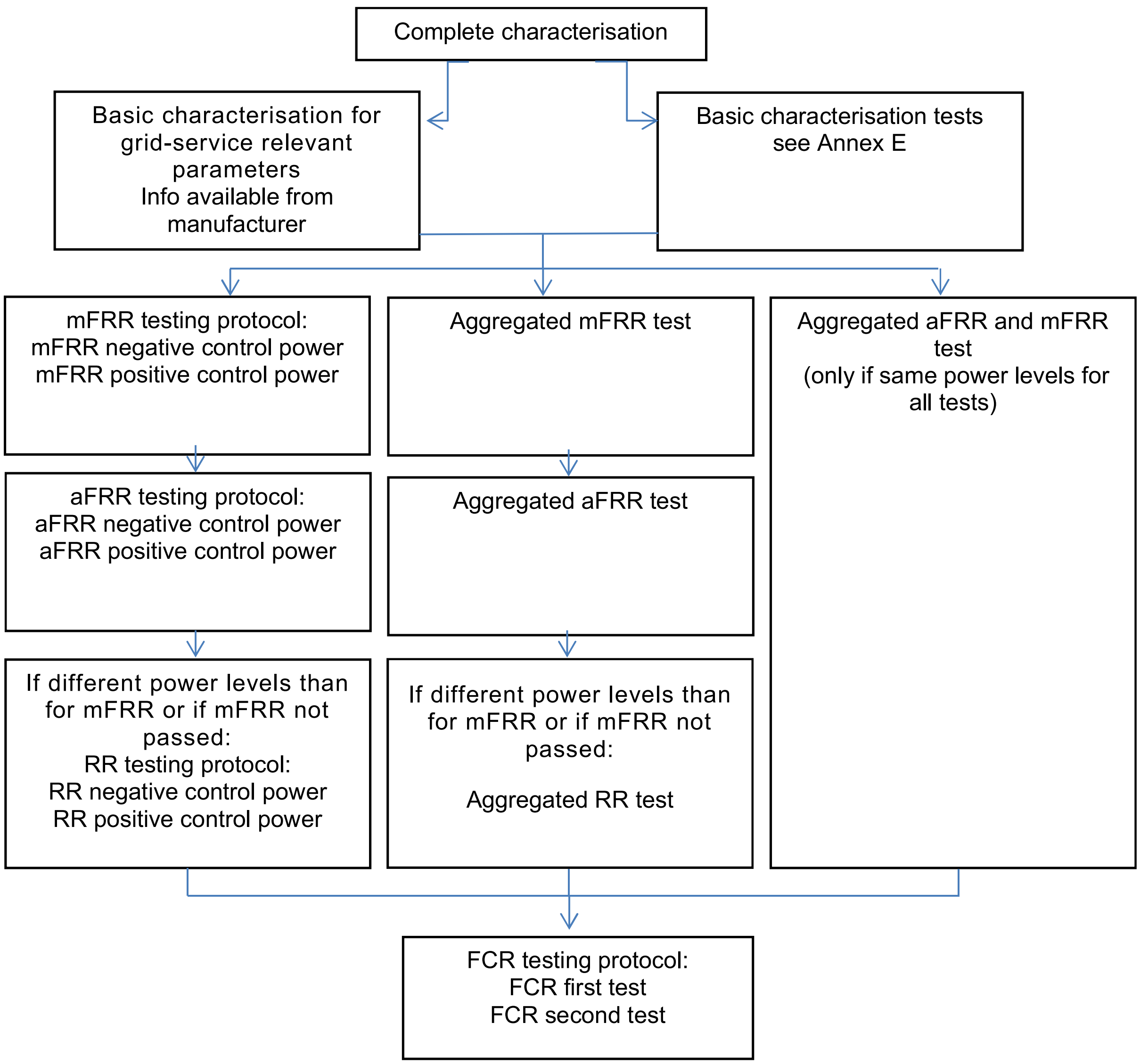
(*) aFRR single tests and aFRR aggregated tests can be considered as alternative tests if the P_{up}, P_{low} levels are selected in the same way

(**) mFRR single tests and mFRR aggregated tests can be considered as alternative tests if the P_{up}, P_{low} levels are selected in the same way

(***) aFRR, mFRR and RR single tests and aFRR-mFRR aggregated tests can be considered as alternative tests if the P_{up}, P_{low} levels are selected in the same way

If a complete characterisation of the electrolyser system is desired the following alternative test sequences could be used:



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1.14 Performance tests

1.14.1 Basic characterisation of electrolyser system for grid-service relevant parameters

In order to decide on the grid services that might have relevance for the electrolyser system tested and as help for designing the tests for the specific grid services several characteristic parameters of the system should be known. Usually these parameters can be provided by the manufacturer. In case that the parameters are not available Annex E gives a guideline how to determine these parameters. It must however be verified that during these tests the settings of the system must always remain within the specifications of the manufacturer to avoid damage to the system.

- Cold Start Time to Nominal Power: τ_{cold}
- Start-up time from Standby State to Nominal Electrical Power Input: $\tau_{start,standby}$
- Average Electrical Power Input of the system in Standby State and in cold standby state: $P_{standby.}$ and $P_{cold\ standby}$.
- The average Electrical Power Input of the system at maximum power level $P_{max\ system}$
- The average Electrical Power Input of the system at 0 or minimum hydrogen output continuously operable: $P_{min\ system}$
- The Total Response Time Minimum Power to Maximum Power $\tau_{min\rightarrow max}$
- The Total Response Time Maximum Power to Minimum Power $\tau_{max\rightarrow min}$
- The Total Response Time Nominal Power to Maximum Power $\tau_{nom\rightarrow max}$
- The Total Response Time Maximum Power to Nominal Power $\tau_{max\rightarrow nom}$
- The duration time of maximum power τ_{max}
- Time from nominal to standby state: $\tau_{down\_to\_standby}$
- Time between reaching standby state and reaching the subsequent Nominal Power state $\tau_{down\rightarrow up}$
- System power at nominal operation $P_{nom\ system}$ as defined by the manufacturer
- Rectifier input power at nominal operation $P_{nom\ rect}$ as defined by the manufacturer

In case that grid service operation not with the entire system but with the recitfier power only is considered, the power levels in the states requested here are to be given separately for rectifier input electrical power.

1.14.1.1 Data evaluation and identification of grid services that might be performed by this system

The available power range for grid services depending on the selected lower power state is:

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Power Range ΔP =

$$\Delta P = \begin{cases} P_{max\ system} - P_{min\ system} \\ \text{or } P_{max\ system} - P_{standby} \\ \text{or } P_{max\ system} - P_{cold\text{-}standby} \end{cases}$$

The dynamics for increasing power is depending on the selected lower and upper power state:

Time to power up τ_{up} =

$$\tau_{up} = \begin{cases} \tau_{cold} + \tau_{nom\rightarrow max} \\ \text{or } \tau_{start,standby} + \tau_{nom\rightarrow max} \\ \text{or } \tau_{min\rightarrow max} \end{cases}$$

The dynamics for decreasing power is depending on the selected lower and upper power state:

Time to power down τ_{down} =

$$\tau_{down} = \begin{cases} \tau_{max\rightarrow min} \\ \text{or } \tau_{down\_to\_standby} + \tau_{max\rightarrow nom} \end{cases}$$

As a first pre-selection a system performing the following services should have characteristic data in the range **(Table 10):**

Service	Power Range ΔP *	Time to power up τ_{up}	Time to power down τ_{down}
FCR	≥ 2 MW	≤60sec **	≤60sec **
aFRR negative control	≥ 5 MW	<133 sec ***	-
aFRR positive control	≥ 5 MW	-	<133 sec ***
mFRR negative control	≥ 10 MW	≤15 min	-
mFRR positive control	≥ 10 MW	-	≤15 min
RR	≥ 10 MW	≤15 min	-
RR	≥ 10 MW	-	≤15 min
DSR	No general information and conditions applying to all countries		

*if system power range is too small for the service, the service provision as part of a pool of an aggregator might still be possible; also in close future access permission of the 1 MW systems to the market can be expected.

**the service requires up and down control from a medium power level with half the reaction time as indicated here

*** Wide variations between the countries. Compare to Annex C

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1.14.2 FCR testing protocol

1.14.2.1 Test objective

This protocol aims at determining the system's response towards positive and negative step responses of power, as well as the time taken for the characteristic duration times identified in FCR prequalification tests. It is based on the European TSO's prequalification procedures trying to integrate all into one generic prequalification procedure. As a second test, to be performed additionally, an input signal taken from real frequency deviations of the grid is taken to verify the system's performance as in a real operating situation following the dynamic varying power request with the system power.

1.14.2.2 Selection of power levels

Based on the electrolyser system's basic characterisation in 1.14.1 or the manufacturer's information a lower and upper power level of the system to be used for provision of the grid service is to be defined by the operator.

Terms:
Lower power level $\mathbf{P_{low}}$
Upper power level $\mathbf{P_{up}}$
Definition: Medium Power level $\mathbf{P_{med}} = 0.5^* (\mathbf{P_{low}} + \mathbf{P_{up}})$

These levels are to be defined, measured and controlled at the total electrolyser system power input. If however the electrical input power to rectifier is used for the grid service and therefore as the control parameter, BOP power should .
Be measured in parallel to the rectifier input power.

NOTE: The levels $\mathbf{P_{low}}$ and $\mathbf{P_{up}}$ need not be the same for this test as for the other grid service testing protocols. They should be defined in an appropriate way that the electrolyser has good chance to pass the test and that in a real application economic operation can be expected, based on the basic characterisation tests in 1.14.1. It is assumed that

- $\mathbf{P_{low}}$ could be either in the interval [$\mathbf{P_{min\ system}}$ … ($\mathbf{P_{min\ system}}$+0.5* ($\mathbf{P_{max\ system}}$ -$\mathbf{P_{min\ system}}$))] or at $\mathbf{P_{standby}}$
- $\mathbf{P_{up}}$ could be in the interval [($\mathbf{P_{min\ system}}$+0.5*($\mathbf{P_{max\ system}}$ -$\mathbf{P_{min\ system}}$) … $\mathbf{P_{max\ system}}$]

For stand-alone grid service operation of the system the power range ($\mathbf{P_{up}}$- $\mathbf{P_{low}}$) should be ≥ 2 MW, for smaller power range an operation with an aggregator should still be possible.
The test results protocol must report the selected $\mathbf{P_{low}}$ and $\mathbf{P_{up}}$.

1.14.2.3 Test method FCR first test

Table 3 – FCR first test

Step	Total test time / sec	Description
1	0	Set system at $P_{med.}$ Measure the system electrical power input and the electrical input power to rectifier vs. time.
2	3600	Set the power set point to P_{up}. Measure the system electrical power input and the electrical input power to rectifier vs. time.

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3	4530	Set the power set point to P_{med}. Measure the system electrical power input and the electrical input power to rectifier vs. time.
4	5460	Set the power set point to P_{up}. Measure the system electrical power input and the electrical input power to rectifier vs. time.
5	7290	Set the power set point to P_{med}. Measure the system electrical power input and the electrical input power to rectifier vs. time.
6	8220	Set the power set point to P_{low}. Measure the system electrical power input and the electrical input power to rectifier vs. time.
7	9150	Set the power set point to P_{med}. Measure the system electrical power input and the electrical input power to rectifier vs. time.
8	10080	Set the power set point to P_{low}. Measure the system electrical power input and the electrical input power to rectifier vs. time.
9	12010	Set the power set point to P_{med}. Measure the system electrical power input and the electrical input power to rectifier vs. time.
10	12940	End of test

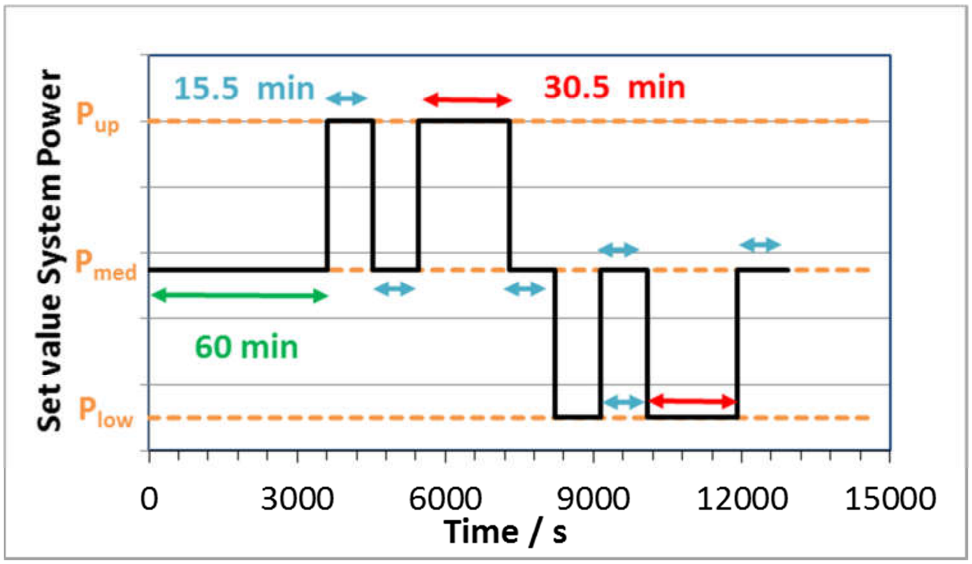

Figure 3 – FCR first test

1.14.2.4 Test method FCR second test

There are two ways of setting up this test:
Option 1: If the system has a frequency to power set-point converter included, in which case the frequency-time profile should be taken as input for the test i.e. the time series file of frequency is fed into the system at the output port of the frequency measurement and is system-internally converted into a power set-point time profile.
Option 2: If the system includes only a power set-point, in which case the power-time profile should be taken as input for the test.

Before the beginning of the test operate the system at P_{med} for 1 hour.

Operate the system as FCR system for 4 hours using
Option 1: the grid frequency f input vs. time as given in Annex B1 following these rules:

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If |f-50.000 Hz|<0.010Hz set point P_{med}
If 0.010Hz ≤ |f-50.000 Hz|<0.100Hz set point (P_{med}+ (f-50.000 Hz)*(P_{med}-P_{low})/0.100 Hz)
If f-50.000 Hz≥0.100Hz set point P_{up}
If f-50.000 Hz≤-0.100Hz set point P_{low}
In words: Set point P_{med} if the grid frequency deviation from 50 Hz is smaller than ±10 mHz; Maximum power consumption if the grid frequency is at least 100 mHz above 50 Hz; Minimum power consumption if the grid frequency is at least 100 mHz below 50 Hz; linear scaling of power consumption for grid frequencies deviating between ±10 mHz and ±100 mHz from 50 Hz.

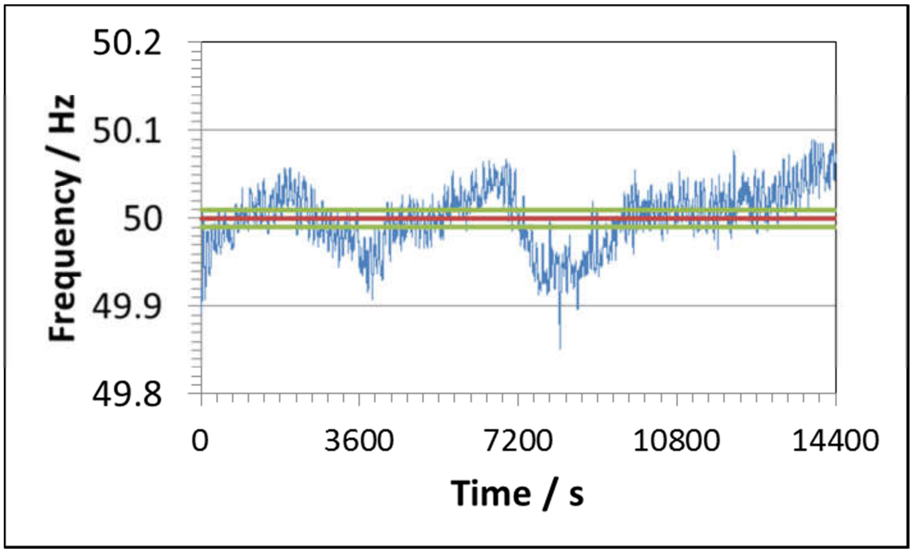

Figure 4 - Real frequency profile for test. Green: lower and upper limit of the range which does not request control power (frequency response deadband). Illustration of the data in Annex B1.

Option 2: As alternative input for the power control of the system (respectively the rectifier) the power vs. time profile derived from this frequency profile using the rules given above can be used. This setpower vs. time profile as input is given in Annex B2. Numbers there are given in % of the control power range with 0% corresponding to P_{low}, 50% corresponding to P_{med} and 100% corresponding to P_{up}.
Note however that in a real electrolyser system installation to provide FCR, a device to measure the grid frequency and an input of this frequency to the control system with the control system calculating the requested control power must be installed.

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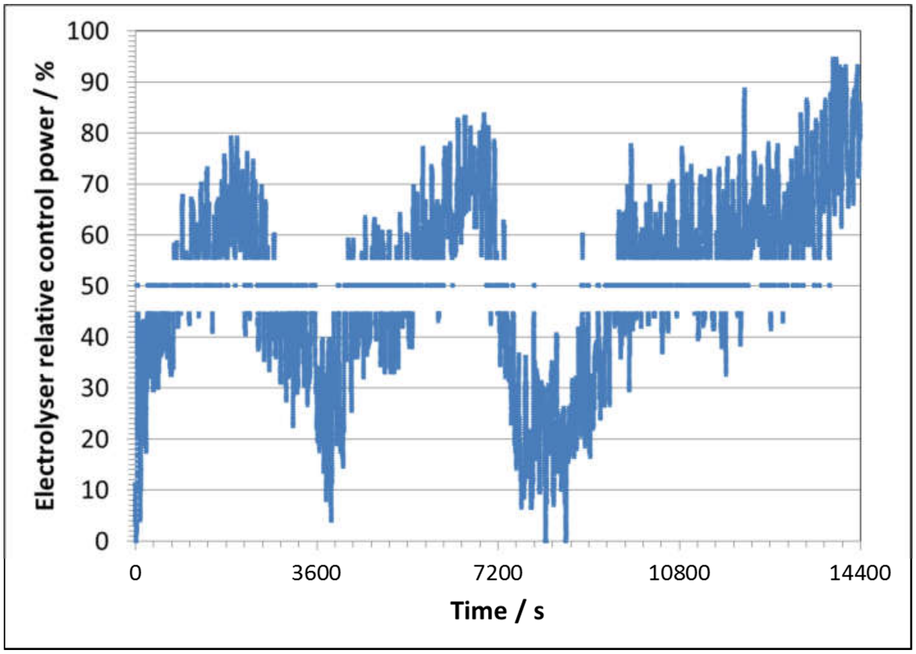

Figure 5 – Power vs. time profile of FCR power derived from real frequency profile of Figure 7. This profile can alternatively be used for FCR second test. Numbers are given in Annex B2.

1.14.2.5 Data evaluation and validation for FCR

Evaluation of First Test:

Power stability when no grid service is provided: During phases A, C, E, G and I the total power must be in the range (P_{med} ± 0.05 (P_{med}-P_{low})). Determine the maximum deviation from P_{med} during phases A, C, E, G and I
with (compare Figure 10)
Phase A: period of 15min before step 2
Phase C: period of 15 min before step 4
Phase E: period of 15 min before step 6
Phase G: period of 15 min before step 8
Phase I: period of 15 min before end of test.

Power stability at P_{up}: During phases B and D the total power must be in the range (P_{up} ± 0.05 (P_{med}-P_{low})). Determine the maximum deviation from P_{up} during phases B and D (see Figure 10) with
Phase B: period between 30 seconds and 15.5 minutes after step 2
Phase D: period between 30 seconds and 30.5 minutes after step 4

Power stability at P_{low}: During phases F and H the total power must be in the range (P_{low} ± 0.05 (P_{med}-P_{low})). Determine the maximum deviation from P_{up} during phases B and D (see Figure 10)
with
Phase F: period between 30 seconds and 15.5 minutes after step 6
Phase H: period between 30 seconds and 30.5 minutes after step 8

KPI power stability: Maximum value Δ_{max} of:

- Absolute value of maximum deviation from P_{med} during phase A, C, E, G, I.

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- Absolute value of maximum deviation from P_{up} during phase B,D.
- Absolute value of maximum deviation from P_{low} during phase F,H.

Required value: ≤ 0.05 (P_{med}-P_{low})

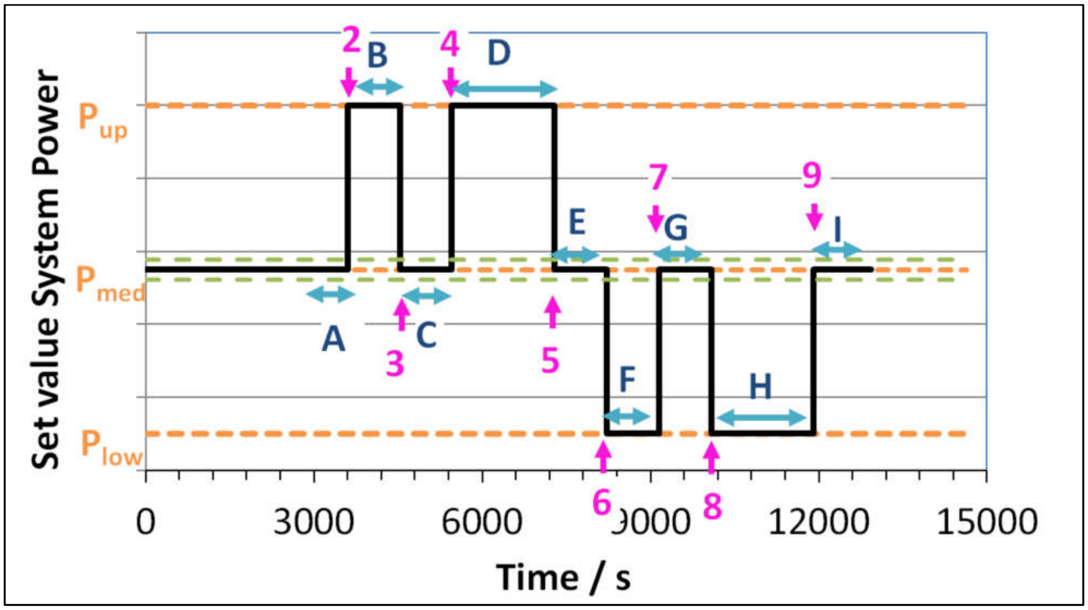

Figure 6 – Illustration of phases A-I for stability evaluation, allowed range for system power during these phases (marked with green dashed line) and steps 1-8.

Duration of ramps up: The dynamics of upward ramps 2, 4, 7, and 9 (Figure 6) is characterised by two characteristic times (Figure 7). For the 4 ramps these times are to be determined.

t_m is the time to reach 50% of the value of the set step response, i.e. system power reaching (P_{med} + 0.5 (P_{up}-P_{med})) for ramps 2 and 4 respectively (P_{med} - 0.5 (P_{up}-P_{med})) for ramps 7 and 9.

t_{full} is the time to reach the full set step response, i.e. in a time interval of 15 min after this moment the system power must be within a range between P_{up} and (P_{up}±5%(P_{up}-P_{med})) for ramps 2 and 4 respectively between P_{med} and (P_{med}±5%(P_{up}-P_{med})) for steps 7 and 9.

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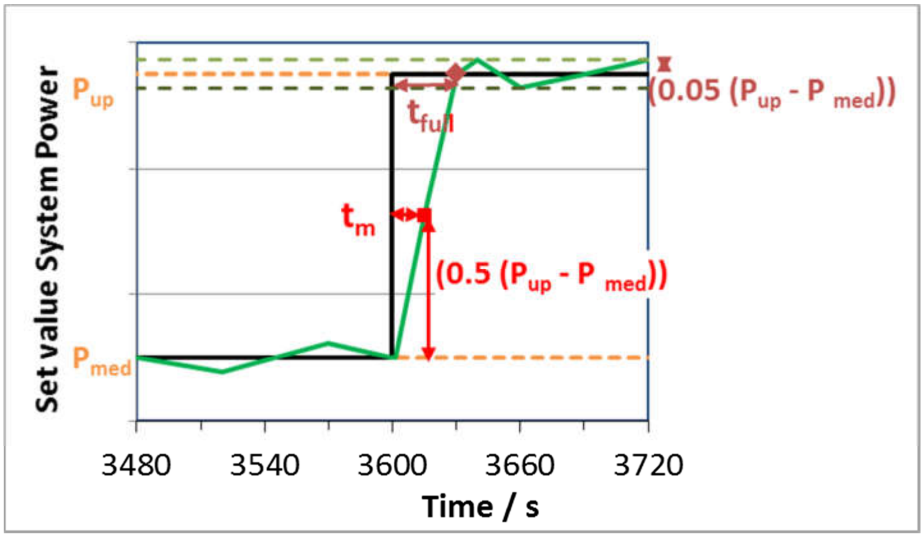

Figure 7 – Illustration evaluation of ramps up. Black full line: power set points, green full line example of real system power

<u>Duration of ramps down:</u> The dynamics of downward ramps 6, 8, 3, and 5 (Figure 8) is accordingly characterised by two characteristic times (Figure 8). For the 4 ramps these times are to be determined.

t_m is the time to reach 50% of the value of the set step response, i.e. system power reaching (P_{med} - 0.5 (P_{med}-P_{low})) for ramps 6 and 8 respectively (P_{med} + 0.5 (P_{med}-P_{low} for ramps 3 and 5.

t_{full} is the time to reach the full set step response, i.e. in a time interval of 15 min after this moment the system power must be within a range between P_{low} and (P_{low}±5%(P_{low}-P_{med})) for ramps 6 and 8 respectively . P_{med} and (P_{med}±5%(P_{low}-P_{med})) for ramps 3 and 5.

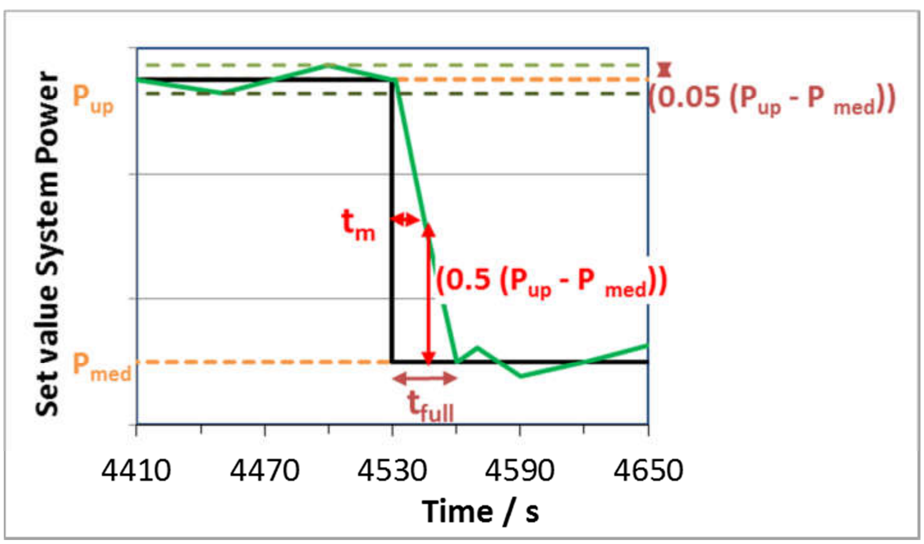

Figure 8 – Illustration evaluation of ramps down. Black full line: power set points, green full line example of real system power

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KPI step ramp duration: Maximum of t_m for all ramps (2, 3, 4, 5, 6, 7, 8 and 9). Required value: ≤15 sec.
Maximum of t_{full} for all ramps (2, 3, 4, 5, 6, 7, 8 and 9). Required value: ≤30 sec.

Initial response time: For steps 2, 4, 6 and 8 the time between the set point change and the beginning of the system reaction is to be determined. For upward ramp this is the time between the step request signal and the moment when the system power continuously increases and has the value $>P_{med}$. For a downward ramp this is the time between the step request signal and the moment when the system power continuously decreases and has the value $<P_{med}$. The initial response time t_{init} must be below 1.5 sec.

KPI Initial response time: Maximum of all values t_{init} for ramps 2, 4, 6 and 8. Required value: ≤ 1.5 sec.

Evaluation of Second Test:
It is to be valuated if the electrolyser power could follow the given frequency/power vs. time profile and if it fulfils the requirements of FCR service as given in table 4.It has to be evaluated if the system power remains within the envelope defined by the lower and upper envelope limit given in Annex B3.
Test result: percentage of data points outside the allowed envelope.

Summary evaluation:

To meet the prequalification requirements of European FCR prequalification tests the following KPIs must be achieved in the FCR testing protocol **(Table 4):**

Performance indicator	Symbol	This system's value	TSO's requirement
Ramp duration	t_m	…	≤ 15 sec*
	t_{full}	…	≤ 30 sec
Stability: maximum deviation	Δ_{max}	…	≤ 0.05 (P_{med}-P_{low})
Initial response time	t_{init}	…	≤ 1.5 sec **
Percentage of data points outside the envelope for FCR second test		…	0%
for power levels Capacity	$\mathbf{P_{low}}$= … kW	$\mathbf{P_{med}}$= … kW ΔP= $\mathbf{P_{up}}$- $\mathbf{P_{med}}$ = kW ***	$\mathbf{P_{up}}$= … kW

**Different from other countries requirements for Fingrid FCR-D, FCR-N and FCR-D in Norway and FCR-D in Denmark D2 Zone , t_m ≤ 5 sec is required. FCR-D in Norway and Denmark D2 zone is only for positive control power i.e. for electrolysers/load for power reduction upon request.*
*** Requirement varying between the countries*

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*** For a symmetric service the capacity is defined as the power that can be increased and decreased from the medium power level.

Report the test results using the test report template in Annex C.

NOTE:
If a system does not meet the requirements of this test it is most likely not suitable for FCR grid service in all considered European countries. However with the FCR requirements being different in all countries the system might still be able to qualify in individual countries. Annex D gives the prequalification procedures of the individual European countries and further links. It is recommended to apply the individual countries' prequalification procedure that avoids the conditions critical to this system to determine for which country the system might be able to qualify.

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1.14.3 aFRR testing protocol

This protocol aims at determining whether the system is able to follow power ramp instructions in a suitable way as described in aFRR prequalification tests.
This protocol aims at determining the system's response towards positive and negative ramps of power, as well as the time taken for the characteristic duration times identified in aFRR prequalification tests. It is based on the European TSO's prequalification procedures trying to integrate all into one generic prequalification procedure. The services of positive and negative control power are considered separately because in many countries provision of only one type of service is allowed.
The test starts with a longer phase of constant operation at the starting level to make sure that the system is in a stable condition and because in real operation of this service the activation will not be very frequently, i.e. the system will operate most of the time at the level being the starting level of this test.

1.14.3.1 Selection of power levels

Based on the electrolyser system's basic characterisation in 1.14.1 or the manufacturer's information a lower and upper power level of the system to be used for provision of the grid service is to be defined. The levels need not be the same as for other types of grid services.

Terms:
Lower power level $\mathbf{P_{low}}$
Upper power level $\mathbf{P_{up}}$

These levels are to be defined, measured and controlled at the total electrolyser system power input. If however the electrical input power to rectifier is used for the grid service and therefore as the control parameter, BOP power should be measured in parallel to rectifier input power.

NOTE: The levels $\mathbf{P_{low}}$ and $\mathbf{P_{up}}$ need not be the same for this test as for the other grid service testing protocols. They should be defined in an appropriate way that the electrolyser has good chance to pass the test and that in a real application economic operation can be expected based on the basic characterisation tests in 1.14.1. It is assumed that

- $\mathbf{P_{low}}$ could be either in the interval [$\mathbf{P_{min\ system}}$ ... ($\mathbf{P_{min\ system}}$+0.5* ($\mathbf{P_{max\ system}}$ -$\mathbf{P_{min\ system}}$))] or at $\mathbf{P_{standby}}$ or at $\mathbf{P_{cold\text{-}standby}}$
- $\mathbf{P_{up}}$ could be in the interval [($\mathbf{P_{min\ system}}$+0.5*($\mathbf{P_{max\ system}}$ -$\mathbf{P_{min\ system}}$) … $\mathbf{P_{max\ system}}$]

$\mathbf{P_{low}}$ and $\mathbf{P_{up}}$ also need not be the same for positive and negative control power aFRR test.
For stand-alone grid service operation of the system the power range ($\mathbf{P_{up}}$- $\mathbf{P_{low}}$) should be ≥ 5 MW in most countries, for smaller power range an operation with an aggregator should still be possible.
The test results protocol must report the selected $\mathbf{P_{low}}$ and $\mathbf{P_{up}}$.

1.14.3.2 aFRR negative control power (electrolyser power increase upon request)

1.14.3.2.1 *Test objective*

This protocol aims at determining whether the system is able to follow power ramp instructions in a suitable way similar to European aFRR prequalification tests.

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1.14.3.2.2 ***Test method: aFRR upward ramp protocol***

Table 5 - Upward aFRR ramp protocol from lower power level for aFRR negative control power

Step	Description	Comment
1	Set system at P_{low}	
2	Wait for system power to stabilize*	
3	Operate at this level for 1 hour	
4	At $t=t_1$, initiate linear power ramp of power (+25%(P_{up}-P_{low})) in 800 seconds	
5	$t=t_1$+800 seconds: end of the ramp	
6	Keep set power for 5 minutes	
7	Set system at P_{low} (the time the system needs to return to P_{low} is not evaluated)	
8	Wait for system power to stabilize *	
9	At $t=t_2$, initiate linear power ramp of power (+50%(P_{up}-P_{low})) in 800 seconds	
10	$t=t_2$+800 seconds: end of the ramp	
11	Keep set power for 5 minutes	
12	Set system at P_{low} (the time the system needs to return to P_{low} is not evaluated)	
13	Wait for system power to stabilize *	
14	At $t=t_3$, initiate linear power ramp of power (+75%(P_{up}-P_{low})) in 800 seconds	
15	$t=t_3$+800 seconds: end of the ramp	
16	Keep set power for 5 minutes	
17	Set system at P_{low} (the time the system needs to return to P_{low} is not evaluated)	
18	Wait for system power to stabilize *	
19	At $t=t_4$, initiate linear power ramp of power (+100%(P_{up}-P_{low})) in 800 seconds	
20	$t=t_4$+800 seconds: end of the ramp	
21	Keep set power for 15 minutes	
22	At $t=t_5$, initiate linear power ramp of power (-100%(P_{up}-P_{low})) in 800 seconds	
23	$t=t_5$+800 seconds: end of the ramp	
24	Keep set power at P_{low} for 15 minutes	
25	At $t=t_6$, initiate linear power ramp of power (+100%(P_{up}-P_{low})) in 800 seconds	
26	$t=t_6$+800 seconds: end of the ramp	
27	Keep set power for 15 minutes	
28	At $t=t_7$, initiate linear power ramp of power (-100%(P_{up}-P_{low})) in 800 seconds	
29	$t=t_7$+800 seconds: end of the ramp	
30	Wait for system power to stabilize *	
31	Operate at this level for 15 minutes	
32	At $t=t_8$, initiate linear power ramp of power (25% (P_{up} - P_{low})) in 133 seconds	
33	$t=t_8$+133 seconds: end of the ramp	
34	Keep set power for 5 minutes	

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35	Set system at P_{low} (the time the system needs to return to P_{low} is not evaluated)	
36	Wait for system power to stabilize *	
37	At $t=t_9$, initiate linear power ramp of power (50% (P_{up} - P_{low})) in 133 seconds	
38	$t=t_9$+133 seconds: end of the ramp	
39	Keep set power for 5 minutes	
40	Set system at P_{low} (the time the system needs to return to P_{low} is not evaluated)	
41	Wait for system power to stabilize *	
42	At $t=t_{10}$, initiate linear power ramp of power (75% (P_{up} - P_{low})) in 133 seconds	
43	$t=t_{10}$+133 seconds: end of the ramp	
44	Keep set power for 5 minutes	
45	Set system at P_{low} (the time the system needs to return to P_{low} is not evaluated)	
46	Wait for system power to stabilize *	
47	At $t=t_{11}$, initiate linear power ramp of power (100% (P_{up} - P_{low})) in 300 seconds	
48	$t=t_{11}$+300 seconds: end of the ramp	
49	Keep set power for 15 minutes	
50	At $t=t_{12}$, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 300 seconds	
51	$t=t_{12}$+300 seconds: end of the ramp	
52	Keep set power for 15 minutes	
53	At $t=t_{13}$, initiate linear power ramp of power (+100% (P_{up} - P_{low})) in 300 seconds	
54	$t=t_{13}$+300 seconds: end of the ramp	
55	Keep set power for 15 minutes	
56	At $t=t_{14}$, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 300 seconds	
57	$t=t_{14}$+300 seconds: end of the ramp	
58	Wait for system power to stabilize*	
59	At $t=t_{15}$, initiate linear power ramp of power (+100% (P_{up} - P_{low})) in 133 seconds	
60	$t=t_{15}$+133 seconds: end of the ramp	
61	Keep set power for 15 minutes	
62	At $t=t_{16}$, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 133 seconds	
63	Keep set power for 5 minutes	
64	End of test	

*The system power is considered stable if the average power of two consecutive intervals of 60sec does not differ by more than (±5% (P_{up}-P_{low}))

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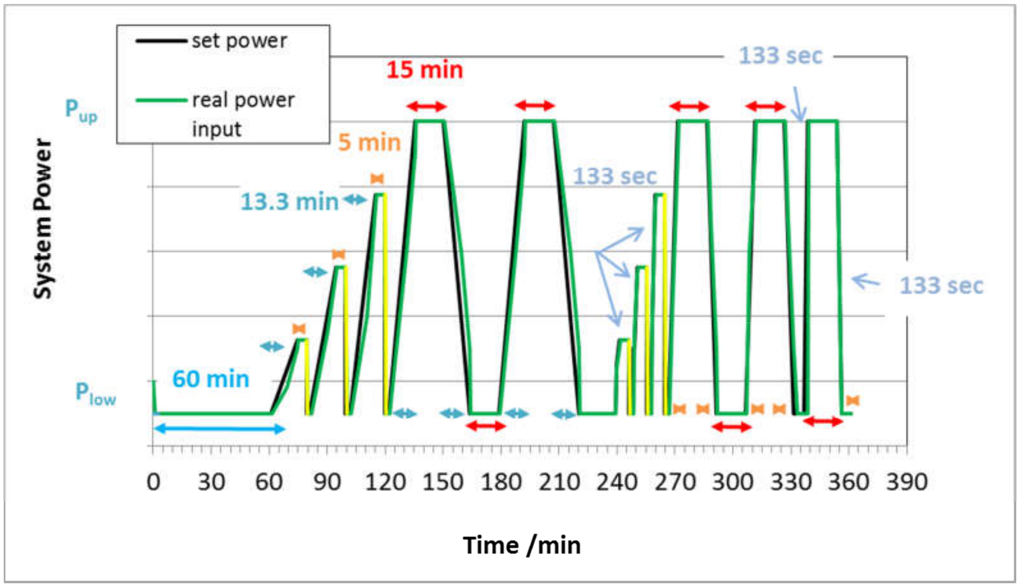

Figure 9 - Illustration of upward aFRR ramp protocol from lower power level for aFRR negative control power. Total duration approx. 6 hours depending on system stabilization time. Not evaluated transitions are depicted in yellow line.

1.14.3.3 aFRR positive control power (electrolyser power decrease upon request)

1.14.3.3.1 *Test objective*

This protocol aims at determining whether the system is able to follow power ramp instructions in a suitable way similar to European aFRR prequalification tests.

1.14.3.3.2 *Test method: aFRR downward ramp protocol*

Table 6 - Downward aFRR ramp protocol from upper power level for aFRR positive control power

Step	Description	Comment
1	Set system at P_{up}	
2	Wait for system power to stabilize*	
3	Operate at this level for 1 hour	
4	At $t=t_1$, initiate linear power ramp of power (-25% (P_{up} - P_{low})) in 800 seconds	
5	$t=t_1$+800 seconds: end of the ramp	
6	Keep set power for 5 minutes	
7	Set system at P_{up} (the time the system needs to return to P_{up} is not evaluated)	
8	Wait for system power to stabilize *	
9	At $t=t_2$, initiate linear power ramp of power (-50% (P_{up} - P_{low})) in 800 seconds	
10	$t=t_2$+800 seconds: end of the ramp	
11	Keep set power for 5 minutes	

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12	Set system at P_{up} (the time the system needs to return to P_{up} is not evaluated)	
13	Wait for system power to stabilize *	
14	At $t=t_3$, initiate linear power ramp of power (-75% (P_{up} - P_{low})) in 800 seconds	
15	$t=t_3$+800 seconds: end of the ramp	
16	Keep set power for 5 minutes	
17	Set system at P_{up} (the time the system needs to return to P_{up} is not evaluated)	
18	Wait for system power to stabilize *	
19	At $t=t_4$, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 800 seconds	
20	$t=t_4$+800 seconds: end of the ramp	
21	Keep set power for 15 minutes	
22	At $t=t_5$, initiate linear power ramp of power (+100% (P_{up} - P_{low})) in 800 seconds	
23	$t=t_5$+800 seconds: end of the ramp	
24	Keep set power for 15 minutes	
25	At $t=t_6$, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 800 seconds	
26	$t=t_6$+800 seconds: end of the ramp	
27	Keep set power for 15 minutes	
28	At $t=t_7$, initiate linear power ramp of power (+100% (P_{up} - P_{low})) in 800 seconds	
29	$t=t_7$+800 seconds: end of the ramp	
30	Keep set power for 15 minutes	
31	At $t=t_8$, initiate linear power ramp of power (-25% (P_{up} - P_{low})) in 133 seconds	
32	$t=t_8$+133 seconds: end of the ramp	
33	Keep set power for 5 minutes	
34	Set system at P_{up} (the time the system needs to return to P_{up} is not evaluated)	
35	Wait for system power to stabilize*	
36	At $t=t_9$, initiate linear power ramp of power (-50% (P_{up} - P_{low})) in 133 seconds	
37	$t=t_9$+133 seconds: end of the ramp	
38	Keep set power for 5 minutes	
39	Set system at P_{up} (the time the system needs to return to P_{up} is not evaluated)	
40	Wait for system power to stabilize*	
41	At $t=t_{10}$, initiate linear power ramp of power (-75% (P_{up} - P_{low})) in 133 seconds	
42	$t=t_{10}$+133 seconds: end of the ramp	
43	Keep set power for 5 minutes	
44	Set system at P_{up} (the time the system needs to return to P_{up} is not evaluated)	
45	Wait for system power to stabilize*	
46	At $t=t_{11}$, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 300 seconds	
47	$t=t_{11}$+300 seconds: end of the ramp	
48	Keep set power for 15 minutes	
49	At $t=t_{12}$, initiate linear power ramp of power (+100% (P_{up} - P_{low})) in 300 seconds	
50	$t=t_{12}$+300 seconds: end of the ramp	

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51	Keep set power for 15 minutes	
52	At t=t_{13}, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 300 seconds	
53	t=t_{13}+300 seconds: end of the ramp	
54	Keep set power for 15 minutes	
55	At t=t_{14}, initiate linear power ramp of power (+100% (P_{up} - P_{low})) in 300 seconds	
56	t=t_{14}+300 seconds: end of the ramp	
57	Wait for system power to stabilize*	
58	At t=t_{15}, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 300 seconds	
59	t=t_{15}+133 seconds: end of the ramp	
60	Keep set power for 15 minutes	
61	At t=t_{16}, initiate linear power ramp of power (+100% (P_{up} - P_{low})) in 133 seconds	
62	Keep set power for 5 minutes	
63	End of test	

*The system power is considered stable if the average power of two consecutive intervals of 60sec does not differ by more than (±5% (P_{up}-P_{low}))

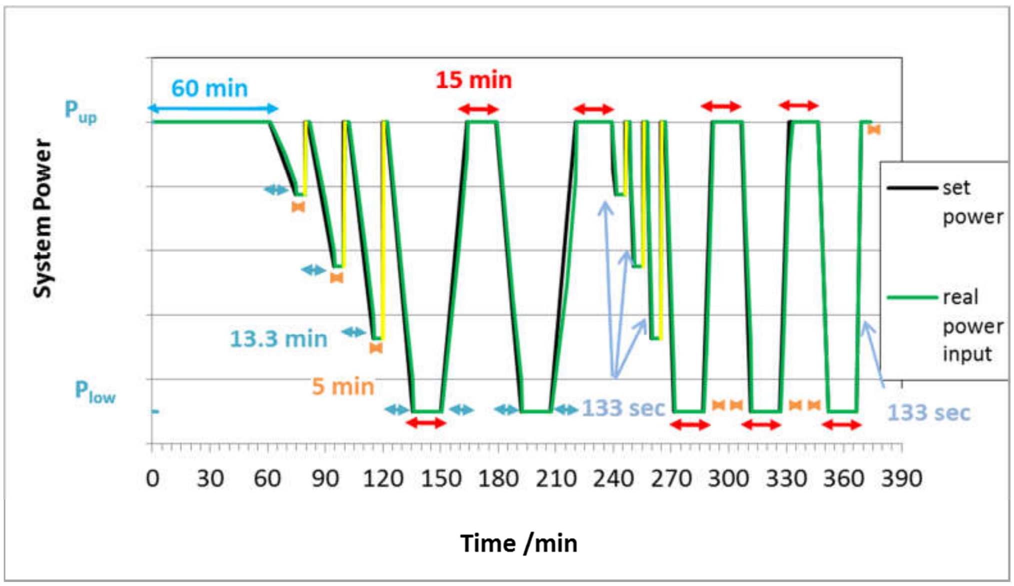

Figure 10 - Illustration of downward aFRR ramp protocol from upper power level for aFRR positive control power. Total duration approx. 6 hours depending on system stabilization time. Not evaluated transitions are depicted in yellow line.

1.14.3.4 Data evaluation and validation for aFRR

The following conditions must be met:

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- The power difference $\Delta P=2P_r$ measured at the end of the ramp must correspond to the target.
- During the periods of constant power request the real system power must be in the range (±5% (P_{up}-P_{low})) around the requested power. This condition is valid as soon as the power enters the interval (P_0+2 P_r±5% (P_{up}-P_{low})) for positive ramp and (P_0-2 P_r±5% (P_{up}-P_{low})) for negative ramp.
- The actual power of the system must remain 95% of the time in the bracket [P_{tol} - ε_v; P_c+ ε_v] in case of a positive ramp, and [P_c- ε_v; P_{tol} +ε_v] for a negative ramp, with:
  - P_0: initial power level of the system at the beginning of the ramp (see Fig. 11 and 12)
  - P_r: absolute value of half of the ramp power amplitude
  - N: parameter going from 0 at t=0 to +2 in the end of the ramp in case of positive ramp, and 0 to -2 in case of negative ramp
  - $P_c=P_0 + N*P_r$
  - $P_{tol}=P_c$(t-20 second): set power at t-20 seconds
  - ε_v : 2.5% of the full ramp power (P_{up} - P_{low})

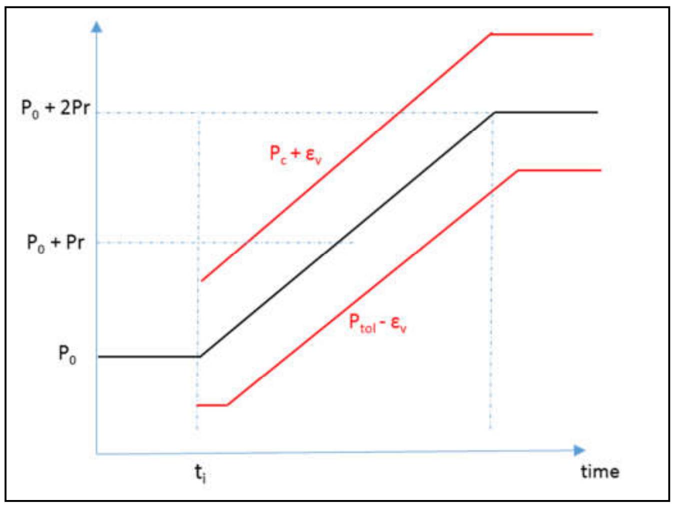

Figure 11 - Case for a positive ramp

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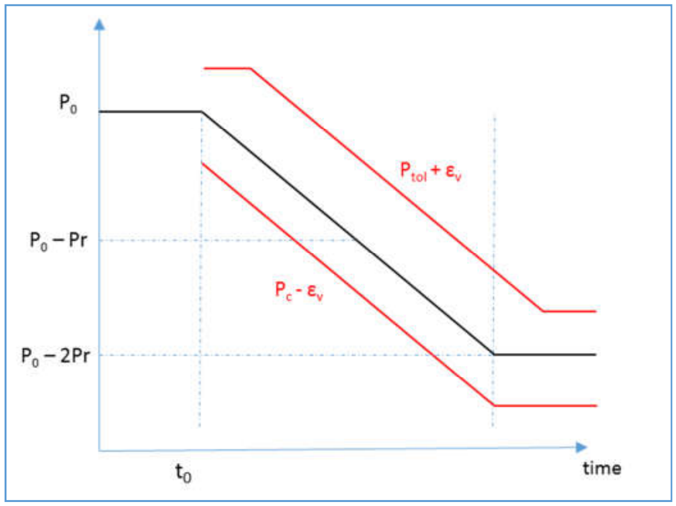

Figure 12 - Case for a negative ramp

<u>Data evaluation</u>:
Indicate the percentage of data points with deviation from the requested ranges during the period of constant power.
Indicate the percentage of data points with deviation from the requested ranges during the ramps.

aFRR negative control power:

Performance indicator	Symbol	This system's value	TSO's requirement
Percentage of data points outside the range for constant power periods		… …	≤ 5%
Percentage of data points outside the range for the ramps		…	≤ 5%
for power levels Capacity		$\mathbf{P_{low}}$= … kW $\mathbf{\Delta P= P_{up} - P_{low}}$ =	$\mathbf{P_{up}}$= … kW kW

aFRR positive control power:

Performance indicator	Symbol	This system's value	TSO's requirement
Percentage of data points outside the range for constant power periods		… …	≤ 5%
Percentage of data points outside the range for the ramps		…	≤ 5%
for power levels Capacity		$\mathbf{P_{low}}$= … kW $\mathbf{\Delta P= P_{up} - P_{low}}$ =	$\mathbf{P_{up}}$ = … kW kW

In case that the deviation during the ramps is higher than 5% evaluate separately the ramps of different duration and indicate for which ramp the deviation of 5% can be met:

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aFRR negative control power:

Performance indicator	Symbol	This system's value	TSO's requirement
Percentage of data points outside the range for 800 sec ramps		… …	≤ 5%
Percentage of data points outside the range for 300 s ramps		…	≤ 5%
Percentage of data points outside the range for 133 s ramps		…	≤ 5%
for power levels Capacity		**P_{low}**= … kW **ΔP**= **P_{up}** - **P_{low}** =	**P_{up}**= … kW kW

aFRR positive control power:

Performance indicator	Symbol	This system's value	TSO's requirement
Percentage of data points outside the range for 800 sec ramps		… …	≤ 5%
Percentage of data points outside the range for 300 s ramps		…	≤ 5%
Percentage of data points outside the range for 133 s ramps		…	≤ 5%
for power levels Capacity		**P_{low}**= … kW **ΔP**= **P_{up}** - **P_{low}** =	**P_{up}**= … kW kW

NOTE:
If a system does not meet the requirements of this test it is most likely not suitable for aFRR grid service in all considered European countries. However with the aFRR requirements being different in all countries the system might still be able to qualify in individual countries. Annex D gives the prequalification procedures of the individual European countries and further links. It is recommended to apply the individual countries' prequalification procedures that avoids the conditions critical to this system to determine for which country the system might be able to qualify.

Report the test results using the test report template in Annex C.

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1.14.4 mFRR testing protocol

This protocol aims at determining whether the system is able to follow power ramp instructions in a suitable way as described in European mFRR prequalification tests.
This protocol aims at determining the system's response towards positive and negative ramps of power, as well as the time taken for the characteristic duration times identified in mFRR prequalification tests. It is based on the European TSO's prequalification procedures trying to integrate all into one generic prequalification procedure. The services of positive and negative control power are considered separately because in many countries provision of only one type of service is allowed.
The test starts with a longer phase of constant operation at the starting level to make sure that the system is in a stable condition and because in real operation of this service the activation will not be very frequently, i.e. the system will operate most of the time at the level being the starting level of this test.

1.14.4.1 Selection of power levels

Based on the electrolyser system's basic characterisation in 1.14.1 or the manufacturer's information a lower and upper power level of the system to be used for provision of the grid service is to be defined. The levels need not be the same as for other types of grid services.

Terms:
Lower power level $\mathbf{P}_{low}$
Upper power level $\mathbf{P}_{up}$

These levels are to be defined, measured and controlled at the total electrolyser system power input. If however the electrical input power to rectifier is used for the grid service and therefore as the control parameter, BOP power should be measured in parallel to rectifier input power.

NOTE: The levels $\mathbf{P}_{low}$ and $\mathbf{P}_{up}$ need not be the same for this test as for the other grid service testing protocols. They should be defined in an appropriate way that the electrolyser has good chance to pass the test and that in a real application economic operation can be expected based on the basic characterisation tests in 1.14.1. It is assumed that

- $\mathbf{P}_{low}$ could be either in the interval [$\mathbf{P}_{min\ system}$ ... ($\mathbf{P}_{min\ system}$+0.5* ($\mathbf{P}_{max\ system}$ -$\mathbf{P}_{min\ system}$))] or at $\mathbf{P}_{standby}$ or at $\mathbf{P}_{cold\text{-}standby}$
- $\mathbf{P}_{up}$ could be in the interval [($\mathbf{P}_{min\ system}$+0.5*($\mathbf{P}_{max\ system}$ -$\mathbf{P}_{min\ system}$) … $\mathbf{P}_{max\ system}$]

$\mathbf{P}_{low}$ and $\mathbf{P}_{up}$ also need not be the same for positive and negative control power mFRR test.
For stand-alone grid service operation of the system the power range ($\mathbf{P}_{up}$- $\mathbf{P}_{low}$) should be ≥ 10 MW in most countries, for smaller power range an operation with an aggregator should still be possible.
The test results protocol must report the selected $\mathbf{P}_{low}$ and $\mathbf{P}_{up}$.

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1.14.4.2 mFRR negative control power (electrolyser power increase upon request)

1.14.4.2.1 mFRR upward slow ramp protocol, from lower power level

1.14.4.2.1.1 *Test objective*

This protocol aims at determining whether the system is able to follow power ramp instructions in a suitable way similar to European mFRR prequalification tests.

1.14.4.2.1.2 *Test method mFRR upward ramp protocol*

Table 7 – mFRR upward ramp protocol from lower power level for mFRR negative control power

Step	Description	Comment
1	Set system at P_{low}	
2	Wait for system power to stabilize*	
3	Operate at this level for 1 hour	
4	At $t=t_1$, initiate linear power ramp of power (25% (P_{up} - P_{low})) in 10 minutes	
5	$t=t_1$+600 seconds: end of the ramp	
6	Keep set power for 5 minutes	
7	Set system at P_{low} (the time the system needs to return to P_{low} is not evaluated)	
8	Wait for system power to stabilize*	
9	At $t=t_2$, initiate linear power ramp of power (50% (P_{up} - P_{low})) in 10 minutes	
10	$t=t_2$+600 seconds: end of the ramp	
11	Keep set power for 5 minutes	
12	Set system at P_{low} (the time the system needs to return to P_{low} is not evaluated)	
13	Wait for system power to stabilize*	
14	At $t=t_3$, initiate linear power ramp of power (75% (P_{up} - P_{low})) in 10 minutes	
15	$t=t_3$+600 seconds: end of the ramp	
16	Keep set power for 5 minutes	
17	Set system at P_{low} (the time the system needs to return to P_{low} is not evaluated)	
18	Wait for system power to stabilize*	
19	At $t=t_4$, initiate linear power ramp of power (100% (P_{up} - P_{low})) in 10 minutes	
20	$t=t_4$+600 seconds: end of the ramp	
21	Keep set power for 60 minutes	
22	At $t=t_5$, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 10 minutes	
23	$t=t_5$+600 seconds: end of the ramp	
24	Keep set power for 15 minutes	
25	At $t=t_6$, initiate power ramp of power (100% (P_{up} - P_{low})) in 10 minutes	
26	$t=t_6$+600 seconds: end of the ramp	
27	Keep set power for 60 minutes	
28	At $t=t_7$, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in	

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Step	Description	Comment
	10 minutes	
29	t=t_7+600 seconds: end of the ramp	
30	Wait for system power to stabilize*	
31	End of test	

*The system power is considered stable if the average power of two consecutive intervals of 60sec does not differ by more than (±5% (P_{up}-P_{low}))

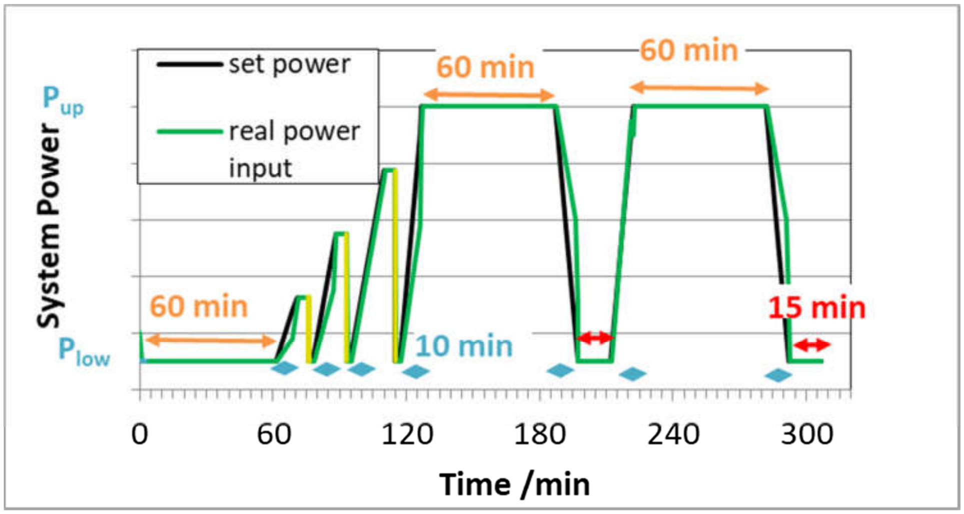

Figure 13 - Illustration of mFRR upward ramp protocol from lower power level for mFRR negative control power. Not evaluated transitions are depicted in yellow line.

1.14.4.3 mFRR positive control power (electrolyser power decrease upon request)

1.14.4.3.1 mFRR downward slow ramp protocol, from upper power level

1.14.4.3.1.1 ***Test objective***

This protocol aims at determining whether the system is able to follow power ramp instructions in a suitable way similar to European mFRR prequalification tests.

1.14.4.3.1.2 ***Test method mFRR downward ramp protocol***

Table 8 – mFRR downward ramp protocol from upper power level for mFRR positive control power

Step	Description	Comment
1	Set system at P_{up}	
2	Wait for system power to stabilize*	

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Step	Description	Comment
3	Operate at this level for 1 hour	
4	At t=t_1, initiate linear power ramp of power (-25% (P_{up} - P_{low})) in 10 minutes	
5	t=t_1+600 seconds: end of the ramp	
6	Keep set power for 5 minutes	
7	Set system at P_{up} (the time the system needs to return to P_{up} is not evaluated)	
8	Wait for system power to stabilize*	
9	At t=t_2, initiate linear power ramp of power (-50% (P_{up} - P_{low})) in 10 minutes	
10	t=t_2+600 seconds: end of the ramp	
11	Keep set power for 5 minutes	
12	Set system at P_{up} (the time the system needs to return to P_{up} is not evaluated)	
13	Wait for system power to stabilize*	
14	At t=t_3, initiate linear power ramp of power (-75% (P_{up} - P_{low})) in 10 minutes	
15	t=t_3+600 seconds: end of the ramp	
16	Keep set power for 5 minutes	
17	Set system at P_{up} (the time the system needs to return to P_{up} is not evaluated)	
18	Wait for system power to stabilize*	
19	At t=t_4, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 10 minutes	
20	t=t_4+600 seconds: end of the ramp	
21	Keep set power for 60 minutes	
22	At t=t_5, initiate linear power ramp of power (+100% (P_{up} - P_{low})) in 10 minutes	
23	t=t_5+600 seconds: end of the ramp	
24	Keep set power for 15 minutes	
25	At t=t_6, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 10 minutes	
26	t=t_6+600 seconds: end of the ramp	
27	Keep set power for 60 minutes	
28	At t=t_7, initiate linear power ramp of power (+100% (P_{up} - P_{low})) in 10 minutes	
29	t=t_7+600 seconds: end of the ramp	
30	Keep set power for 15 minutes	
31	End of test	

*The system power is considered stable if the average power of two consecutive intervals of 60sec does not differ by more than (±5% (P_{up}-P_{low}))

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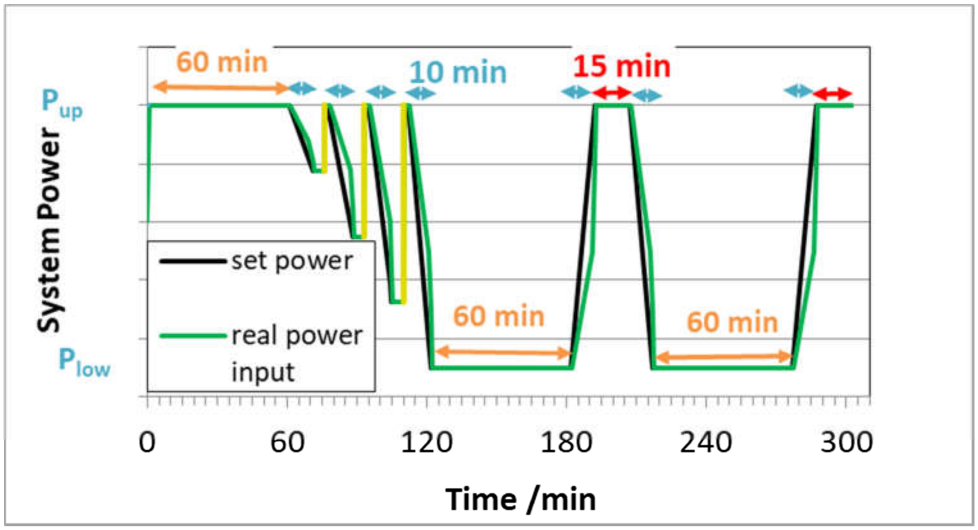

Figure 14 - Illustration of mFRR downward ramp protocol from upper power level for mFRR positive control power. Not evaluated transitions are depicted in yellow line.

1.14.4.4 Data evaluation and validation for mFRR

The following conditions must be met:

- The power difference $\Delta P=2P_r$ measured at the end of the ramp must correspond to the target. During the periods of constant power request the real system power must be in the range (±5% (P_{up}-P_{low})) around the requested power. This condition is valid as soon as the power enters the interval (P_0+2 P_r±5% (P_{up}-P_{low})) for positive ramp and (P_0-2 P_r±5% (P_{up}-P_{low})) for negative ramp.
- The actual power of the system must remain 95% of the time in the bracket [P_{tol} - ε_v; Pc+ ε_v] in case of a positive ramp, and [Pc- ε_v; P_{tol} +ε_v] for a negative ramp, with:
  - P_0: initial power level of the system at the beginning of the ramp (see Fig. 15 and 16)
  - P_r: absolute value of half of the ramp power amplitude
  - N: parameter going from 0 at t=0 to +2 in the end of the ramp in case of positive ramp, and 0 to -2 in case of negative ramp
  - P_c=P_0 + N*Pr
  - P_{tol}=P_c(t-20 second): set power at t-20 seconds
  - ε_v : 2.5% of the full ramp power (P_{up} - P_{low})

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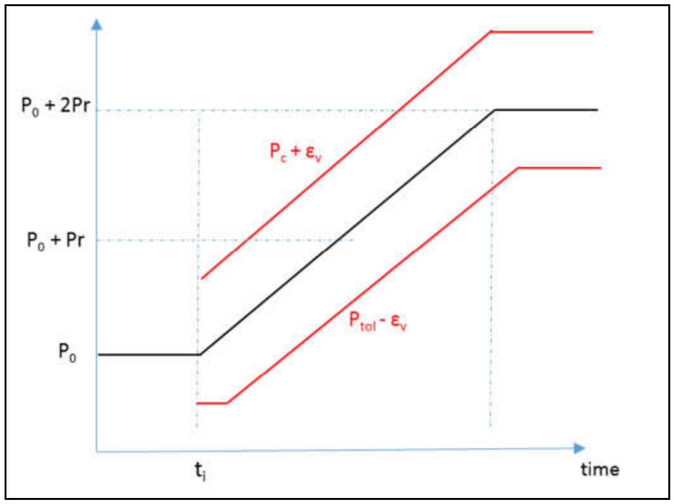

Figure 15 - Case for a positive ramp

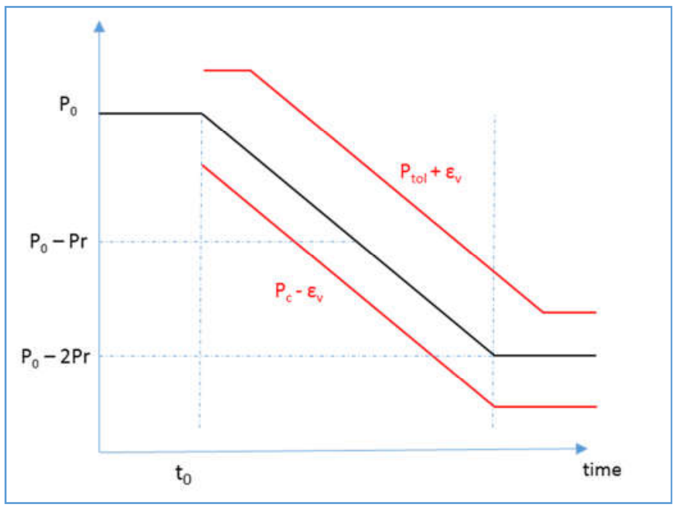

Figure 16 - Case for a negative ramp

Data evaluation:
Indicate the percentage of data points with deviation from the requested ranges during the period of constant power.
Indicate the percentage of data points with deviation from the requested ranges during the ramps.

mFRR negative control power:

Performance indicator	Symbol	This system's value	TSO's requirement
Percentage of data points outside the range for constant power periods		… …	≤ 5%

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Percentage of data points outside the range for the ramps		…	≤ 5%
for power levels Capacity		$\mathbf{P_{low}}$= … kW $\mathbf{\Delta P}$= $\mathbf{P_{up}}$ - $\mathbf{P_{low}}$ =	$\mathbf{P_{up}}$= … kW kW

mFRR positive control power:

Performance indicator	Symbol	This system's value	TSO's requirement
Percentage of data points outside the range for constant power periods		… …	≤ 5%
Percentage of data points outside the range for the ramps		…	≤ 5%
for power levels Capacity		$\mathbf{P_{low}}$= … kW $\mathbf{\Delta P}$= $\mathbf{P_{up}}$ - $\mathbf{P_{low}}$ =	$\mathbf{P_{up}}$= … kW kW

NOTE:
If a system does not meet the requirements of this test it is most likely not suitable for mFRR grid service in all considered European countries. However with the mFRR requirements being different in all countries the system might still be able to qualify in individual countries. Annex D gives the prequalification procedures of the individual European countries and further links. It is recommended to apply the individual countries' prequalification procedures that avoids the conditions critical to this system to determine for which country the system might be able to qualify.

Report the test results using the test report template in Annex C.

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1.14.5 RR testing protocol

Power conformity protocols

This protocol, based on requirements for RR mechanism, aims at verifying the concordance between consumption based on set point and real consumption.

It is based on the European TSO's prequalification procedures trying to integrate all into one generic prequalification procedure. The services of positive and negative control power are considered separately because in many countries provision of only one type of service is allowed.

Different from the mFRR protocol here, for RR, the ramp need not be run in a precisely defined way. Only the total time to ramp up/down must be below a given maximum value.

The test starts with a longer phase of constant operation at the starting level to make sure that the system is in a stable condition and because in real operation of this service the activation will not be very frequently, i.e. the system will operate most of the time at the level being the starting level of this test

1.14.5.1 Selection of power levels

Based on the electrolyser system's basic characterisation in 1.14.1 or the manufacturer's information a lower and upper power level of the system to be used for provision of the grid service is to be defined.

Terms:
Lower power level $\mathbf{P_{low}}$
Upper power level $\mathbf{P_{up}}$

These levels are to be defined, measured and controlled at the total electrolyser system power input. If however the electrical input power to rectifier is used for the grid service and therefore as the control parameter, BOP power should be measured in parallel to the rectifier input power.

NOTE: The levels $\mathbf{P_{low}}$ and $\mathbf{P_{up}}$ need not be the same for this test as for the other grid service testing protocols. They should be defined in an appropriate way that the electrolyser has good chance to pass the test and that in a real application economic operation can be expected based on the basic characterisation tests in 1.14.1. It is assumed that

- $\mathbf{P_{low}}$ could be either in the interval [$\mathbf{P_{min\ system}}$ ... ($\mathbf{P_{min\ system}}$+0.5* ($\mathbf{P_{max\ system}}$ -$\mathbf{P_{min\ system}}$))] or at $\mathbf{P_{standby}}$ or at $\mathbf{P_{cold\text{-}standby}}$
- $\mathbf{P_{up}}$ could be in the interval [($\mathbf{P_{min\ system}}$+0.5*($\mathbf{P_{max\ system}}$ -$\mathbf{P_{min\ system}}$) … $\mathbf{P_{max\ system}}$]

$\mathbf{P_{low}}$ and $\mathbf{P_{up}}$ also need not be the same for positive and negative control power RR test.
For stand-alone grid service operation of the system the power range ($\mathbf{P_{up}}$- $\mathbf{P_{low}}$) should be ≥ 1.5 MW in most countries, usually bigger.
The test results protocol must report the selected $\mathbf{P_{low}}$ and $\mathbf{P_{up}}$.

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NOTE 2: A System that has passed the mFRR testing protocol needs not to be tested for RR testing protocols if the same levels $\mathbf{P_{low}}$ and $\mathbf{P_{up}}$ will be used. The requirements for RR test are less severe than for mFRR. However it might be considered to use different levels $\mathbf{P_{low}}$ and $\mathbf{P_{up}}$ for RR test, e.g. starting from standby state because this will be more efficient in a real application. Also the data evaluation as described here for RR might be applied accordingly to the test performed with the mFRR protocol to achieve the relevant performance indicators.

1.14.5.2 RR negative control power (electrolyser power increase upon request)

1.14.5.2.1 RR upward power conformity, from lower power level

1.14.5.2.1.1 *Test objective*

This protocol aims at verifying the concordance between consumption based on set point and real consumption.

1.14.5.2.1.2 *Test method*

Table 9 – RR upward power conformity protocol, from lower power level for RR negative control power

Step	Description	Comment
1	Set system at P_{low}	
2	Wait for system power to stabilize*	
3	Operate at this level for 1 hour	
4	At $t=t_1$, set system power to P_{low}+25% (P_{up} - P_{low})	
5	Wait until $t=t_1$+15 minutes	
6	Keep set power for 5 minutes	
7	Set system at P_{low}	
8	Wait for system power to stabilize*	
9	At $t=t_2$, set system power to P_{low}+50% (P_{up} - P_{low})	
10	Wait until $t=t_2$+15 minutes	
11	Keep set power for 5 minutes	
12	Set system at P_{low}	
13	Wait for system power to stabilize*	
14	At $t=t_3$, set system power to P_{low}+75% (P_{up} - P_{low})	
15	Wait until $t=t_3$+15 minutes	
16	Keep set power for 5 minutes	
17	Set system at P_{low}	
18	Wait for system power to stabilize*	
19	At $t=t_4$, set system power to P_{up}	
20	Wait until $t=t_4$+15 minutes	
21	Keep set power for 60 minutes	
22	At $t=t_5$, set system power to P_{low}	
23	Wait until $t=t_5$+15 minutes	
24	Keep set power for 15 minutes	
25	At $t=t_6$, set system power to P_{up}	
26	Wait until $t=t_6$+15 minutes	
27	Keep set power for 60 minutes	
28	At $t=t_7$ set power to P_{low}	
29	Wait until $t=t_7$+15 minutes	

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Step	Description	Comment
30	Wait for system power to stabilize*	
31	End of test	

*The system power is considered stable if the average power of two consecutive intervals of 60sec does not differ by more than (±5% (P_{up}-P_{low}))

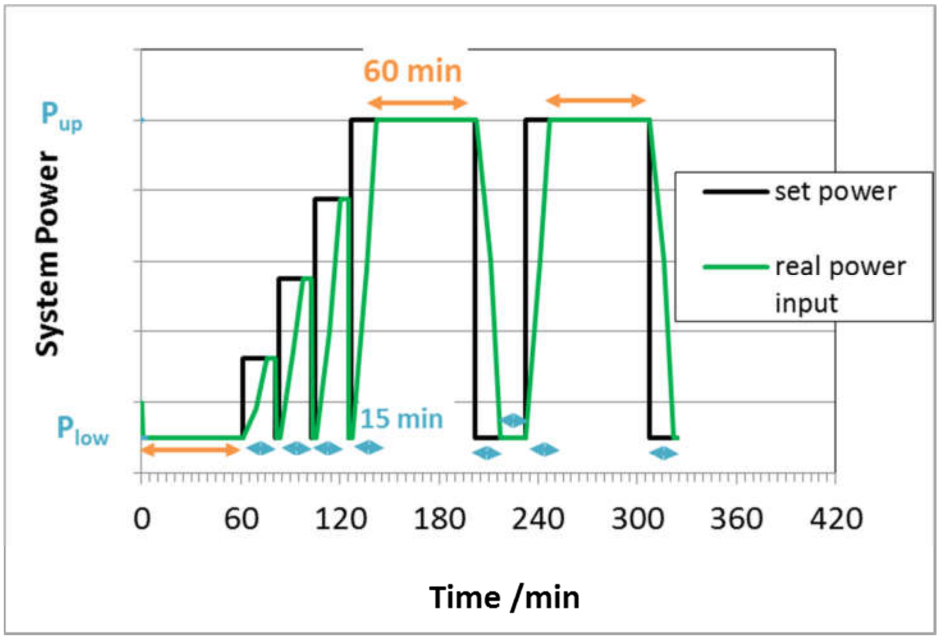

Figure 17 - Illustration of RR upward power conformity protocol, from lower power level for RR negative control power

1.14.5.3 RR positive control power (electrolyser power decrease upon request)

1.14.5.3.1 RR downward power conformity, from upper power level

1.14.5.3.1.1 *Test objective*

This protocol aims at verifying the concordance between consumption based on set point and real consumption.

1.14.5.3.1.2 *Test method*

Table 10 – RR downward power conformity protocol, from upper power level for RR positive control power

Step	Description	Comment
1	Set system at P_{up}	
2	Wait for system power to stabilize*	
3	Operate at this level for 1 hour	
4	At t=t_1, set system power to P_{up}-25% (P_{up} - P_{low})	
5	Wait until t=t_1+15 minutes	
6	Keep set power for 5 minutes	
7	Set system at P_{up}	

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Step	Description	Comment
8	Wait for system power to stabilize*	
9	At $t=t_2$, set system power to P_{up}-50% (P_{up} - P_{low})	
10	Wait until $t=t_2$+15 minutes	
11	Keep set power for 5 minutes	
12	Set system at P_{up}	
13	Wait for system power to stabilize*	
14	At $t=t_3$, set system power to P_{up}-75% (P_{up} - P_{low})	
15	Wait until $t=t_3$+15 minutes	
16	Keep set power for 5 minutes	
17	Set system at P_{up}	
18	Wait for system power to stabilize*	
19	At $t=t_4$, set system power to P_{low}	
20	Wait until $t=t_4$+15 minutes	
21	Keep set power for 60 minutes	
22	At $t=t_5$, set system power to P_{up}	
23	Wait until $t=t_5$+15 minutes	
24	Keep set power for 15 minutes	
25	At $t=t_6$, set system power to P_{low}	
26	Wait until $t=t_6$+15 minutes	
27	Keep set power for 60 minutes	
28	At $t=t_7$ set power to P_{up}	
29	Wait until $t=t_7$+15 minutes	
30	Wait for system power to stabilize*	
31	End of test	

*The system power is considered stable if the average power of two consecutive intervals of 60sec does not differ by more than (±5% (P_{up}-P_{low}))

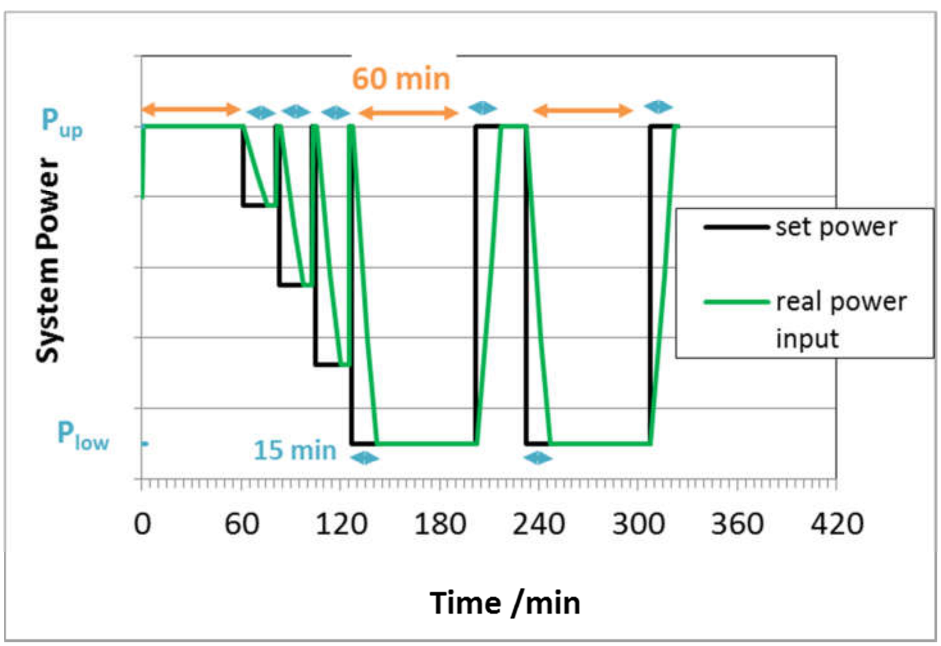

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Figure 18 - Illustration of RR downward power conformity protocol, from upper power level for RR positive control power

1.14.5.4 Data evaluation and validation for RR control power

For each step response, the test is considered as passed if the measured power achieved is equal to the target power. During the activation the power should remain in an interval of P_{up} (±5% (P_{up}-P_{low})) for negative control power and P_{low} (±5% (P_{up}-P_{low})) for positive control power, The target power must be reached after no more than 900 sec.

<u>Power stability during activation i.e. at P_{up} for negative control power and at P_{low} for positive control power:</u>
For RR negative control power determine the maximum deviation Δ_{max} from P_{up} during the full activation phases B and D (see Figure 19)
with

Phase B: period between 15 minutes and 75 minutes after step 19
Phase D: period between 15 minutes and 75 minutes after step 25

For RR positive control power determine the maximum deviation Δ_{max} from P_{low} during the full activation phases B and D
with

Phase B: period between 15 minutes and 75 minutes after step 19
Phase D: period between 15 minutes and 75 minutes after step 25

Furthermore the percentage of data points outside the interval P_{up} (±5% (P_{up}-P_{low})) during phase B and D for negative control power and the interval P_{low} (±5% (P_{up}-P_{low})) during phase B and D for positive control power is to be determined.

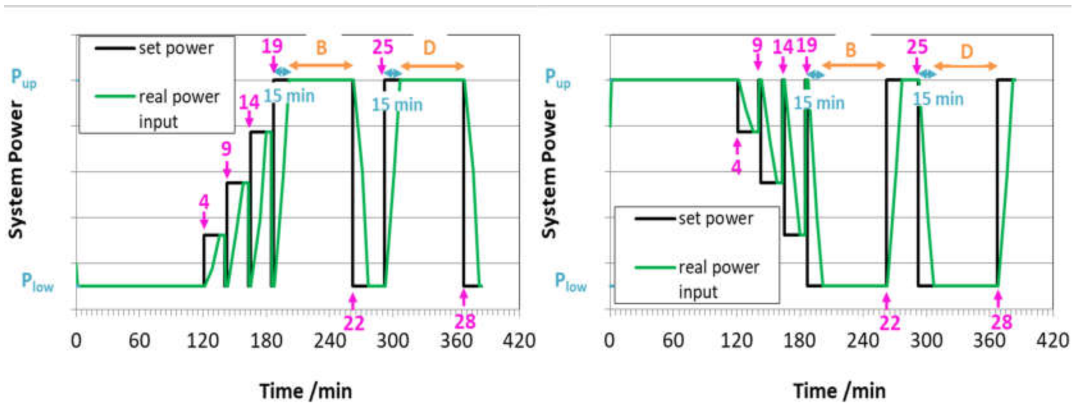

Figure 19 – Illustration of phases B and D and the starts of the ramps to be evaluated for RR negative control power (left) and RR positive control power (right).

<u>Duration of ramps:</u> The dynamics of upward and downward ramps starting with the steps 4, 9, 14, 19, 22, 25 and 28 (Figure 19) is characterised by the characteristic time for full activation and deactivation (Figure 20).

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t_{full} is the time to reach the full set step response, i.e. in a time interval of at least 2 min after the moment of reaching the full set step response the system power must be within a range of ±5%(P_{up}-P_{low})) of the target power.

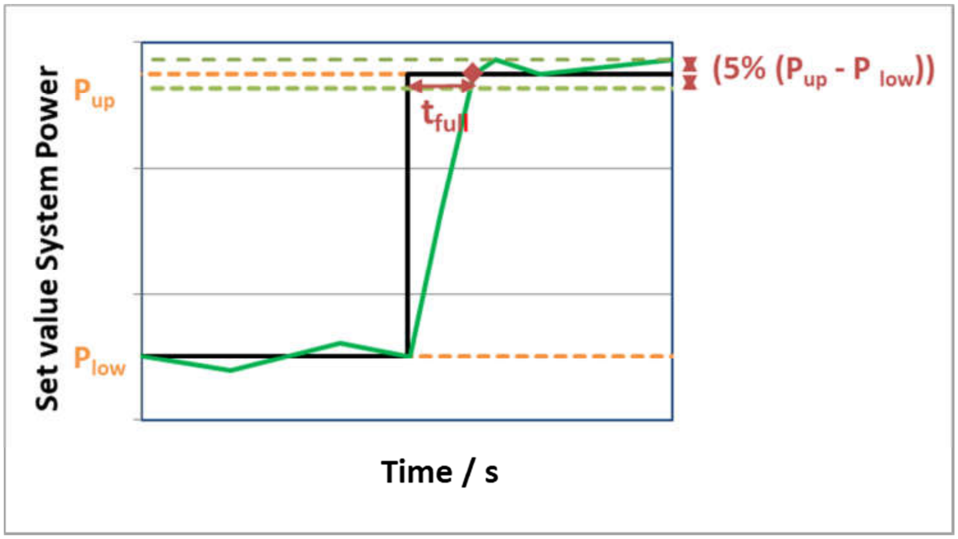

Figure 20 – Illustration evaluation of ramps up. Black full line: power set points, green full line example of real system power; ramps down and ramps between different power set levels to be treated accordingly

KPI step ramp duration: Maximum of t_{full} for ramps 2, 3, 4, 5, 6, 7, 8 and 9. Required value: ≤15 min

Performance indicator	Symbol	This system's value	TSO's requirement
Ramp duration	t_{full}	…	≤ 15 min
Stability: maximum deviation	Δ_{max}	…	≤ 0.05 (P_{up}-P_{low})
Percentage of data points outside (±5% (P_{up}-P_{low})) during full activation phase		…	
for power levels		**P_{low}**= … kW	**P_{up}**= … kW
Capacity		**ΔP= P_{up} - P_{low}** =	kW

1.14.6 DSR testing protocol

By changing or shifting consumption, Demand Side Response (DSR) is able to increase the electricity system's adequacy and to provide various kinds of grid services in an economic manner. DSR services exist in several European countries, however they have few common features and published prequalification procedures do not exist. Common to all, however, is that a large power electrical load has to reduce power on

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demand of the grid operator. The time between the signal to reduce power and the stabilisation of the system at a lower power state to reduce load in the grid goes from below 1 second to 2 hours depending on the country and the service.
For an electrolyser providing DSR service the start state will be continuous operation e.g. at nominal power input or maximum power input. Upon DSR request the power can e.g. be reduced to lowest possible continuous power operation or to standby state. To characterize the system's relevant parameters therefore the test in 1.14.1 Basic characterisation can be conducted. Also the system performance tested in the tests 1.14.2 FCR, 1.14.3 aFRR, 1.14.4 mFRR and 1.14.5 RR (positive control power) can give indications on the system's capabilities.
Characteristic parameters for DSO service provision:

- The Total Response Time Maximum Power to Minimum Power $\tau_{\mathbf{max\text{->}min}}$
- Time from nominal to standby state: $\tau_{\mathbf{down\_to\_standy}}$
- Dynamics of ramp duration for a step power change t_{full} as measured in FCR and RR tests
- Initial response time as measured in FCR protocol
- Capacity ($\mathbf{P_{up}}$- $\mathbf{P_{low}}$) used in FCR and RR tests

1.14.7 Aggregated tests

1.14.7.1 Test objective

These protocols aim at determining the system's response towards positive and negative step and ramp profiles of power, as well as the time taken for the characteristic duration times identified in aFRR, mFRR and RR prequalification tests. It is the aggregation of tests for single grid services aggregating the "up" and "down" test for each service and thereby saving some testing time because initial phases of constant system operation are not repeated. Aggregated tests should only be used if the upper and lower power level is selected as the same for positive and negative control power.

1.14.7.2 Selection of power levels

Based on the electrolyser system's basic characterisation in 1.14.1 or the manufacturer's information a lower and upper power level of the system to be used for provision of the grid service is to be defined by the operator.

Terms:
Lower power level $\mathbf{P_{low}}$
Upper power level $\mathbf{P_{up}}$

These levels are to be defined, measured and controlled at the total electrolyser system power input. If however the electrical input power to rectifier is used for the grid service and therefore as the control parameter, BOP power should be measured in parallel to the rectifier input power.

NOTE: The levels $\mathbf{P_{low}}$ and $\mathbf{P_{up}}$ need not be the same for this test as for the other grid service testing protocols. They should be defined in an appropriate way that the electrolyser has good

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chance to pass the test and that in a real application economic operation can be expected based on the basic characterisation tests in 1.14.1. It is assumed that

- P_{low} could be either in the interval [$P_{min\ system}$ ... ($P_{min\ system}$+0.5* ($P_{max\ system}$ -$P_{min\ system}$))] or at $P_{standby}$ or at $P_{cold\text{-}standby}$
- P_{up} could be in the interval [($P_{min\ system}$+0.5*($P_{max\ system}$ -$P_{min\ system}$) … $P_{max\ system}$]

P_{low} and P_{up} also need not be the same for positive and negative control power test. If it seems reasonable to use different values of P_{low} and P_{up} for the positive and negative control power application the aggregated tests cannot be used.
For stand-alone grid service operation of the system the power range (P_{up}- P_{low}) should be ≥ 1.5 MW in most countries, usually bigger.
The test results protocol must report the selected P_{low} and P_{up}.

1.14.7.3 Test method aggregated grid services tests

The two aFRR tests are merged into one with repeating parts removed and also some of the partial ramps removed and times for initial conditioning reduced.

Table 11 - Aggregated aFRR test

Step	Description	
1	Set system at P_{low}	
2	Wait for system power to stabilize*	
3	Operate at this level for 30 minutes	
4	At t=t_1, initiate linear power ramp of power (+25%(P_{up}-P_{low})) in 800 seconds	
5	t=t_1+800 seconds: end of the ramp	
6	Keep set power for 5 minutes	
7	Set system at P_{low} (the time the system needs to return to P_{low} is not evaluated)	
8	Wait for system power to stabilize *	
9	At t=t_2, initiate linear power ramp of power (+50%(P_{up}-P_{low})) in 800 seconds	
10	t=t_2+800 seconds: end of the ramp	
11	Keep set power for 5 minutes	
12	Set system at P_{low} (the time the system needs to return to P_{low} is not evaluated)	
13	Wait for system power to stabilize *	
14	At t=t_3, initiate linear power ramp of power (+75%(P_{up}-P_{low})) in 800 seconds	
15	t=t_3+800 seconds: end of the ramp	
16	Keep set power for 5 minutes	
17	Set system at P_{low} (the time the system needs to return to P_{low} is not evaluated)	
18	Wait for system power to stabilize *	
19	At t=t_4, initiate linear power ramp of power (+100%(P_{up}-P_{low})) in 800 seconds	
20	t=t_4+800 seconds: end of the ramp	
21	Keep set power at P_{up} for 15 minutes	
22	At t=t_5, initiate linear power ramp of power (-100%(P_{up}-P_{low})) in 800 seconds	
23	t=t_5+800 seconds: end of the ramp	
24	Keep set power at P_{low} for 15 minutes	
25	At t=t_6, initiate linear power ramp of power (+100%(P_{up}-P_{low})) in 800	

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	seconds	
26	$t=t_6$+800 seconds: end of the ramp	
27	Keep set power at P_{up} for 15 minutes	
28	At $t=t_7$, initiate linear power ramp of power (-100%(P_{up}-P_{low})) in 800 seconds	
29	$t=t_7$+800 seconds: end of the ramp	
30	Keep set power at P_{low} for 30 minutes	
31	At $t=t_8$, initiate linear power ramp of power (+100%(P_{up}-P_{low})) in 800 seconds	
32	$t=t_8$+800 seconds: end of the ramp	
33	Keep set power at P_{up} for 15 minutes	
34	At $t=t_9$, initiate linear power ramp of power (-25% (P_{up} - P_{low})) in 800 seconds	
35	$t=t_9$+800 seconds: end of the ramp	
36	Keep set power for 5 minutes	
37	Set system at P_{up} (the time the system needs to return to P_{up} is not evaluated)	
38	Wait for system power to stabilize *	
39	At $t=t_{10}$, initiate linear power ramp of power (-50% (P_{up} - P_{low})) in 800 seconds	
40	$t=t_{10}$+800 seconds: end of the ramp	
41	Keep set power for 5 minutes	
42	Set system at P_{up} (the time the system needs to return to P_{up} is not evaluated)	
43	Wait for system power to stabilize *	
44	At $t=t_{11}$, initiate linear power ramp of power (-75% (P_{up} - P_{low})) in 800 seconds	
45	$t=t_{11}$+800 seconds: end of the ramp	
46	Keep set power for 5 minutes	
47	Set system at P_{up} (the time the system needs to return to P_{up} is not evaluated)	
48	Wait for system power to stabilize *	
49	Keep set power for 5 minutes	
50	At $t=t_{12}$, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 5 minutes	
51	$t=t_{12}$+5 minutes: end of the ramp	
52	Keep set power for 15 minutes	
53	At $t=t_{13}$, initiate linear power ramp of power (+100% (P_{up} - P_{low})) in 5 minutes	
54	$t=t_{13}$+5 minutes: end of the ramp	
55	Keep set power for 15 minutes	
56	At $t=t_{14}$, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 133 seconds	
57	$t=t_{14}$+133 seconds: end of the ramp	
58	Keep set power for 15 minutes	
59	At $t=t_{15}$, initiate linear power ramp of power (+100% (P_{up} - P_{low})) in 133 seconds	
60	$t=t_{15}$+133 seconds: end of the ramp	
61	Keep set power for 15 minutes	
62	At $t=t_{16}$, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 133 seconds	
63	$t=t_{16}$+133 seconds: end of the ramp	

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64	Wait for system power to stabilize *	
65	Keep set power for 5 minutes	
66	At t=t_{17}, initiate linear power ramp of power (50% (P_{up} - P_{low})) in 133 seconds	
67	t=t_{17}+133 seconds: end of the ramp	
68	Keep set power for 5 minutes	
69	Set system at P_{up} (the time the system needs to reach P_{up} is not evaluated)	
70	Wait for system power to stabilize *	
71	At t=t_{18}, initiate linear power ramp of power (-50% (P_{up} - P_{low})) in 133 seconds	
72	t=t_{18}+133 seconds: end of the ramp	
73	Keep set power for 5 minutes	
74	End of test	

*The system power is considered stable if the average power of two consecutive intervals of 60sec does not differ by more than (±5% (P_{up}-P_{low}))

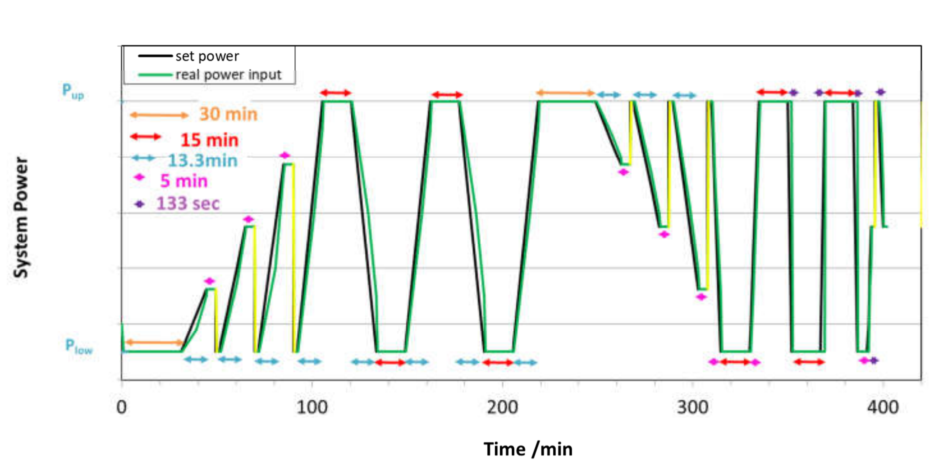

Figure 21 - Illustration of aggregated aFRR test. Not evaluated transitions are depicted in yellow line. Duration approx. 6.7h

The two mFRR tests are merged into one with repeating parts removed and also the times for initial conditioning is reduced.

Table 12 - Aggregated mFRR test

Step	Description	Comment
1	Set system at P_{low}	
2	Wait for system power to stabilize*	
3	Operate at this level for 30 minutes	
4	At t=t_1, initiate linear power ramp of power (25% (P_{up} - P_{low})) in 10 minutes	

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Step	Description	Comment
5	$t=t_1$+600 seconds: end of the ramp	
6	Keep set power for 5 minutes	
7	Set system at P_{low}(the time the system needs to return to P_{low} is not evaluated)	
8	Wait for system power to stabilize*	
9	At $t=t_2$, initiate linear power ramp of power (50% (P_{up} - P_{low})) in 10 minutes	
10	$t=t_2$+600 seconds: end of the ramp	
11	Keep set power for 5 minutes	
12	Set system at P_{low}(the time the system needs to return to P_{low} is not evaluated)	
13	Wait for system power to stabilize*	
14	At $t=t_3$, initiate linear power ramp of power (75% (P_{up} - P_{low})) in 10 minutes	
15	$t=t_3$+600 seconds: end of the ramp	
16	Keep set power for 5 minutes	
17	Set system at P_{low} (the time the system needs to return to P_{low} is not evaluated)	
18	Wait for system power to stabilize*	
19	At $t=t_4$, initiate linear power ramp of power (100% (P_{up} - P_{low})) in 10 minutes	
20	$t=t_4$+600 seconds: end of the ramp	
21	Keep set power for 60 minutes	
22	At $t=t_5$, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 10 minutes	
23	$t=t_5$+600 seconds: end of the ramp	
24	Keep set power for 15 minutes	
25	Set system at P_{up} (the time the system needs to return to P_{up} is not evaluated)	
26	Wait for system power to stabilize*	
27	Operate at this level for 10 minutes	
28	At $t=t_6$, initiate linear power ramp of power (-25% (P_{up} - P_{low})) in 10 minutes	
29	$t=t_6$+600 seconds: end of the ramp	
30	Keep set power for 5 minutes	
31	Set system at P_{up}(the time the system needs to return to P_{up} is not evaluated)	
32	Wait for system power to stabilize*	
33	At $t=t_7$, initiate linear power ramp of power (-50% (P_{up} - P_{low})) in 10 minutes	
34	$t=t_7$+600 seconds: end of the ramp	
35	Keep set power for 5 minutes	
36	Set system at P_{up}(the time the system needs to return to P_{up} is not evaluated)	
37	Wait for system power to stabilize*	
38	At $t=t_8$, initiate linear power ramp of power (-75% (P_{up} - P_{low})) in 10 minutes	
39	$t=t_8$+600 seconds: end of the ramp	
40	Keep set power for 5 minutes	
41	Set system at P_{up}(the time the system needs to return to P_{up} is not evaluated)	
42	Wait for system power to stabilize*	
43	At $t=t_9$, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 10	

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Step	Description	Comment
	minutes	
44	$t=t_9$+600 seconds: end of the ramp	
45	Keep set power for 60 minutes	
46	At $t=t_{10}$, initiate linear power ramp of power (+100% (P_{up} - P_{low})) in 10 minutes	
47	Keep set power for 15 minutes	
48	End of test	

*The system power is considered stable if the average power of two consecutive intervals of 60sec does not differ by more than (±5% (P_{up}-P_{low}))

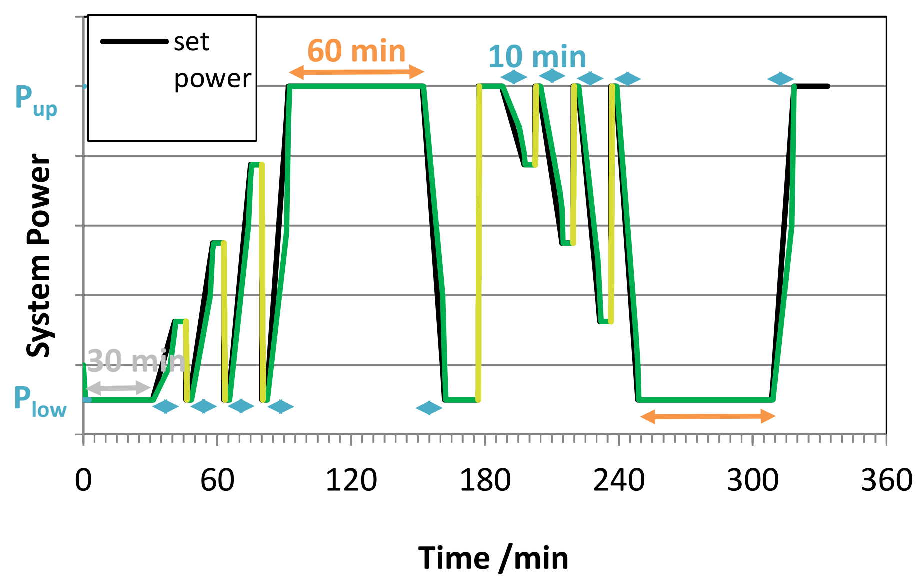

Figure 22 - Illustration of aggregated mFRR test. Not evaluated transitions are depicted in yellow line.

The two RR test are merged into one.

Table 13 - Aggregated RR test

Step	Description	Comment
1	Set system at P_{low}	
2	Wait for system power to stabilize*	
3	Operate at this level for 30 minutes	
4	At $t=t_1$, set system power to P_{low}+25% (P_{up} - P_{low})	
5	Wait until $t=t_1$+15 minutes	
6	Keep set power for 5 minutes	
7	Set system at P_{low}	

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Step	Description	Comment
8	Wait for system power to stabilize*	
9	At $t=t_2$, set system power to P_{low}+50% (P_{up} - P_{low})	
10	Wait until $t=t_2$+15 minutes	
11	Keep set power for 5 minutes	
12	Set system at P_{low}	
13	Wait for system power to stabilize*	
14	At $t=t_3$, set system power to P_{low}+75% (P_{up} - P_{low})	
15	Wait until $t=t_3$+15 minutes	
16	Keep set power for 5 minutes	
17	Set system at P_{low}	
18	Wait for system power to stabilize*	
19	At $t=t_4$, set system power to P_{up}	
20	Wait until $t=t_4$+15 minutes	
21	Keep set power for 60 minutes	
22	At $t=t_{5,}$ set system power to P_{low}	
23	Wait until $t=t_5$+15 minutes	
24	Keep set power for 15 minutes	
25	At $t=t_6$, set system power to P_{up}	
26	Wait until $t=t_6$+15 minutes	
27	Operate at this level for 30 minutes	
28	At $t=t_7$, set system power to P_{up}-25% (P_{up} - P_{low})	
29	Wait until $t=t_7$+15 minutes	
30	Keep set power for 5 minutes	
31	Set system at P_{lup}	
32	Wait for system power to stabilize*	
33	At $t=t_8$, set system power to P_{up}-50% (P_{up} - P_{low})	
34	Wait until $t=t_8$+15 minutes	
35	Keep set power for 5 minutes	
36	Set system at P_{up}	
37	Wait for system power to stabilize*	
38	At $t=t_9$, set system power to P_{up}-75% (P_{up} - P_{low})	
39	Wait until $t=t_9$+15 minutes	
40	Keep set power for 5 minutes	
41	Set system at P_{up}	
42	Wait for system power to stabilize*	
43	At $t=t_{10}$, set system power to P_{low}	
44	Wait until $t=t_{10}$+15 minutes	
45	Keep set power for 60 minutes	
46	At $t=t_{11,}$ set system power to P_{up}	
47	Wait until $t=t_{11}$+15 minutes	
48	Keep set power for 15 minutes	
49	End of test	

*The system power is considered stable if the average power of two consecutive intervals of 60sec does not differ by more than (±5% (P_{up}-P_{low}))

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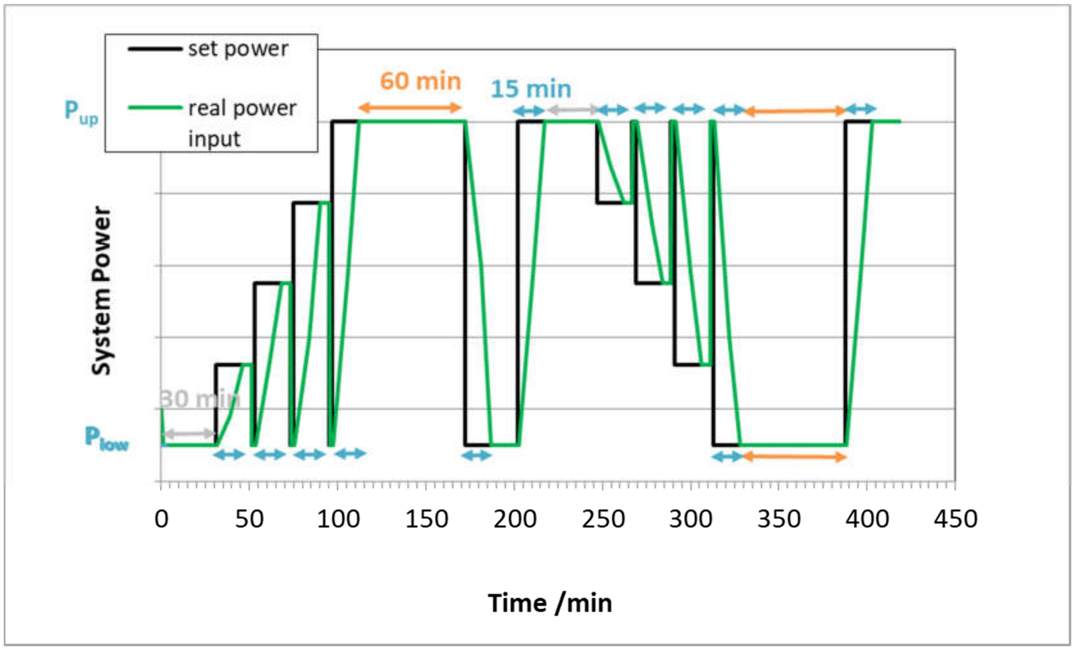

Figure 23 - Illustration of aggregated RR test. Not evaluated transitions are depicted in yellow line.

aFRR and mFRR positive and negative control power can also be tested in 1 sequence if the limiting power levels are selected the same for all services. In most cases this test can also be considered as including the RR tests.

Table 14 - Aggregated aFRR and mFRR test

Step	Description	
1	Set system at P_{low}	
2	Wait for system power to stabilize*	
3	Operate at this level for 30 minutes	
4	At $t=t_1$, initiate linear power ramp of power (+25%(P_{up}-P_{low})) in 800 seconds	
5	$t=t_1$+800 seconds: end of the ramp	
6	Keep set power for 5 minutes	
7	Set system at P_{low} (the time the system needs to return to P_{low} is not evaluated)	
8	Wait for system power to stabilize *	
9	At $t=t_2$, initiate linear power ramp of power (+50%(P_{up}-P_{low})) in 800 seconds	
10	$t=t_2$+800 seconds: end of the ramp	
11	Keep set power for 5 minutes	
12	Set system at P_{low} (the time the system needs to return to P_{low} is not evaluated)	
13	Wait for system power to stabilize *	
14	At $t=t_3$, initiate linear power ramp of power (+75%(P_{up}-P_{low})) in 800	

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	seconds	
15	t=t_3+800 seconds: end of the ramp	
16	Keep set power for 5 minutes	
17	Set system at P_{low} (the time the system needs to return to P_{low} is not evaluated)	
18	Wait for system power to stabilize *	
19	At t=t_4, initiate linear power ramp of power (+100%(P_{up}-P_{low})) in 800 seconds	
20	t=t_4+800 seconds: end of the ramp	
21	Keep set power at P_{up} for 15 minutes	
22	At t=t_5, initiate linear power ramp of power (-100%(P_{up}-P_{low})) in 800 seconds	
23	t=t_5+800 seconds: end of the ramp	
24	Keep set power at P_{low} for 15 minutes	
25	At t=t_6, initiate linear power ramp of power (+100%(P_{up}-P_{low})) in 800 seconds	
26	t=t_6+800 seconds: end of the ramp	
27	Keep set power at P_{up} for 15 minutes	
28	At t=t_7, initiate linear power ramp of power (-100%(P_{up}-P_{low})) in 800 seconds	
29	t=t_7+800 seconds: end of the ramp	
30	Keep set power at P_{low} for 15 minutes	
31	At t=t_8, initiate linear power ramp of power (+100%(P_{up}-P_{low})) in 800 seconds	
32	t=t_8+800 seconds: end of the ramp	
33	Keep set power at P_{up} for 15 minutes	
39	At t=t_9, initiate linear power ramp of power (-50% (P_{up} - P_{low})) in 800 seconds	
40	t=t_9+800 seconds: end of the ramp	
41	Keep set power for 5 minutes	
42	Set system at P_{up} (the time the system needs to return to P_{up} is not evaluated)	
43	Wait for system power to stabilize *	
49	Keep set power for 5 minutes	
50	At t=t_{10}, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 5 minutes	
51	t=t_{10}+5 minutes: end of the ramp	
52	Keep set power for 15 minutes	
53	At t=t_{11}, initiate linear power ramp of power (+100% (P_{up} - P_{low})) in 5 minutes	
54	t=t_{11}+5 minutes: end of the ramp	
55	Keep set power for 15 minutes	
56	At t=t_{12}, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 133 seconds	
57	t=t_{12}+133 seconds: end of the ramp	
58	Keep set power for 15 minutes	
59	At t=t_{13}, initiate linear power ramp of power (+100% (P_{up} - P_{low})) in 133 seconds	
60	t=t_{13}+133 seconds: end of the ramp	
61	Keep set power for 15 minutes	
62	At t=t_{14}, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 133 seconds	
63	t=t_{14}+133 seconds: end of the ramp	

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64	Wait for system power to stabilize *	
65	Keep set power for 5 minutes	
66	At $t=t_{15}$, initiate linear power ramp of power (50% (P_{up} - P_{low})) in 133 seconds	
67	$t=t_{15}+133$ seconds: end of the ramp	
68	Set system at P_{up} (the time the system needs to reach P_{up} is not evaluated)	
69	Wait for system power to stabilize *	
71	At $t=t_{16}$, initiate linear power ramp of power (-50% (P_{up} - P_{low})) in 133 seconds	
72	$t=t_{16}+133$ seconds: end of the ramp	
73	Keep set power for 5 minutes	
74	Set system at P_{up} (the time the system needs to reach P_{up} is not evaluated)	
75	Keep set power at P_{up} for 15 minutes	
76	At $t=t_{17}$, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 10 minutes	
77	$t=t_{17}+10$ minutes: end of the ramp	
78	Keep set power at P_{low} for 60 minutes	
79	At $t=t_{18}$, initiate linear power ramp of power (+100% (P_{up} - P_{low})) in 10 minutes	
80	$t=t_{18}+10$ minutes: end of the ramp	
81	Keep set power at P_{up} for 15 minutes	
82	At $t=t_{19}$, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 10 minutes	
83	$t=t_{19}+10$ minutes: end of the ramp	
84	Keep set power at P_{low} for 60 minutes	
85	At $t=t_{20}$, initiate linear power ramp of power (+100% (P_{up} - P_{low})) in 10 minutes	
86	$t=t_{20}+10$ minutes: end of the ramp	
87	Keep set power at P_{up} for 60 minutes	
88	At $t=t_{21}$, initiate linear power ramp of power (-100% (P_{up} - P_{low})) in 10 minutes	
89	$t=t_{21}+10$ minutes: end of the ramp	
90	Keep set power at P_{low} for 15 minutes	
91	At $t=t_{22}$, initiate linear power ramp of power (+100% (P_{up} - P_{low})) in 10 minutes	
92	$t=t_{22}+10$ minutes: end of the ramp	
93	Keep set power at P_{up} for 60 minutes	
94	End of test	

*The system power is considered stable if the average power of two consecutive intervals of 60sec does not differ by more than (±5% (P_{up}-P_{low}))

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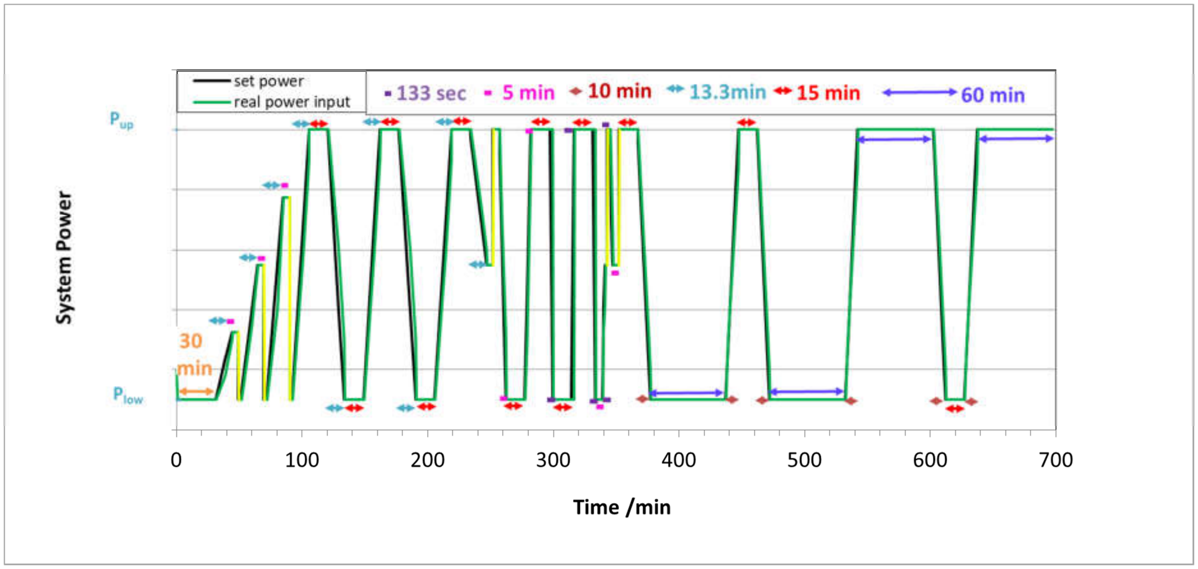

Figure 24 - Illustration of aggregated aFRR and mFRR test. Not evaluated transitions are depicted in yellow line. Total duration approx. 11.6 hours.

1.14.7.4 Data evaluation

For data evaluation follow the instructions in 1.14.3.4 (aFRR), 1.14.4.4 (mFRR) and 1.14.5.4 (RR).

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1.14.1 Performance indicators for electrolysers performing grid services

Performance Indicators	How determine from these tests	Target value
Dynamics: Ramp duration for step power change t_{full}	→maximum of all values t_{full} determined in the different protocols	10 (30) sec*
Stability in %:	→ (maximum of all values Δ_{max} in the different protocols)/(capacity P_{up}-P_{low}) *100	<5%
Initial response time	→from FCR protocol	<1.5 sec
Ramp precision: percentage of data points outside the defined range	→ maximum of (Percentage of data points outside the range for the ramps) for all tests	0-5%
Capacity	→ minimum (P_{up}-P_{low}) for all tests	>1MW
Reliability	Percentage of all tests following these protocols that were completed as described	>99%
Efficiency	Not determined in these tests	

* 10 seconds are only needed for one specialized service in the Nordic grids. In most cases 30 sec is enough if also the requirements in FCR second test are fulfilled.

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This work is supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 17.00009.

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Annex A

Requirements of Grid services in Selected EU member states and Switzerland and Norway

Source: QualyGridS Deliverable Report D1.1 Electrical Grid Service Catalogue for Water Electrolyser, published 15.11.2017, http://www.qualygrids.eu/app/uploads/sites/5/2017/02/Deliverable-1.1-Electrical-Grid-Service-Catalogue-for-Water-Electrolysers-27-11-2017.pdf, updated with the new available grid services documents (Annex D) in August 2019

Appendix 1-1 Requirements of FCR in selected EU member states and Switzerland and Norway					**FCR**			
Country (Syn-chronous area)	Capacity	Dynam-ic/Static	Symmet-rical/Asymmetrical	Preparation time	Ramping	Duration	Provider(s)	Procure-ment/Remuneration
CH (UCTE)	≥1MW	Dynamic	Symmetrical	≤1.5s	Full capacity within 30s	≤15min	Genera-tion/demand	Capacity (Pay-as-bid)
DE(UCTE)	≥1MW	Dynamic	Symmetrical	≤2s	Full capacity within 30s. half capacity within 15 s	≤15min	Generation	Capacity (Pay-as-bid, capacity price)
ES(UCTE)	All generators	Dynamic	Symmetrical	≤30s	-	≤15min	Generation	Obligatory (no remuneration)
NL(UCTE)	≥1MW	Dynamic	Symmetrical	≤2s	Full capacity within 30sec, half capacity within 15 s	≤15min (prequalification) / 8 hours real service	Generation	Mandatory for those with >5MW. Capacity. (Pay-as-bid, capacity price)
FR(UCTE)	≥1MW	Dynamic	Asymmetrical (adjustments up or down)	≤30s	Half capacity within 15s, full capacity within 30s	≥15min	Genera-tion/Demand[1,2]	Mandatory provision by all new generation capacity >= 40MW (formerly 120 MW) connected to the trans-mission grid; Capacity
DK-W(UCTE)	≥0.3MW	Dynamic	Symmetrical	≤30s	Half capacity within 15s, full capacity within 30s	≥15min	Genera-tion/Demand[1]	Capacity (marginal price) and energy(imbalance price)
DK-E(Nordic)	≥0.3MW (FCR-N and FCR-D)	Dynamic	FCR-N Symmetrical and FCR-D Asymmetrical	≤1min	150s, linearly to frequency deviation between 0 and 100mHz for FCR-N; first half 5s, second half 30s, inverse-linearly for FCR-D	≤15min	Genera-tion/Demand[1]	Capacity (Pay-as-bid) and energy(imbalance price)
Finland (Nordic)	≥1MW	Dynamic	Symmetrical	?	Full capacity within 3 min for FCR-N . Half capacity within 5 s, full capacity within 30 s for FCR-D	>30 min	Genera-tion/Demand[1]	?

Requirements of aFRR in selected EU member states and Switzerland and Norway							
Country (Syn-chronous area)	Capacity	Symmet-rical/Asymmetrical	Preparation time	Ramping	Duration	Provider(s)	Procure-ment/Remuneration
CH (UCTE)	≥5MW	Symmetrical /asymmetrical	≤20s	The gradient must be 0.5% of the normal output per second	≥15min	Genera-tion/Demand[1]	Capacity (Pay-as-bid) and energy

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DE(UCTE)	≥5MW	Asymmetrical	30 s	Full capacity within 5min	≥15min	Genera-tion/Demand1	Capacity (Pay-as-bid) and energy
ES(UCTE)	All generators except for non-manageable	Symmetrical	≤100s	-	≤15min	Generation	Marginal price (Capacity and energy)
NL(UCTE)	≥4MW	Symmetrical	≥30s	≥7%/min.	≥15min	Generation	Regulating power, market-based energy price, contracted reserve receives a pay-as-bid capcity price
FR(UCTE)	≥1MW	Asymmetrical (adjustments up or down)	≤15min	-	-	Genera-tion/Demand1,2	Compulsory contract for any new production site >120 MW, payments are according to capacity and energy.
DK-W(UCTE)	≥1MW	Symmetrical	-	Full capacity within 15min	-	Genera-tion/Demand1	Monthly auction, Capaci-ty (marginal price) and energy)
DK-E(Nordic)	≥1MW	Symmetrical	-	Full capacity within 5min	-	Genera-tion/Demand1	Monthly auction, Capaci-ty (marginal price) and energy
NO(Nordic)	≥5MW	-	30 s	Set-point capacity within 120s(or 210s)	≤30min	Generation	Capacity (marginal price) and energy

According to ENTSO-E News "*Developments on the European balancing capacity markets*" of Dec 18, 2019 (https://www.entsoe.eu/news/2019/12/18/developments-on-the-european-balancing-capacity-markets/ accessed on 14.1.2020) TSOs have submitted to Agency for the Cooperation of Energy Regulators (ACER) a proposal about RR, mFRR and aFRR capacity markets. It can be assumed that the products and rules defined in these documents:
("*All TSOs' proposal on list of standard products for balancing capacity for frequency restoration reserves and replacement reserves pursuant to Article 25(2) of Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing* " 18.12.2019, https://docstore.entsoe.eu/Documents/nc-tasks/EBGL/EB_GL_A40.1_191218_ALL%20TSOs_Co-optimised_CZC_allocation_Proposal.pdf accessed 14.1.2020
and "*Explanatory document to all TSOs' proposal on a list of standard products for balancing capacity for frequency restoration reserves and replacement reserves in accordance with Article 25(2) of Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing*", 18.12.2019, https://docstore.entsoe.eu/Documents/nc-tasks/EBGL/EB_GL_A25.2_191218_ALL%20TSOs_Standard_products_balancing_capacity_Proposal_Explanatory_doc.pdf accessed 14.01.2020)
will be very close to the rules valid in future.
For aFRR 5 different products are suggested with a **Balancing Capacity Validity Period of 15min, 1h, 4h, 1 day or 1 week** alternatively, the minimum duration between the end of deactivation period and the following activation of 0 min and **upward or downward direction** alternatively and the **minimum bid quantity and granularity of 1 MW**. The full activation time of aFRR is requested to be harmonized but no number given yet.

Requirements of mFRR in selected EU member states and Switzerland and Norway
Status 2017

Country (Syn-chronous area)	Capacity	Symmet-rical/Asymmetrical	Preparation time	Ramping	Duration	Provider(s)	Procure-ment/Remuneration
CH (UCTE)	≥5MW	Asymmetrical	-	Full capacity within 15min for Fast energy(±);	-	Genera-tion/Demand	weekly, daily, Pay-as-bid (capacity and energy)

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DE(UCTE)	-	-	-	-	-	-	-
ES(UCTE)	-	-	-	-	-	-	-
NL(UCTE)	≥4MW	Asymmetrical	≤15min	-	≥15min	Genera-tion/Demand1	Reserve power balanc-ing, (energy price)
FR(UCTE)	≥10MW	Asymmetrical	≤13min	-	≥30min	Genera-tion/Demand1	Tender-based capacity and energy
DK-W(UCTE)	≥10MW	Asymmetrical	≤15min	-	-	Genera-tion/Demand1	Capacity (marginal price) and energy
DK-E(Nordic)	≥10MW	Asymmetrical	≤15min	-	-	Genera-tion/Demand1	Capacity (marginal price) and energy
NO(Nordic)	≥10MW	Asymmetrical	≤15min	-	≥1hour	Genera-tion/Demand1	Capacity (marginal price) and energy

According to ENTSO-E News "*Developments on the European balancing capacity markets*" of Dec 18, 2019 (https://www.entsoe.eu/news/2019/12/18/developments-on-the-european-balancing-capacity-markets/ accessed on 14.1.2020) TSOs have submitted to Agency for the Cooperation of Energy Regulators (ACER) a proposal about RR, mFRR and aFRR capacity markets. It can be assumed that the products and rules defined in these documents:
("*All TSOs' proposal on list of standard products for balancing capacity for frequency restoration reserves and replacement reserves pursuant to Article 25(2) of Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing* " 18.12.2019, https://docstore.entsoe.eu/Documents/nc-tasks/EBGL/EB_GL_A40.1_191218_ALL%20TSOs_Co-optimised_CZC_allocation_Proposal.pdf accessed 14.1.2020
and "*Explanatory document to all TSOs' proposal on a list of standard products for balancing capacity for frequency restoration reserves and replacement reserves in accordance with Article 25(2) of Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing*", 18.12.2019, https://docstore.entsoe.eu/Documents/nc-tasks/EBGL/EB_GL_A25.2_191218_ALL%20TSOs_Standard_products_balancing_capacity_Proposal_Explanatory_doc.pdf accessed 14.01.2020)
will be very close to the rules valid in future.
For mFRR 7 different products are suggested:

mFRR Product	#1	#2	#3	#4	#5	#6	#7
Balancing Capacity Validity period	15 minutes		1 hour		4 hours	1 day	1 week
The minimum duration between the end of deactivation period and the following activation	0	0-8 hours	0	0-8 hours	0	0	0
Direction	Upward or downward						

The full activation time of mFRR is suggested as 12.5 min with a linear ramp of 10 min.

RR
Requirements of RR in selected EU member states and Switzerland and Norway
Status 2017

Country (Syn-chronous area)	Capacity	Symmet-rical/Asymmetrical	Preparation time	Ramping	Duration	Provider(s)	Procure-ment/Remuneration
CH (UCTE)	≥5MW	Asymmetrical, negative	-	within 20 min for Slow energy(-).	-	Genera-tion/Demand1	Pay-as-bid (capacity and energy)
DE(UCTE)	≥5MW	Asymmetrical	≤15min	Full capacity	-	Genera-	Pay-as-bid

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				within 15min		tion/Demand[1]	(capacity and energy)
ES(UCTE)	All generators except for non-manageable	Symmetrical	≤15min		≤120min	Generation	Marginal price (energy)
NL(UCTE)	≥4MW	Asymmetrical	≥75min	-	≥60min	Genera-tion/Demand[1]	Reserve Power Other purposes (energy price)
FR(UCTE)	≥10MW	Asymmetrical	30min	-	≥30min	Genera-tion/Demand[1]	Tender-based, capacity and energy.
DK-W(UCTE)	-	-	-	-	-	-	-
DK-E(Nordic)	-	-	-	-	-	-	-
NO(Nordic)	-	-	-	-	-	-	-
ENTSO-E Document Proposal of TSOs for RR standard product [10]	>1 MW	Asymmetrical	≤30 min	≤30 min	15 min-60 min		

According to the ENTSO-E News "Trans European Replacement Reserves Exchange (TERRE) project to deliver a European platform for the exchange of balancing energy from replacement reserves based on LIBRA solution live in January 2020 of Jan 9, 2020 (https://www.entsoe.eu/news/2020/01/09/trans-european-replacement-reserves-exchange-terre-project-to-deliver-a-european-platform-for-the-exchange-of-balancing-energy-from-replacement-reserves-based-on-libra-solution-live-in-january-2020/ accessed 14.1.2020) Czech Republic (ČEPS a.s), United Kingdom (National Grid ESO), Poland (Polskie Sieci Elektroenergetyczne S.A.), Spain (Red Eléctrica de España S.A.U.), Portugal (REN – Rede Eléctrica Nacional, S.A), France (Réseau de Transport d'Electricité), Switzerland (Swissgrid AG) and Italy (Terna-Rete Elettrica Nazionale SpA) will access to a common Replacement Reserves Platform in the year 2020 respectively 2022. Details can also be found in the ENTSO-E document "The proposal of all Transmission System Operators performing the reserve replacement process for the implementation framework for the exchange of balancing
energy from Replacement Reserves in accordance with Article 19 of Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing" published on 18 June 2018 (https://docstore.entsoe.eu/Documents/Network%20codes%20documents/NC%20EB/180618_RR_TSOs_RRIF_final.pdf accessed on 13 Jan. 2020).
According to ENTSO-E News "*Developments on the European balancing capacity markets*" of Dec 18, 2019 (https://www.entsoe.eu/news/2019/12/18/developments-on-the-european-balancing-capacity-markets/ accessed on 14.1.2020) TSOs have submitted to Agency for the Cooperation of Energy Regulators (ACER) a proposal about RR, mFRR and aFRR capacity markets. It can be assumed that the products and rules defined in these documents:
("*All TSOs' proposal on list of standard products for balancing capacity for frequency restoration reserves and replacement reserves pursuant to Article 25(2) of Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing* " 18.12.2019, https://docstore.entsoe.eu/Documents/nc-tasks/EBGL/EB_GL_A40.1_191218_ALL%20TSOs_Co-optimised_CZC_allocation_Proposal.pdf accessed 14.1.2020

[10] "The proposal of all Transmission System Operators performing the reserve replacement process for the implementation framework for the exchange of balancing energy from Replacement Reserves in accordance with Article 19 of Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing" published 18 June 2018 https://docstore.entsoe.eu/Documents/Network%20codes%20documents/NC%20EB/180618_RR_TSOs_RRIF_final.pdf accessed on 2019/10/31

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and "*Explanatory document to all TSOs' proposal on a list of standard products for balancing capacity for frequency restoration reserves and replacement reserves in accordance with Article 25(2) of Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing*", 18.12.2019, https://docstore.entsoe.eu/Documents/nc-tasks/EBGL/EB_GL_A25.2_191218_ALL%20TSOs_Standard_products_balancing_capacity_Proposal_Explanatory_doc.pdf accessed 14.01.2020)
will be very close to the rules valid in future.
For RR 5 different products are suggested with a **Balancing Capacity Validity Period of 15min, 1h, 4h, 1 day or 1 week** alternatively, a minimum duration between the end of deactivation period and the following activation of 0 min and **upward or downward direction** alternatively and the **minimum bid quantity and granularity of 1 MW**. The full activation time of the RR standard product is **30 minutes**. The ramping period can be from 0 to 30 minutes.

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Requirements of balancing products in UK

Note: this is based on UK information as available in August 2017. Changes in UK grid services since that time will have to be considered in an update of this document.

Function	**Products**	**Characteristics**							
		Short description	Capacity	Symmetrical/Asymmetrical	Activation time	Ramping	Duration	Provider(s)	Procurement/Remuneration
Frequency control services	Mandatory frequency response (MFR)	Obligatory service for large generators to provide primary, secondary and high frequency response.	>=100MW(National Grid) >=30MW(Scottish Power) >=10MW(Scottish Hydro)	Symmetrical for primary response	≤10s for primary response	-	20s	Obligatory for large generators	Capacity and energy
				Symmetrical for secondary response	≤30s for secondary response	-	30min		
				Asymmetrical for high frequency response	≤10s for high frequency response	-	indefinitely		
	Firm Frequency Response (FFR)	designed to complement other sources of Frequency Response and delivers dynamic or non-dynamic firm availability for primary, secondary and high frequency response.	≥10MW	Symmetrical	≤10s for primary and high frequency response, ≤30s for secondary response	-	≥30min	balancing mechanism (BM) units, dynamic and non BM, static and non BM, as well as aggregation based non BM, including generators, loads, and storage[1]	Monthly electronic tender process, different agreements for different kinds of providers.
	Frequency control by demand response(FCDM)	Relay-based automatic interruption at low frequency, i.e. 49.7Hz.	≥3MW	Asymmetrical	<=2s	-	≥30min	Demand[1]	Availability Fee (£/MW/h) is paid against the Metered Demand.
	Enhanced Frequency Response (EFR)	Dynamic, symmetric, combatting expected decrease in inertia	≥1MW	Symmetrical	≤1s	Begin producing after 0.5s in proportion to frequency deviation	≥15min	balancing mechanism (BM) units, dynamic and non BM, static and non BM, as well as aggregation based non BM[1]	Tender
Reserve	Fast reserve	Combatting sudden unexpected changes in generation or demand as secondary frequency response	≥50MW	Asymmetrical	<=2min	in excess of 25MW/min	≥15min	Generators, loads, and storage[1]	Three possible tender periods: monthly, multi-month, long-term. Multi-part payment structure, including Availability Fee (£/hr), (£/MWh) , utilization fee (£/MW/h) and holding fee (£/h).

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	Short term operating reserve (STOR)	Function as tertiary reserve	≥3MW	Asymmetrical	- <=4 hour	-	≥2hour	Generators, loads, and storage[1]	Three tender rounds each year. Multi-part payment structure, including Availability Fee (£/hr), (£/MWh) , utilization fee (£/MW/h)
	BM Start-up	Made up of M Start Up and Hot Stand-by. Applied to generators that couldn't be made available in balancing mechanism timescales due to their technical characteristics and associated lead-times.	-	-	-	-	-	Generators	-
	STOR Runway	An opportunity for Demand Side providers to secure a contract for an envelope of volume which will then be grown in their portfolio within an agreed timeframe to be delivered as new STOR volume.	≥3MW	Asymmetrical	- <=4 hour	-	≥2hour	Loads[1]	-
	Enhanced optional STOR	Provision of a volume of an Enhanced Optional STOR Service from non-BM Providers on a trial basis for winter 2017. This service creates an opportunity for National Grid to access additional non-BM volume closer to the real time.	-	Asymmetrical	<=20min	-	-	Generators, loads, and storage[1]	-
	Demand turn up	Developed to allow demand side providers to increase demand (either through shifting consumption or reducing embedded generation) as an economic solution to managing excess renewable generation when demand for electricity is low (curtailment avoiding).	≥1MW	Asymmetrical -	<5 minutes	-	Specified time windows, Time windows. ~12h per day in summer	Loads/distributed generators[1]	- Two routes to market for Demand Turn Up providers in 2017: Fixed and Flexible.

[1] Service provided by an aggregation-based portfolio is allowed.

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Status and requirements of DSR in selected EU member states and Switzerland and Norway
Status August 2017

Country (Synchronous area)	DSR status	DSR (tailored) requirements
CH (UCTE)	Individual or aggregated DSR can act in a balancing group.	No tailored DSR programs, therefore DSR are treated the same as generation technologies when providing grid services
DE(UCTE)	In principle, individual or aggregated DSR allowed in Balancing markets, but the actual share is almost none due to entry barriers. There are DSR tailored programs like immediately and quickly interruptible loads.	Immediately interruptible load, 5-200MW, automatically activated by frequency deviation or remote control, activated within 350 milliseconds for frequency-deviation controlled, within 1second for remote control , maximum duration 32x15min,
		Quickly interruptible load, 5-200MW, remote control, activated within 15min, maximum duration 32x15min,
ES(UCTE)	DSR has access only to Interruptible Load Program.	Interruptible Mainland (automatic), minimum 5MW/90MW. Three execution methods (preparation-maximum duration): a) Instant-1hour; b) Fast 15min-1hour; c) hourly 2hour-1hour,
		Interruptible Islands (automatic), minimum 5MW. Five options: a) instant -1hour; b)5min-2hour; c)1hour-3hour; d) 2hour-8hour; e) 2hour-12 hours,
NL(UCTE)	Individual or aggregated DSR can act in balancing markets (secondary and tertiary Reserve). DSR can offer balancing services to BRPs.	No tailored DSR programs, therefore DSR are treated the same as generation technologies when providing grid services.
FR(UCTE)	Individual or aggregated DSR allowed in Balancing and ancillary markets. Tailored program such as DSR-RR is also available.	DSR-RR is a tender-based manual reserve, minimum 1MW, activation time less than 2 hour, duration up to 10 hours.
DK-W(UCTE)	Balancing regulation is generation-centric but not excluding DSR. DSR can be aggregated in a balancing group, therefore accessing balancing markets and ancillary services.	No tailored DSR programs, therefore DSR are treated the same as generation technologies when providing grid services.
DK-E(Nordic)		
NO(Nordic)	DSR can be aggregated in a balancing group, therefore accessing balancing markets and ancillary services.	No tailored DSR programs, therefore DSR are treated the same as generation technologies when providing grid services.

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UK(United Kingdom)	Ancillary service market is open to DSR, also with several tailored programs.	FCDM for frequency control, STOR Runway, Demand turn up (requirements see Appendix 1-5)

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Annex B Frequency profile for FCR testing

B1 Frequency vs time data input for FRC second test

Frequency data in steps of 0.1 seconds to be used in the test of 1.14.2.4.
Real frequency profile from FinGrid frequency profile 1 December 2017 11:00-15:00h [11].

This list is available as extra file in different formats:
as an Excel-file, a csv-File or a text-file.
These files as well can be downloaded from Zenodo repository https://DOI.org/10.5281/zenodo.3913188, Files FCR_secondtest_frequency_4h_D2_4.txt, FCR_secondtest_frequency_4h_D2_4.xlsx, FCR_secondtest_frequency_4h_D2_4.csv

```
49.922
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49.92
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49.919
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...continuation in file FCR_secondtest_frequency_4h_D2_4.txt

[11] downloaded from https://data.fingrid.fi/en/dataset/frequency-historical-data

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This work is supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 17.00009.

B2 Power vs time data input for FRC second test

FCR control power data in steps of 0.1 seconds to be used in the test of 1.14.2.4 derived from the frequency profile. Numbers are given in % of the control power range with 0% corresponding to P_{low}, 50% corresponding to P_{med} and 100% corresponding to P_{up}.

This list is available as extra file in different formats:
as an Excel-file, a csv-file or a text-file. at
These files can be downloaded from Zenodo repository
https://DOI.org/10.5281/zenodo.3913188, Files FCR_secondtest_power_4h_D2_4.txt, FCR_secondtest_power_4h_D2_4.csv, FCR_secondtest_power_4h_D2_4.xlsx

```
11
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8
7.5
8
8
8
8
8
```

...continuation in file FCR_secondtest_power_4h_D2_4.txt

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B3 Envelope of permitted power range, upper and lower limit

FCR control power vs time upper and lower limit of the permitted range in steps of 0.1 seconds to be used in the test of 1.14.2.4 derived from the frequency profile. Numbers are given in % of the control power range with 0% corresponding to P_{low}, 50% corresponding to P_{med} and 100% corresponding to P_{up}.

This list is available as extra file in different formats:
as an Excel-file in
FCR_test_curve_4h_controlpower_upper_limit2020.xlsx
FCR_test_curve_4h_controlpower_lower_limit2020.xlsx
, as an ASCII-List in
FCR_test_curve_4h_controlpower_upper_limit2020.txt
FCR_test_curve_4h_controlpower_lower_limit2020.txt
and as .csv-file in
FCR_test_curve_4h_controlpower_upper_limit2020.csv
FCR_test_curve_4h_controlpower_lower_limit2020.csv
These files are available for download on the Zenodo repository with DOI number
https://doi.org/10.5281/zenodo.3912068

Time after beginning of the 4h test / sec	Lower permitted limit / (% of the power range [P_{low} .. P_{up}])	Upper permitted limit / (% of the power range [P_{low} .. P_{up}])
0.1	8.50	52.50
0.2	8.50	52.50
0.3	8.50	52.50
0.4	8.50	52.50
0.5	8.50	52.50
0.6	8.50	52.50
0.7	8.50	52.50
0.8	8.00	52.50
0.9	8.00	52.50
1.0	8.00	52.50
1.1	8.00	52.50
1.2	7.50	52.50
1.3	7.50	52.50
1.4	7.50	52.50
1.5	7.00	52.50
1.6	6.50	52.32
1.7	6.50	52.15
1.8	6.00	51.97
1.9	6.00	51.80
2.0	6.00	51.62
2.1	5.50	51.45
2.2	5.50	51.27
2.3	5.50	51.10
2.4	5.50	50.92
2.5	5.00	50.75
2.6	5.50	50.57

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2.7	5.50	50.39
2.8	5.50	50.22
2.9	5.50	50.04
…	...continuation in file FCR_test_curve_4h_controlpower_lower_limit2020.txt	...continuation in file FCR_test_curve_4h_controlpower_upper_limit2020.txt

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Annex C Test report template

Describe precisely the electrolyser system investigated.

Describe the interfaces to the test station and describe the test station.

Describe the history of use of the investigated system.

Name the testing protocol applied.

Document the control and metering solution applied to the test system. The documentation shall enable the readers /evaluators to understand

- what can and can not be controlled, e.g. current vs. power,
- what control algorithm has been applied, e.g. setpoint based, linear droop control, if the control includes feedback or not,
- limitations of the control solution, such as maximum number of setpoints can be included in a setpoint profile,
- where and what type of meters are installed, rate of accuracy, resolution of metering.

Name the characteristic values e.g, P_{up} and P_{low} and the criteria why to choose these values.

Name any deviation from the testing protocol and the reason for it.

Provide the set of all tested values vs. time as a list or a graph or both.

Give timestamps.

Give the KPIs relevant for this test.

Document the BOP power average and maximum value.

Give the file name and foulder where the electronic values of the test results are stored.

Optionally give the time series or graph for any other parameter of the system registered during the test, especially hydrogen production, hydrogen quality, stack voltage, stack current, stack temperature, … This data might be useful for identifying economic operation and learning about the electrolyser system's component's state.

Report the ambient temperature during the test.

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Annex D (informative) Grid service prequalification procedures of the individual European countries by service

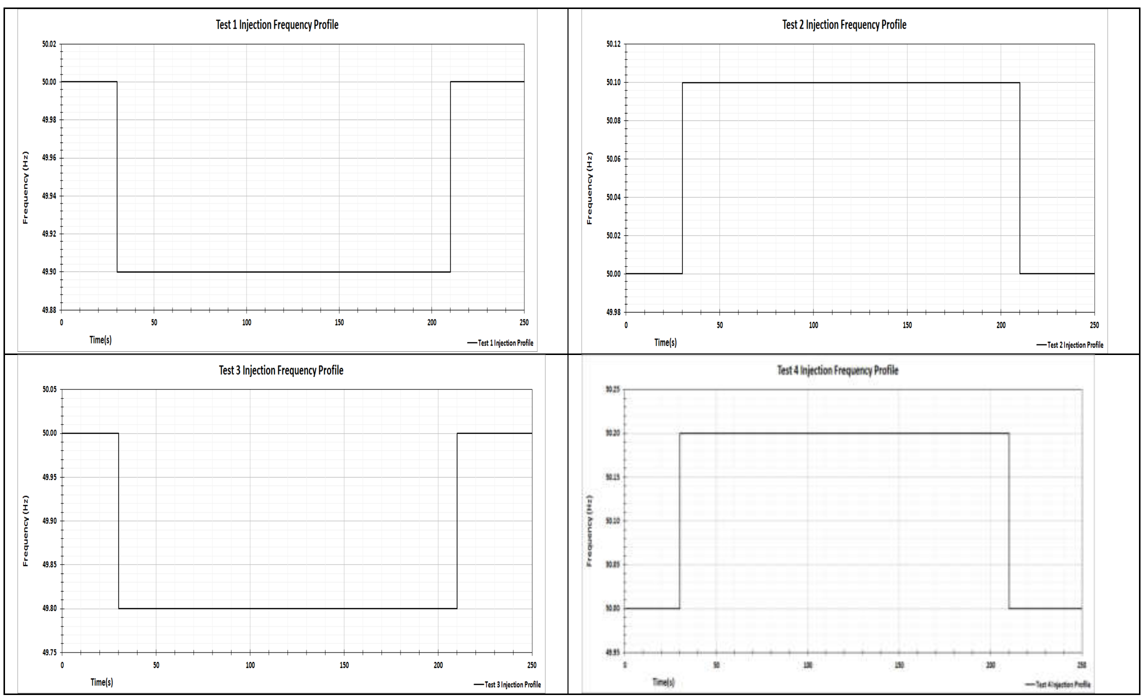
On 2 August 2017 EU published the Commission Regulation (EU) 2017/1485 “establishing a guideline on electricity transmission system operation” and on 23 November 2017 the Commission regulation (EU) 2017/2195 “establishing a guideline on electricity balancing”. This has set the basis for further unification of electricity grid services in the EU countries, causing changes to the relevant directives in most of the countries. However this document still leaves some flexibility to the products so that still there are significant deviations between the countries. The updated definitions of grid services and prequalification procedures are given in this Annex D.

Annex-D-1 Injection profiles for Prequalification of Frequency Control (UK)

An electrolyzer that qualifies for some of the prequalification tests presented in this document (especially FCR and aFRR) could potentially perform FFR and EFR services in the UK.

https://www.nationalgrideso.com/document/148811/download FFR July 2019

https://www.nationalgrideso.com/document/88766/download EFR



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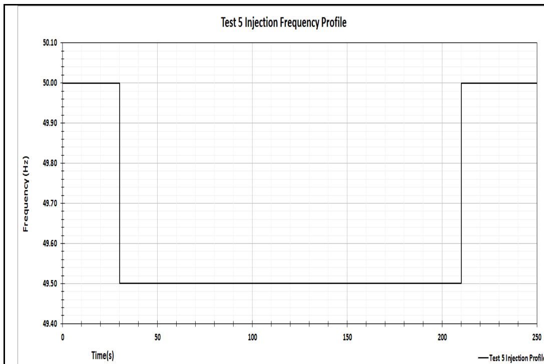

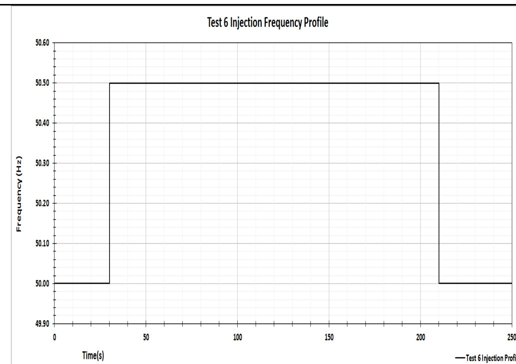

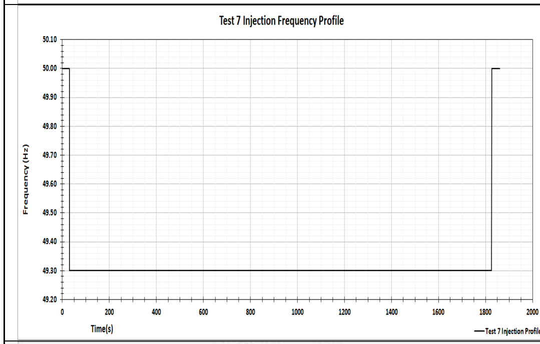

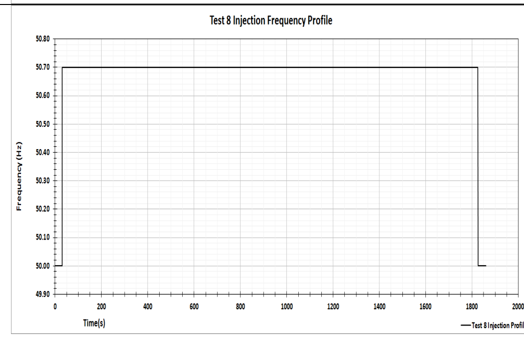

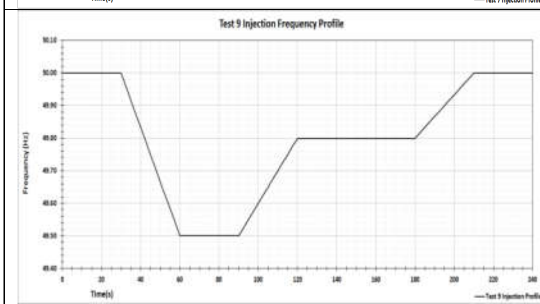

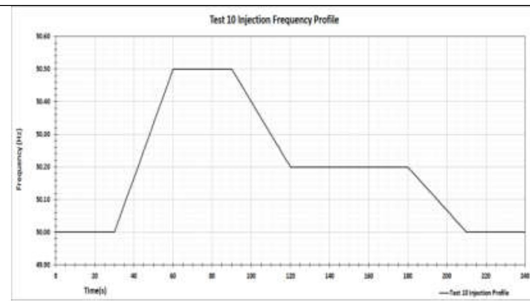

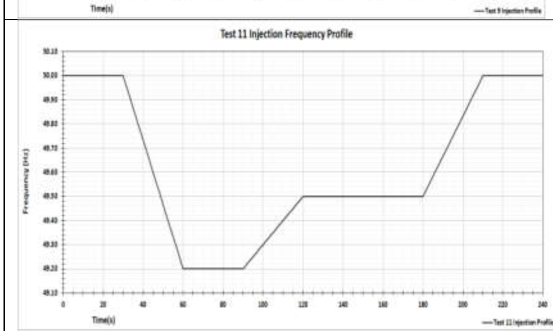

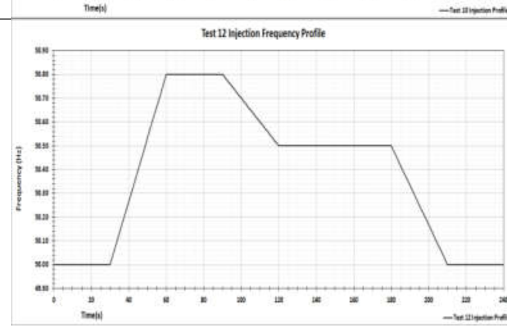

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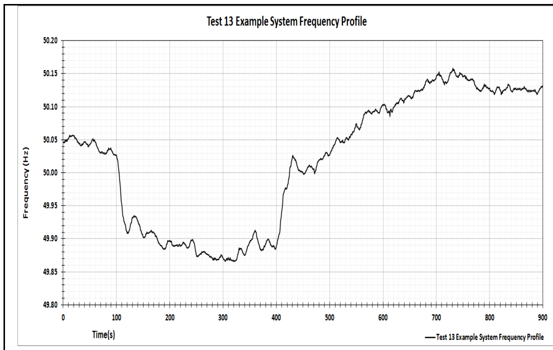

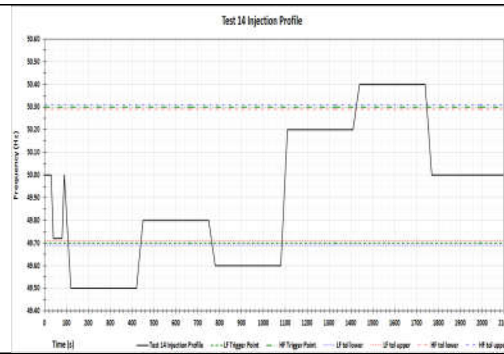

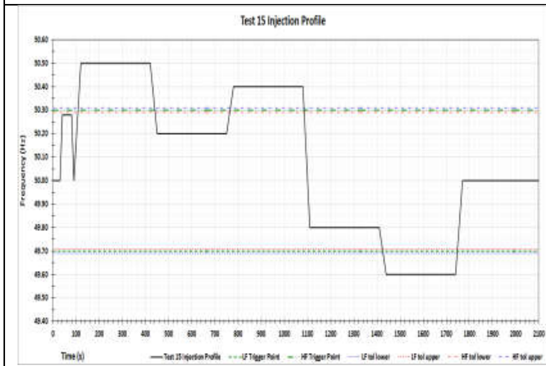

These 15 test signals are combined in different ways to test the performance of various technical characteristics, such as Speed of Response Delivery (T1-T8), Proportionality of Response (T1-T12), and Sustainability of Response (T7-T8 for dynamic services and T14-T15 for static services). Detailed requirements can be found in

- National Grid, "DSR Testing Consultation", 2016, Dec. accessed Aug. 2017 http://www2.nationalgrid.com/uk/services/balancing-services/frequency-response/firm-frequency-response/
- National Grid, "Enhanced Frequency Response: Invitation to tender for pre-qualified parties", 2016, July, V2.2. accessed Aug. 2017 http://www2.nationalgrid.com/WorkArea/DownloadAsset.aspx?id=8589934901
- National Grid, "Short Term Operating Reserve (STOR): Tender Assessment Principles", 2013, Dec, V4.0. accessed Aug. 2017 http://www2.nationalgrid.com/WorkArea/DownloadAsset.aspx?id=28065.

Annex-D-2 Pre-qualification test Primary and Secondary Frequency Control (CH)

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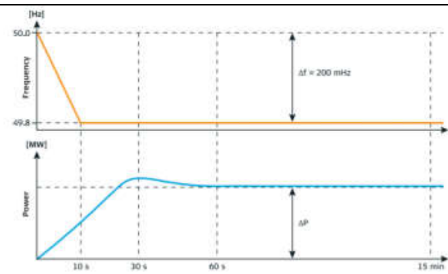
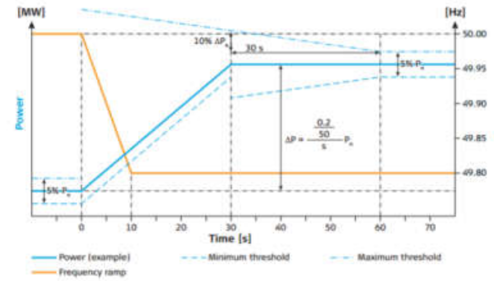
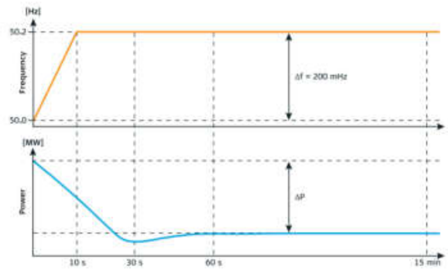


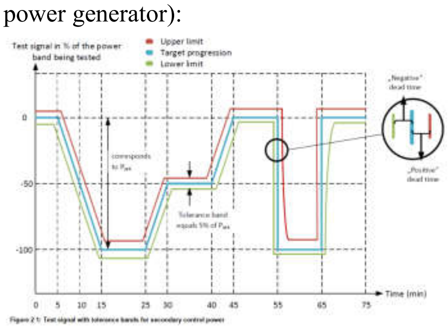




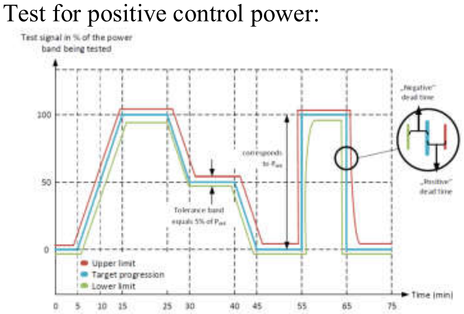
The test for Primary Frequency Control constitutes ideal testing signals indicated by left figure, with recorded performance characteristics must be within the tolerance limits indicated by the figure above. "Test for Primary Control Capability", 26.04.2011 downloaded from https://www.swissgrid.ch/dam/swissgrid/customers/topics/ancillary-services/prequalification/3/D110426-test-for-primary-control-capability-V1R1-EN.pdf on 2019/08/16Requirements for the technical setup include

- Accuracy of the transformer: < 0.5 % (of the nominal value, where possible Class 0.1)
- Metering time period: 100 ms
- Recording period: ≤ 30 min
- Nominal frequency: < 5 mHz

Test for negative control power (assuming a power generator):



Test for positive control power:



Test signal with tolerance band for Secondary Frequency Control: Signal is issued by grid operator. The difference between the maximum and the minimum power should be at least 60 % of the nominal output P_n, must be greater than 10 MW and should be aligned with the secondary control power subsequently offered.

"Test for secondary control capability" Swissgrid, update of 30.11.2017

https://www.swissgrid.ch/dam/swissgrid/customers/topics/ancillary-services/prequalification/4/D171130-Test-for-secondary-control-capability-V3R0-EN.pdf downloaded 2019/08/22

During the test, the data from the generating unit must be recorded at a time resolution of at least 10 s, although Swissgrid recommends a time resolution of 2s:

Evaluation of the tolerance bands:

The actual power of the generating unit must be within tolerance bands superimposed on the test signal sent by Swissgrid in accordance with the red and green lines in the figures. At each increase in power, the nominal minimum control power is calculated with the help of a PT1 element(**). In addition, an amplitude band is applied around the target sequence and the following parameters defined:

- «Negative» dead time: 10 s[12]
- «Positive» dead time: 20 s
- Amplitude band: 5 % of the secondary control power to be provided Psek

All values in excess of the band are added together and

[12] The «negative» dead time is primarily relevant for synchronisation of the time stamp. Since the time resolution of the meter data is usually 10 s, a different time stamp can only be offset with an accuracy of 10 s based on the frequency. If the time stamp were to deviate forwards by 7 s, for example, and assuming no delay over the signal path, the generating unit would always react 7 s before the test signal. This offsets the «positive» dead time

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	applied across the entire test signal. They must be no more than 1 % of the total surface from the length of the pre-qualification test multiplied with the prequalified power. Formula (1) illustrates this process. $t_t \cdot \sum_{i=0}^{i=t_d/t_t} \lvert P_{diff}(i) \rvert \leq 0.01\, P_{sek}\, t_d$ (1) where: • P_{sek} Difference between maximum and minimum secondary control power • $P_{diff}(i)$ Values in excess of the band i • t_d Test duration • t_t Sampling rate (**) The time constant of the PT1 element is calculate in accordance with formula (2). For every generating unit, the initial gradient must be at least 0.5 % of the nominal output per second. $T_1 = \frac{P_{sek}}{P_n}\frac{1}{0.005}$ (2) The time-discrete progression of the PT1 element is described by formula (3). $L_i = \frac{1}{1+\frac{T_1}{t_t}}\left(\frac{T_1}{t_t}L_{i-1} + S_i\right)$ (3) Where: • L_i Limit at time point i • S_i Signal from Swissgrid at time point I, delayed by the respective dead time from the respective target progression • t_t Sampling interval

Annex-D-3 Pre-qualification test FCR and aFRR (TENNET for NL)

FCR Prequalification tests: a) At a power setting between minimum net power and maximum net power, established in consultation with TenneT, the full power reduction must be achieved within 30 seconds at a simulated frequency step of +200 mHz. The power change shall be then maintained for at least 15 minutes, after which a simulated frequency step shall be made to 0 mHz deviation (in relation to the nominal frequency). For each of the two frequency steps, the power change must meet the requirements set out in section 6.1.4, paragraph A and paragraph B. b) At the power setting stated under a), the full power increase must be achieved within 30 seconds at a simulated frequency step of -200 mHz. The power change shall be maintained for at least 15 minutes, after which a simulated frequency step shall be made to 0 mHz deviation (in relation to the nominal frequency). For each of the two frequency steps, the power change must meet the requirements set out in section 6.1.4, paragraph A and paragraph B. c) At the power setting stated under a), half of the power reduction must be realised in 30 seconds at a simulated frequency step of +100 mHz. The power change shall be maintained for at least 15 minutes, after which a simulated frequency step shall be made to 0 mHz deviation (in relation to the nominal frequency). For each of the two frequency steps, the power change must meet the requirements set out in section 6.1.4, paragraph A and paragraph B. d) At the power setting stated under a), the full power increase must be achieved within 30 seconds at a simulated frequency step of -100 mHz. The power change shall be maintained for at least 15 minutes, after which a simulated frequency step shall be made to 0 mHz deviation (in relation to the nominal frequency). For each of the two frequency steps, the power change must meet the requirements set out in section 6.1.4, paragraph A and paragraph B.	FCR Manual for BSPs. Requirements and procedures for supply of FCR. Tennet 2019/07/01 downloaded from https://www.tennet.eu/fileadmin/user_upload/SO_NL/Handboek_FCR_voor_BSPs_01.pdf on 2019/08/19

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e) At the power setting stated under a) the frequency steps enlisted below must be simulated successively. For each frequency step, the power change must meet the requirements set out in section 6.1.4,paragraph A and paragraph B. ○ Frequency deviation = 0, at the beginning of the test. ○ Frequency step shall be made to +50 mHz deviation (in relation to the nominal frequency), the corresponding power change shall be maintained for at least 15 minutes. ○ Frequency step shall be made to +200 mHz deviation (in relation to the nominal frequency), the corresponding power change shall be maintained for at least 15 minutes. ○ Frequency step shall be made to 0 mHz deviation (in relation to the nominal frequency). f) At the power setting stated under a) the following frequency steps must be simulated successively. For each frequency step, the power change must meet the requirements set out in section 6.1.4, paragraph A and paragraph B. ○ Frequency deviation = 0, at the beginning of the test. ○ Frequency step shall be made to -50 mHz deviation (in relation to the nominal frequency), the corresponding power change shall be maintained for at least 15 minutes. ○ Frequency step shall be made to -200 mHz deviation (in relation to the nominal frequency), the corresponding power change shall be maintained for at least 15 minutes. ○ Frequency step shall be made to 0 mHz deviation (in relation to the nominal frequency). g) At the power setting stated under a), a steady power decrease of the full power must be realised in 2 minutes at a simulated steadily increasing frequency deviation of 0 mHz to +200 mHz. After the power set point due to the power change has been reached (corresponding to a frequency deviation of +200mHz) and the supply is stable, then the simulated frequency deviation will steadily return to 0 mHz in 2 minutes. For each of the two equal changes in simulated frequency steps, the power change must meet the requirements set out in section 6.1.4, paragraph A. The power changes must be linear and be fully achieved within 2.5 minutes (max 30-second lag in simulated frequency response). h) At the power setting stated under a), a steady power increase up to full power must be achieved in 2 minutes where there is a simulated steadily decreasing frequency deviation of 0 mHz to -200 mHz. After the power set point due to the power change has been reached (corresponding to a frequency deviation of -200 mHz) and the supply is stable, then the simulated frequency deviation will steadily return to 0 mHz in 2 minutes. For each of the two equal changes in simulated frequency steps, the power change must meet the requirements set out in section 6.1.4, paragraph A. The power changes must be linear and be fully achieved within 2.5 minutes (max 30-second lag in simulated frequency response). i) Once the above tests have been completed satisfactorily, the RPU/RPG shall follow the frequency for 8 hours under normal operational conditions. This final test is needed to be able to assess the quality of the frequency support. **Conditions:** Initial response time no more than 2 sec. Overshoot (only in the direction of the requested power change) of the power change may not exceed 20% of the required response. The overshoot may not detract the activation obligation. For step tests: 1) At least 50% of the power change corresponding with the simulated frequency change must be supplied within 15 seconds from the beginning of each frequency step. 2) The power change corresponding with the simulated frequency change must be supplied within 30 seconds from the beginning of each frequency step. 3) The power change should behave at least linearly between 15 and 30 seconds after each frequency step.	
aFRR: aFRR bids must be able to ramp up or down by at	Product information automatic Frequency Restoration Reserve.

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least 7% of the bid volume per minute. A bid can be activated fully or partially during the timespan of the ISP (Imbalance Settlement Period, 15 min) to which the bid applies. An observable power change is expected within 30 seconds after a setpoint change.	Tennet, 2018/12/18 downloaded from https://www.tennet.eu/fileadmin/user_upload/SO_NL/aFRR_-_Product_information_aFRR_2018-12-18.pdf on 2019/08/19

Annes-D-8 Pre-qualification test (Norway):
Presently (August 2019) no valid prequalification procedure can be found in the published files of TSO Statnett. There are some documents suggesting future activities in the frame of ENTSO-E and Nordic collaboration e.g. https://www.statnett.no/globalassets/for-aktorer-i-kraftsystemet/utvikling-av-kraftsystemet/nordisk-frekvensstabilitet/fcr-d-design-of-requirements--phase-2.pdf).
https://www.statnett.no/globalassets/for-aktorer-i-kraftsystemet/utvikling-av-kraftsystemet/implementeringsplan-ikt-kort-sikt---systemdrifts--og-markedsutvikling-020519.pdf indicates a planned transition in prequalification in 2019

FCR "Vilkår for tilbud, aksept, rapportering og avregning i marked for FCR, Gjeldende fra 08.05.2019" (Translations: Terms for quotation, acceptance, reporting and settlement in the FCR market) downloaded from https://www.statnett.no/globalassets/for-aktorer-i-kraftsystemet/reservemarkeder/fcr-vilkar-gjeldende-fra-08.05.2019.pdf on 2019/08/21. The document is referring to: "AGREEMENT (Translation) regarding operation of the interconnected Nordic power system (System Operation Agreement) 2006/06/13 "Appendix 6 of System Operation Agreement 4 (9), 2013-04-25, downloaded from https://docstore.entsoe.eu/Documents/Publications/SOC/Nordic/System_Operation_Agreement_2014.pdf on on 2019/08/21	
Frequency Containment Reserve for Normal Operation FCR-N:	Frequency controlled normal operating reserve (FCR-N): activated automatically at frequency deviation ± 0.1 Hz. FCR-N is a **symmetrical** reserve, which should be able to deliver up and down regulation. FCR-N full activation for ±0.1 Hz, proportional at lower frequency deviation. 50% of the contribution must be regulated within 5 sec after measured frequency deviation. 100% of the contribution must be regulated within 30 s after measured frequency deviation. (in contradiction to this the Appendix 6 document says *"activated automatically within a ±0.1 Hz deviation and shall be regulated out within 2-3 minutes")* Frequency measurement must have measurement accuracy of at least 0.01% (5 mHz). There should be no active dead band (measurement / activation) that prevents the activation of frequency backlog
Frequency Containment Reserve for Disturbances FCR-D	Automatically activated at 49.9 Hz and is fully activated at 49.5 Hz with resultant activation according to requirements in FIKS (production) or Appendix 1 (consumption). FCR-D only contributes to **up-regulation**. At least 50 %

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shall be regulated out within 5 s and 100 % within 30 s.

aFRR

"Vilkår for tilbud, aksept, rapportering og avregning i sekundærreservemarkedet, Gjeldende fra 01.07.2019" (translation: Terms for quotation, acceptance, reporting and settlement in the secondary reserve market, Applicable from 01.07.2019), downloaded from https://www.statnett.no/globalassets/for-aktorer-i-kraftsystemet/systemansvaret/reservemarkeder/vilkar-for-sekundarreserver-afrr-gjeldende-fra-072019.pdf on 2019/08/20. Document refers to ""Appendix 1: Technical Product Specification For delivery of Frequency Restoration Reserves to Statnett" January 2012" downloaded https://www.statnett.no/globalassets/for-aktorer-i-kraftsystemet/systemansvaret/reservemarkeder/lfc-technical-product-specification.pdf on 2019/08/20

Reserve capacity is purchased separately for up and down regulation parameters that form the FRR Unit response.

Block Size	5 MW	Minimum value; every set-point is a multiple of this. N:B Statnett have changed this from 10MW according to Nordic harmonization
Delivery time	**120 s**	Maximum value, N.B Statnett **may request a longer time period up to 210 s** should Nordic harmonisation require it.
Delay	30 s	Maximum value
Duration	30 Min	The maximum duration of a single set-point[1]
Maximum step	20 MW	This is the maximum step required from a provider in single set-point change
Ramp rate	N/A	Not specified dependent on Block size and Delivery time, note the Block is Provider defined.
Set-point signal rate	10s	Cycle time of Statnett EMS
Turn time limit	60 s	
Minimum change per Unit	5 MW	A set-point change from the AGC to a single generator should not be less than this value. [to ensure accuracy in activation]

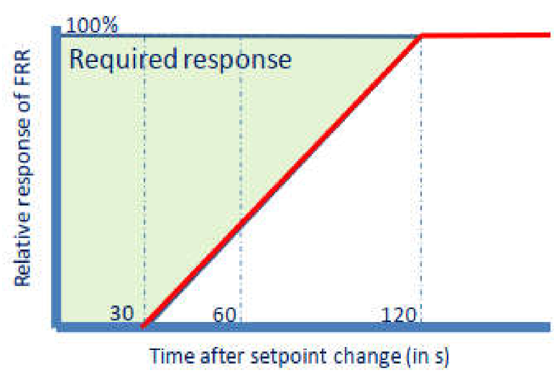

Figure 1- Required response required

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Annex-D-5 Pre-qualification test (FR)
"Documentation Technique de Reference, Chapitre 8 – Trames types, Article 8.3 – Cahier des charges des capacités constructives pour une installation de production raccordée au RPT", Version applicable a compter du 16 octobre 2017 downloaded from https://clients.rte-france.com/lang/fr/clients_producteurs/mediatheque_client/dtr.jsp on 2019/08/22

FCR

Test 1:

- unit at max power ($P_{maximum\ groupe}$, maximum power notwithstanding the reserved power for FCR/FRRa)
- Injection of an artificial echelon of Δf = -200mHz for 15 minutes at the speed regulator

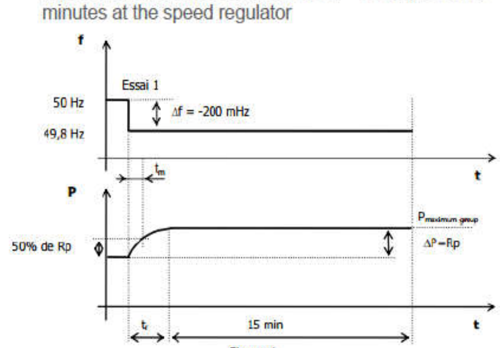


Figure 1

- t_m: time to obtain 50% of Rp
- t_r: time to obtain 95% of Rp

Test 2:

- unit at max power ($P_{maximum\ groupe}$, maximum power notwithstanding the reserved power for FCR/FRRa)
- Injection of an artificial echelon of Δf = +200mHz at the speed regulator

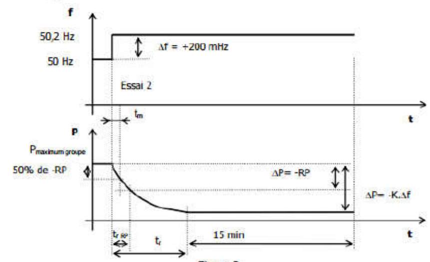


Figure 2

- t_m: time to obtain 50% of -Rp
- $t_{r\ RP}$: time to obtain -Rp
- t_r: time to obtain 95% of –K.Δf

with K: regulating energy of the group (MW/Hz)
Δf: echelon used

Test 3:

- unit at max power ($P_{maximum\ groupe}$, maximum power notwithstanding the reserved power for FCR/FRRa)
- Injection of an artificial echelon of -50mHz at the speed regulator

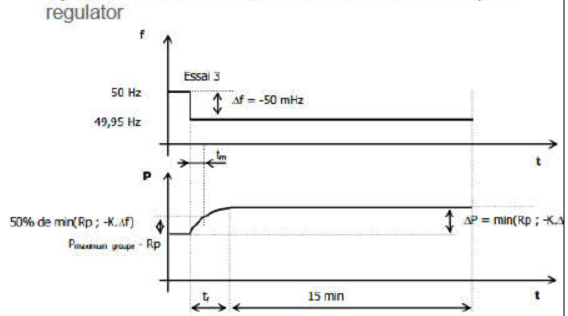


Figure 3

- tm: time to obtain 50% of min(Rp; –K.Δf)
- t_r: time to obtain 95% of min(Rp; –K.Δf)

Test 4:

- Same as test 3 with an echelon of Δf = -15mHz

Test 5:

unit at max power ($P_{maximum\ groupe}$, maximum power notwithstanding the reserved power for FCR/FRRa)

Injection of an artificial echelon of +50mHz at the speed regulator

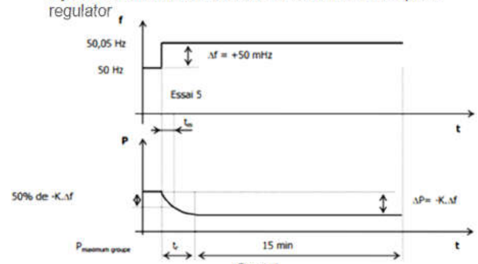


Figure 4

tm: time to obtain 50% of –K.Δf

t_r: time to obtain 95% of –K.Δf

Test 6:

Same as test 5 with an echelon of Δf =+15mHz

Test 7:

unit at min power ($P_{min\ groupe}$)

Injection of an artificial echelon of -50mHz at the speed regulator for 15 min

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 735485. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme and Hydrogen Europe and N.ERGHY
This work is supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 17.00009.

Compliance criteria:

Non oscillating waveform response

Time t_r < 30 sec. for all tests except test 2

Time t_r < 30+20 sec. for test 2 (if –K.Δf ≥ -RT)

Time t_m <15 sec.

For test 1: the variation ΔP=Rp maintained for 15 minutes (after t_r)

For tests 2 and 5: the variation ΔP= -K.Δf maintained for 15 minutes (after t_r)

For tests 3 and 7: the variation ΔP=min(Rp; -K.Δf) maintained for 15 minutes (after t_r)

For tests 4 and 6: the variation ΔP ≥ 0.005*K MW maintained 15 min (after t_r)

For tests 2, 3 and 5, the recordings must prove that regulating energy K measured = regulating energy preset within 5%.
The regulating energy K is calculated thanks to the test 2 and is equal to $\frac{(P-P_{co})}{(f_0-f)}$ $ie. \frac{\Delta P}{\Delta f}$

aFRR

Test 1:

Group at its max power ($P_{maximum\ groupe}$) at which is subtracted the FFRa range 2*Pr

Artificial injection of a ramp for the parameter N from -1 to +1 (see figure 1) in 800 seconds and sustain the +1 level for 15 minutes

Test 2:

Group at its max power ($P_{maximum\ groupe}$)

Artificial injection of a ramp for the parameter N from +1 to -1 (see figure 1) in 800 seconds and sustain the -1 level for 15 minutes

Test 3:

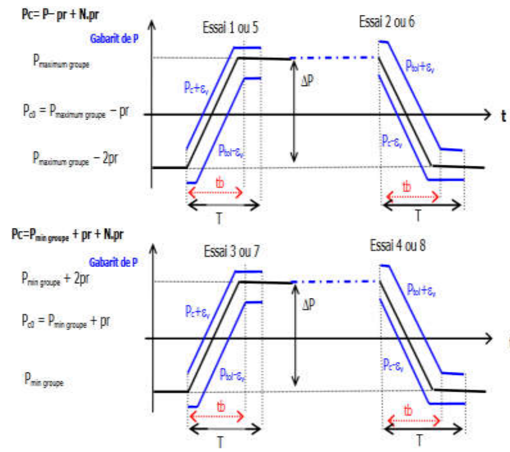
Group at its minimum power ($P_{min\ groupe}$)

Artificial injection of a ramp for the parameter N from -1 to +1 (see figure 1) in 800 seconds and sustain the +1 level for 15 minutes

Test 4:

Group at its minimum power ($P_{min\ groupe}$) at which is added the FFRa range 2*Pr

Artificial injection of a ramp for the parameter N from +1 to -1 (see figure 1) in 800 seconds and sustain the +1 level for 15 minutes



Test 5:

- Same as test 1 but with a variation time of 133s instead of 800s.

Test 6:

- Same as test 2 but with a variation time of 133s instead of 800s.

Test 7:

- Same as test 3 but with a variation time of 133s instead of 800s.

Test 8:

- Same as test 4 but with a variation time of 133s instead of 800s.

ε_v: uncertainty on the active power mesure, equal to max(1 MW ; 5% Pr)

tb: time response to attain the FFRa fully

T: time of the ramp augmented by 100s

P_{tol}: $P_c/(1+T_{max}*p)$ (Filtering the set point by a time constant)

Compliance criteria:

For each test:

- Non oscillating waveform response as shown is figure 1
- ΔP=2*Pr

For positive ramps (tests 1,3,5 and 7):

- The measured power must be within the [Pc+ ε_v;P_{tol} - ε_v] range at least 95% of the time
- Pc=P0 + N*Pr
- $P_{tol} = P_c/(1+T_{max}*p)$
- T max=20sec.
- ε_v = max(1 MW ; 5% Pr)

For negative ramps (tests 3,4,6 and 8):

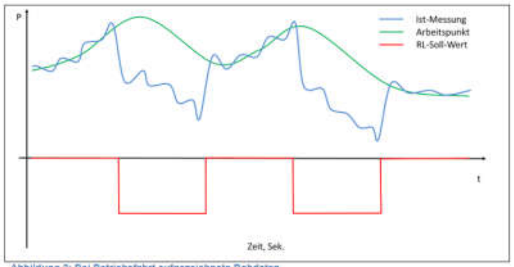
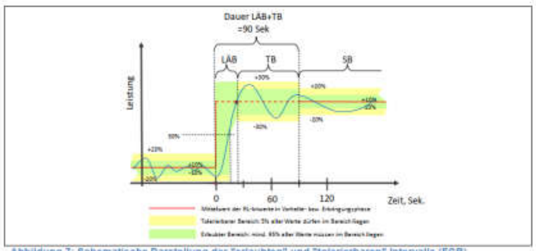
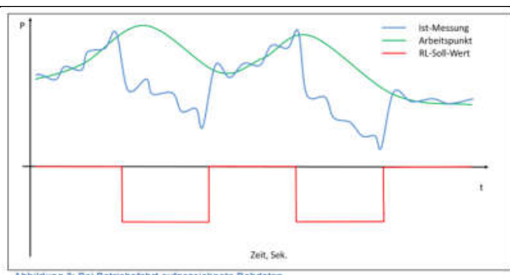
- The measured power must be within the [Pc- ε_v;P_{tol} +ε_v] range at least 95% of the time
- Pc=P0 + N*Pr
- $P_{tol} = P_c/(1+T_{max}*p)$
- T max=20sec.
- ε_v = max(1 MW ; 5% Pr)

The FFRa must be maintained for 15 minutes

Annex-D-6 Pre-qualification test (DE)
„Neue PQ-Bedingungen“ downloaded from

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 735485. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme and Hydrogen Europe and N.ERGHY
This work is supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 17.00009.

https://www.regelleistung.net/ext/download/PQ_Bedingungen_FCR_aFRR_mFRR/ Neue PQ-Bedingungen - 23.05.2019.pdf on 2019/08/19

FCR	
 Abbildung 2: Bei Betriebsfahrt aufgezeichnete Rohdaten Ist-Messung=measured value; Arbeitspunkt=planned operating point; RL-Soll-Wert=grid service set value  Abbildung 7: Schematische Darstellung der "erlaubten" und "tolerierbaren" Intervalle (FCR) Mittelwert der RL-Istwerte in Vorhalte- bzw. Erbringungsphase= mean value of grid service real values during period with or without activation of grid service. Tolerierbarer Bereich=tolerated region. Erlaubter Bereich=allowed region. Zeit, Sek.=time in sec. Leistung = power. LÄB Laständerungsbereich=period of power change. TB Transienter Bereich=transient period. SB Stationärer Bereich=stationary period.	Activation of the FCR unit no more than 2 sec after frequency deviation. Given a reaction time RT of the unit of T_{RZ} Sekunden, the minimum FCR real power $P(t)_{FCR}$ at time t seonds after the frequency deviation is $P(t)_{FCR} = 0$ für t in period $0 \le t \le T_{RT}$ $P(t)_{FCR} = P_{PQ} \cdot \frac{\Delta f}{200mHz} \cdot \frac{t-T_{RZ}}{2\cdot(15\,s-T_{RZ})}$ for $T_{RZ} \le t \le 15s$ $P(t)_{FCR} = P_{PQ} \cdot \frac{\Delta f}{200mHz} \cdot \frac{t}{30\,s}$ for $15s \le t \le 30s$ $P(t)_{FCR} = P_{PQ} \cdot \frac{\Delta f}{200mHz}$ for $t > 30s$ In case of a frequency deviation of less than 200 mKz the activated FCR capacity must be at least proportional to time behaviour for full activation. During the period of power change the deviation from the requested power step size may be no more than +30%. During transient period at least 95% of values in range ±20%, max. 5% of values in range ±30%. During stationary period at least 95% of values in range ±10%, max. 5% of values in range ±20%
Secondary control reserve	
 Abbildung 2: Bei Betriebsfahrt aufgezeichnete Rohdaten Ist-Messung=measured value; Arbeitspunkt=planned operating point; RL-Soll-Wert=grid service set value	Period of power change <300 sec. Max. initial response time 30 sec. Allowed power see graph. Min 95% of the values must be in the green range, max 5% of the values may be in the yellow range. The percentage refers to the prequalified power capacity i.e. the power step size set value at full activation.

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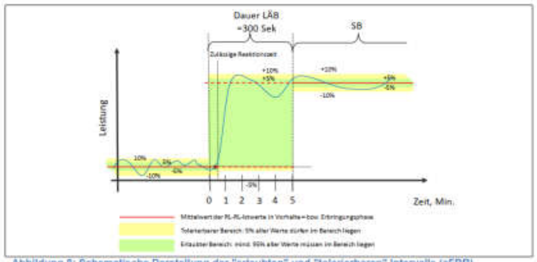
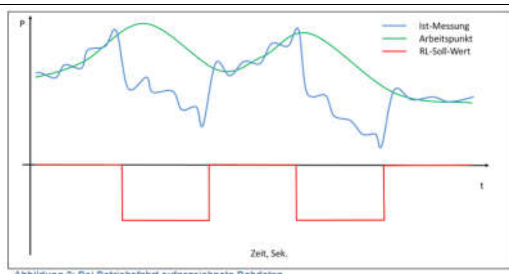
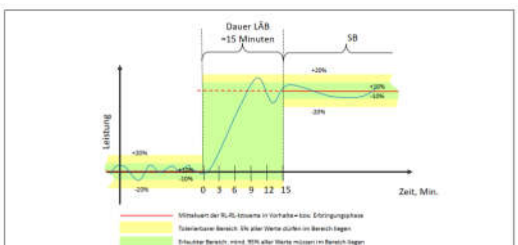
This work is supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 17.00009.

 Abbildung 8: Schematische Darstellung der "erlaubten" und "tolerierbaren" Intervalle (aFRR) Mittelwert der RL-Istwerte in Vorhalte- bzw. Erbringungsphase= mean value of grid service real values during period with or without activation of grid service. Tolerierbarer Bereich=tolerated region. Erlaubter Bereich=allowed region. Zeit, Min..=time in minutes. Leistung = power. LÄB Laständerungsbereich=period of power change. TB Transienter Bereich=transient period. SB Stationärer Bereich=stationary period	
mFRR	
 Abbildung 2: Bei Betriebsfahrt aufgezeichnete Rohdaten Ist-Messung=measured value; Arbeitspunkt=planned operating point; RL-Soll-Wert=grid service set value  Abbildung 9: Schematische Darstellung der "erlaubten" und "tolerierbaren" Intervalle (mFRR) Mittelwert der RL-Istwerte in Vorhalte- bzw. Erbringungsphase= mean value of grid service real values during period with or without activation of grid service. Tolerierbarer Bereich=tolerated region. Erlaubter Bereich=allowed region. Zeit, Min..=time in minutes. Leistung = power. LÄB Laständerungsbereich=period of power change. TB Transienter Bereich=transient period. SB Stationärer Bereich=stationary period	Period of power change <15 min Allowed power see graph. Min 95% of the values must be in the green range, max 5% of the values may be in the yellow range. The percentage refers to the prequalified power capacity i.e. the power step size set value at full activation.

Annex-D-7 Pre-qualification test (Denmark)

"ANCILLARY SERVICES TO BE DELIVERED IN DENMARK, TENDER CONDITIONS" Valid from 20 December 2017 downloaded from https://en.energinet.dk/-/media/Energinet/El-RGD/Dokumenter/Ancillary-services-to-be-delivered-in-Denmark.pdf
on 2019/08/21

"PREQUALIFICATION OF UNITS AND AGGREGATED PORTFOLIOS" https://en.energinet.dk/-/media/B54DC862C434466783F6E3A5ECC7F93E.pdf?la=en&hash=08CF09285AA86A888DAF7704C46C1623444E95FE downloaded from on 2019/08/21

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 735485. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme and Hydrogen Europe and N.ERGHY
This work is supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 17.00009.

FCR

FCR at DK1 zone

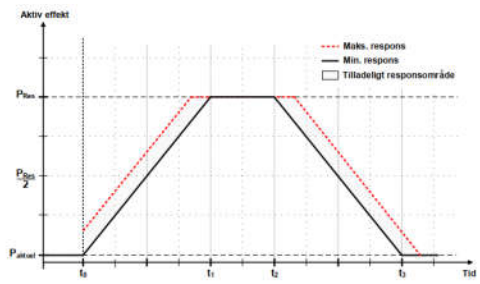


Figure 3 - Random FCR activation response sequence.

with

Time parameters	Time
t_0 - t_1	< 30 s
t_1 - t_2	Frequency imbalance length, at least 15 min
t_2 - t_3	< 30 s

Table 1 - Time parameters for response sequence described in Figure 3.

Prequalification test:

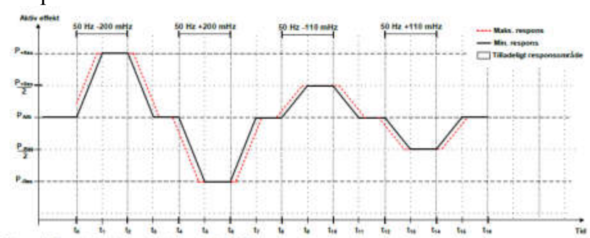


Figure 4 - Tests of minimum requirements for FCR response.

with

Time parameters	Time
t_0 - t_1	As specified in Figure 3
t_1 - t_2	15 min
t_2 - t_3	As specified in Figure 3
t_3 - t_4	1 min
t_4 - t_5	As specified in Figure 3
t_5 - t_6	15 min
t_6 - t_7	As specified in Figure 3
t_7 - t_8	1 min
t_8 - t_9	As specified in Figure 3
t_9 - t_{10}	5 min
$t_{10} - t_{11}$	As specified in Figure 3
$t_{11} - t_{12}$	1 min
$t_{12} - t_{13}$	As specified in Figure 3
$t_{13} - t_{14}$	5 min
$t_{14} - t_{15}$	As specified in Figure 3
$t_{15} - t_{16}$	1 min

Table 2 - Time parameters for tests described in Figure 4.

Power frequency control must be supplied at a frequency deviation of up to +/-200 mHz relative to the reference frequency of 50 Hz. This will normally mean in the 49.8-50.2 Hz range. A deadband of +/-20 mHz is permitted. The first half of the activated reserve must be supplied within 15 seconds, while the last half must be supplied in full within 30 seconds at a frequency deviation of +/-200 mHz. It must be possible to maintain the regulation until the automatic and manual regulating reserve can take over; however, minimum 15 minutes. accuracy of frequency measurements for primary regulation must be better than 10 mHz. The sensi-tivity of frequency measurements must be better than +/-10 mHz. The resolution of the player's SCADA system must be better than 1 second. Auction blocks of 4 hours

FCR-N(DK2 zone)

The normal operation reserve must be supplied at a frequency deviation of up to +/-100 mHz relative to the reference frequency of 50 Hz. This means in the 49.9-50.1 Hz range. Deliveries must be made without deadband. The reserve must as a minimum be supplied linearly at frequency deviations of between 0 and 100 mHz. The activated reserve must be supplied within **150 seconds**, regardless of the size of the

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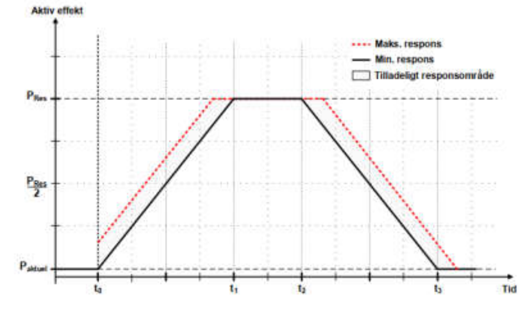


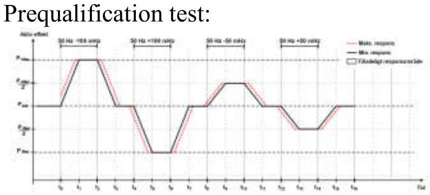
Figure 11 - Random FCR (FNR) activation response sequency in DK2.

with

Time parameters	Time
$t_0 - t_1$	150 s
$t_1 - t_2$	Frequency imbalance length, at least 15 min
$t_2 - t_3$	150 s

Table 5 - Time parameters for response sequences described in Figure 11.

Prequalification test:



with

Time parameters	Time
$t_0 - t_1$	As specified in Figure 11
$t_1 - t_2$	15 min
$t_2 - t_3$	As specified in Figure 11
$t_3 - t_4$	1 min
$t_4 - t_5$	As specified in Figure 11
$t_5 - t_6$	15 min
$t_6 - t_7$	As specified in Figure 11
$t_7 - t_8$	1 min
$t_8 - t_9$	As specified in Figure 11
$t_9 - t_{10}$	5 min
$t_{10} - t_{11}$	As specified in Figure 11
$t_{11} - t_{12}$	1 min
$t_{12} - t_{13}$	As specified in Figure 11
$t_{13} - t_{14}$	5 min
$t_{14} - t_{15}$	As specified in Figure 11
$t_{15} - t_{16}$	1 min

Table 6 - Time parameters for tests described in Figure 12.

deviation. Regulation must be active in all times, maintenance of 100% power for minimum 15 minutes.

FCR-D (DK2 zone)

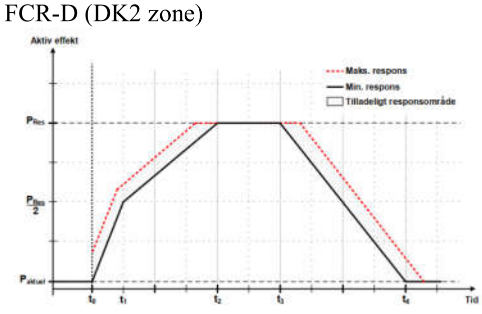


Figure 7 - Random FCR-D activation response sequence.

with

Automatic upward regulation reserve provided by production or consumption facilities.
Supply non-inverse power at frequencies between 49.9 and 49.5 Hz
- Supply 50% of the response within 5 seconds
- Supply the remaining 50% of the response within an additional 25 seconds.

Regulation must be active in all times, maintenance of 100% power for minimum 15 minutes

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This work is supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 17.00009.

Time parameters	Time
t_0 - t_1	< 5 s
t_1 - t_2	< 25 s
t_2 - t_3	Frequency imbalance length, at least 15 min
t_3 - t_4	< 30 s

Table 3 - Time parameters for response sequence described in Figure 7.

Prequalification test:

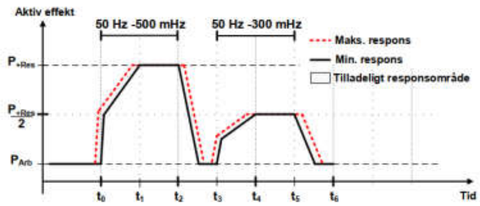

Figure 8 - Tests of minimum requirements for response for FCR-D.

Time parameters	Time
t_0 - t_1	As specified in Figure 7
t_1 - t_2	15 min
t_2 - t_3	1 min
t_3 - t_4	As specified in Figure 7
t_4 - t_5	5 min
t_5 - t_6	1 min

with Table 4 - Time parameters for tests described in Figure 8.

aFRR

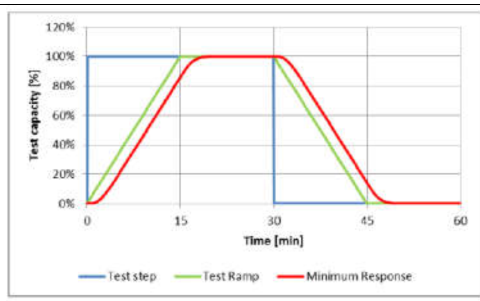

Figure 19 - Example of required response when the unit/portfolio is tested against a step or a set point change of a gradient in DK1 where responses between 20% and 80% are limited to a maximum delay of 135 seconds in relation to the test gradient values. 85% of full activation must be reached within 15 minutes.

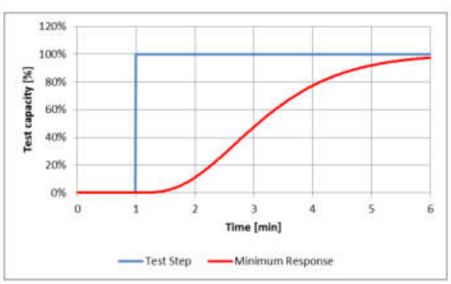

Figure 17 - Example of minimum response when testing an unit/portfolio against a step-wise set point change in DK2, where 90% of full activation must be reached within 5 minutes.

The aFRR response times are different for DK1 and DK2.
DK1: Full activation must be achieved within 15 minutes
DK2: Full activation must be achieved within 5 minutes
Thus, if a balance responsible party in DK2 wants to prequalify capacity of 15 MW, this market participant must be able to follow a gradient of (15 MW/5 min) = 3 MW/min or to respond to a step of 15 MW.
The minimum response when doing tests with a gradient equals a "delay", from receipt of a set point change until response is measured, of maximum 135 seconds (corresponding to three Pt1-time constraints with T_{au} = 45 sec).

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 735485. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme and Hydrogen Europe and N.ERGHY
This work is supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 17.00009.

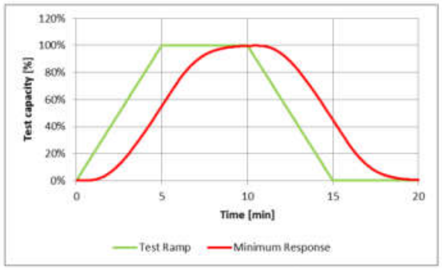

Figure 18 - Example of requirements, when testing an unit/portfolio against a gradient in DK2, where responses between 20% and 80% are limited to a maximum delay of 135 seconds in relation to the test gradient.

mFRR

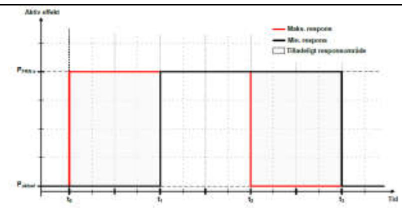

Figure 13 - Random mFRR activation response sequence.

with

Time parameters	Time
t_0 - t_1	< 15 min
t_1 - t_2	Unlimited
t_2 - t_3	< 15 min

Table 7 - Time parameters for response sequence described in Figure 13.

Prequalification

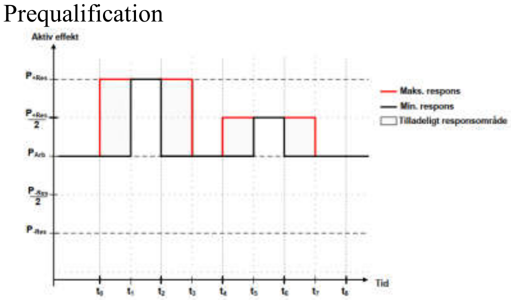

Figure 15 - Tests of minimum requirements for response for mFRR at upward regulation.

or

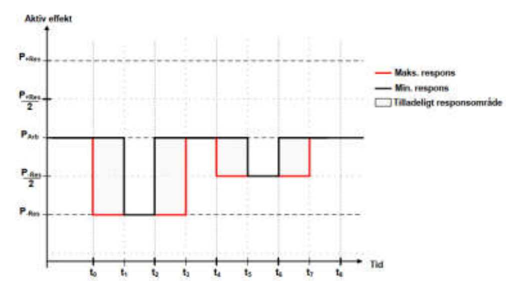

Figure 16 - Tests of minimum requirements for response for mFRR at downward regulation.

with

Minor deviations, positive as well as negative, near the permissible response range near P_{res} when response is fully regulated, are accepted. This applies to both prequalification tests of reserves and subsequent operation.

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This work is supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 17.00009.

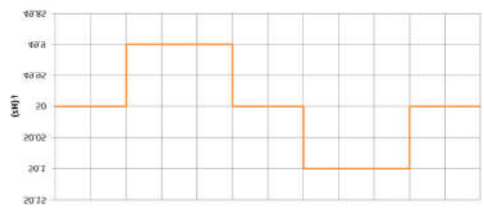
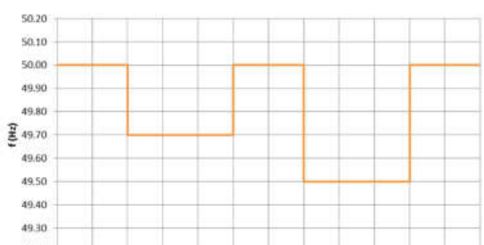
Time parameters	Time
$t_0 - t_1$	As specified in Figure 13
$t_1 - t_2$	30 min
$t_2 - t_3$	As specified in Figure 13
$t_3 - t_4$	15 min
$t_4 - t_5$	As specified in Figure 13
$t_5 - t_6$	30 min
$t_6 - t_7$	As specified in Figure 13

Table 9 - Time parameters for tests described in Figure 15 and Figure 16.

Annex-D-8 Pre-qualification test (Finland):

FCR

"The technical requirements and the prequalification process of Frequency Containment Reserves (FCR)", Fingrid Oyj 2019/01/01 downloaded from https://www.fingrid.fi/globalassets/dokumentit/en/electricity-market/reserves/appendix3---technical-requirements-and-prequalification-process-of-fcr.pdf on 2019/08/19

Frequency Containment Reserve for Normal Operation: 	100 per cent of the reserve capacity shall be activated as upward balancing, when the frequency is 49.9 Hz or less. Correspondingly, when the frequency is 50.1 Hz or more, 100 per cent of the reserve capacity shall be activated as downward balancing. As a result of a stepwise frequency change of 0.10 Hz, the control shall be activated in full in **three minutes**. From 1 January 2020, the maximum dead band may be 50 ±0.01 Hz. Unit must be capable of activation of the reserve in full for the entire delivery period. Exception: units with limited capacity must be capable of continuous full activation of at least 30 minutes.
Frequency Containment Reserve for Disturbances 	The activation of the reserve capacity shall begin when the frequency goes below 49.9 Hz. 100 per cent of the reserve capacity shall be activated, when the frequency is 49.5 Hz or less. In the frequency range of 49.5 to 49.9 Hz, at **least 50 per cent** of the Frequency Containment Reserve for Disturbances shall be **activated in five seconds and 100 per cent shall be activated in 30 seconds** as a result of a stepwise frequency change of -0.50 Hz. Unit must be capable of activation of the reserve in full for the entire delivery period. Exception: units with limited capacity must be capable of continuous full activation of at least 30 minutes. A Reserve Unit used

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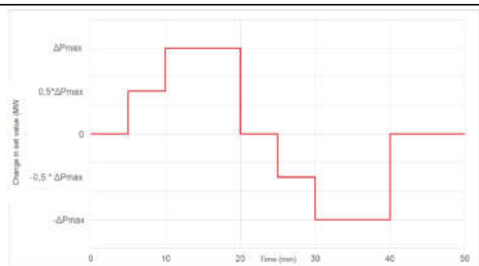
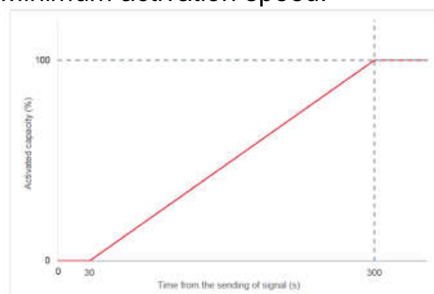
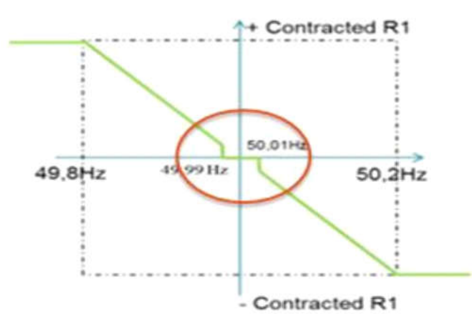
	in the maintaining of the Frequency Containment Reserve for Disturbances shall be capable of re-activating the reserve capacity in full no later than 15 minutes from the previous activation.
aFRR "The technical requirements and the prequalification process of Automatic Frequency Restoration Reserve (aFRR)", Fingrid Oyi 2019/01/01 downloaded from https://www.fingrid.fi/globalassets/dokumentit/en/electricity-market/reserves/automaattisen-taajuudenhallintareservin-afrr-teknisten-vaatimusten-todentaminen-ja-hyvaksyttamispr_en.pdf on 2018/08/19	
 *Figure 5.1 Test sequence*	Symmetrical service Minimum activation speed:  The volume of the activated reserve shall be 90 – 110% of the power request.

Annex-D-9 Pre-qualification test (Sweden):
FCR only for Hydro power plants and thermal power plants

mFRR https://www.svk.se/siteassets/aktorsportalen/elmarknad/information-om-reserver/prekvalificering/test-program-for-provision-of-mfrr.docx downloaded on 2019/08/20	
	Test full activation, in 15 min for category A, more than 15 min for category B, keep maximum activation for 1 hour.

Annex-D-10 Pre-qualification test (Belgium):

FCR Elia FCR Service Design Mode 2019 downloaded from https://www.elia.be/en/electricity-market-and-system/system-services/keeping-the-balance/fcr at 7/10/2019	
 	(a)"The activation of FCR shall not be artificially delayed and begin as soon as possible after a frequency deviation" (b) "In case of frequency deviation equal to or larger than 200 mHz, at least 50 % of the full FCR capacity shall be delivered after 15 seconds" (c) "In case of a frequency deviation equal to or larger than 200 mHz, 100 % of the FCR capacity shall be delivered at latest after 30 seconds"

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	(d) "In case of a frequency deviation equal to or larger than 200 mHz, the activation of the full FCR capacity shall at least rise linearly from 15 to 30 seconds and"; (e) "In case of a frequency deviation smaller than 200 mHz, the related activated FCR capacity shall be at least proportional with the same time behavior referred to in points (a) to (d) above" A FCR provider with assets with limited energy reservoir must always guarantee enough energy to be able to fully activate for 15 minutes, once the alert state is triggered. A FCR provider with assets with limited energy reservoir must be continuously available in normal state. This signifies, in terms of energy delivered equivalent to a full FCR reaction and for the "worst case scenario" an additional 10 minutes (for FCR 200 mHz).

Annex-D-11 Pre-qualification test (Ireland):

FCR
Synchronous Area Operational Agreement (SAOA) for Synchronous Area IE/NI 23/8/2019 downloaded from http://www.eirgridgroup.com/site-files/library/EirGrid/SAOA-for-the-Ireland-and-Northern-Ireland-Synchronous-area-V3.0-(post-co....pdf at 7/10/2019

standard frequency range	± 200 mHz
maximum instantaneous frequency deviation	1000 mHz
maximum steady-state frequency deviation	500 mHz
time to recover frequency	1 minute
frequency recovery range	± 500 mHz
time to restore frequency	15 minutes
frequency restoration range	± 200 mHz
alert state trigger time	10 minutes

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Annex E Basic characterisation of electrolyser system for grid-service relevant parameters

Test objective

The objective of these tests is to find out for which grid services the electrolyser might in principle be suitable. Based on this pre-selection the testing protocol for the specific grid service can then be applied in the next step.
These protocols aims at determining basic characteristics of the tested system, such as available power range and start-up duration. The main characteristics are:

- Cold Start Time to Nominal Power and Start-up time from Standby State.
- Maximum and minimum power consumption of the system:
    - $P_{max\ system}$ and $P_{min\ system}$ defining the system's total available range for grid services respectively the standby system power $P_{standby}$ and $P_{cold\ standby}$.
    - The system's total available range for grid services is the value ($P_{max\ system}$ - $P_{min\ system}$) or ($P_{max\ system}$ - $P_{standby}$) or ($P_{max\ system}$ - $P_{cold\ standby}$). It can be shared with both upscale and downscale services.
- Dynamics of the system: Total Response Time from $P_{min\ system}$ to $P_{max\ system}$; Total Response Time from $P_{max\ system}$ to $P_{min\ system}$.
- Dynamics of the system: Power down to standby and time to next restart
- Maximum operation time at maximum power

Test methods

Ensure during these tests that the manufacturer's recommendations and requirements for the electrolyser system are always obeyed to avoid damage to the system. Preferentially these tests should be run in close collaboration with the manufacturer. Possibly not all these tests can be run on all systems. If the required values are available from the manufacturer this basic characterisation might not be necessary. Run the tests 3 times to determine the variation of the results.
Report the test results using the report template in Annex C.

Protocol for determination of Cold Start Time to Nominal Power

Start-up protocol

At the beginning of this test the system should have been in cold standby state (definition see 1.3.22) for at least 1 hour.

Step	Description
1	Trigger the "start" button on the system
2	Wait for end of start-up protocol to reach nominal power
3	Wait for system power to be constant by ± 5% in a 15 min interval

Cold Start Time to Nominal Power: τ_{cold}=Time from Step 1 started to Step 3 finished minus 15 min.

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In case the nominal power is not reached within 30 minutes, the test can be interrupted since performing the following grid services from standby state will not be possible for this system.
Average Electrical Power Input of the system in Cold Standby State is $\mathbf{P}_{\mathbf{cold\ standby}}$ (Arithmetic average during 30 minutes before step 1).
In case that rectifier power and BOP power/system power are measured separately, the average value of both powers during step 1 are to be determined.

Describe the status of the system in “standby state”.

Protocol for determination of start-up time from standby mode

At the beginning of this test the system should have been in standby state (definition see 1.3.23 and 1.3.24) for at least 1 hour. For systems that have different types of standby modes the start-up time from standby mode should be determined for each of these states.

Start-up protocol

Step	Description
1	Remain at standby for 15 min
2	Set the power of the system power control to nominal power
3	Wait for system power to be constant by ± 5% in a 15 min interval

Start-up time from Standby State to Nominal Electrical Power Input: $\tau_{\mathbf{start,standby}}$= Time from Step 2 started to Step 3 finished minus 15 min.
Average Electrical Power Input of the system in Standby State is $\mathbf{P}_{\mathbf{standby}}$ (Arithmetic average during step 1).
In case that rectifier power and BOP/system power are measured separately, the average value of both powers during step 1 are to be determined.

Describe the status of the system in “standby state”.

Protocol for Identification of available range

At the beginning of this test the system should be in “off” state or standby state or minimum power state.

Protocol for identification of the power range available for grid services

NOTE: consider the manufacturer’s recommendations and limits

Step	Description
1	Start system
2	Set system to maximum power with maximum possible continuous H_2 production output (Comment: for most systems this state will be the Nominal Operational Mode, for systems with overload capability it might be higher than nominal power)
3	Wait for power to stabilize *

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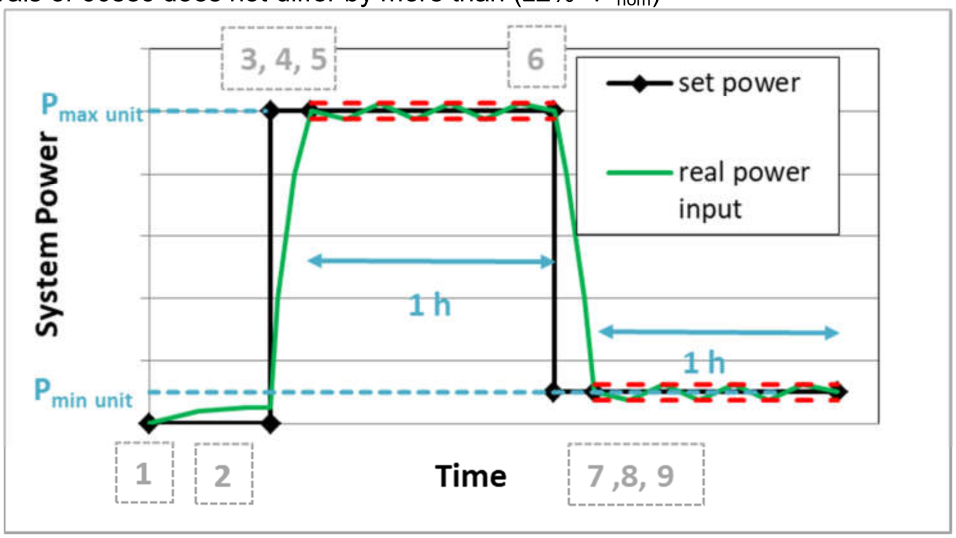
4	Note the power P_1=$P_{start\ max}$
5	Keep the state for 1 hour with power variation below ±5%* $P_{start\ max}$ during this time
6	Set system at 0% H_2 production output (or minimal continuously attainable output) respectively minimum rectifier power input
7	Wait for power to stabilize*
8	Note the power P_2=$P_{min\ system}$
9	Keep the state for 1 hour with power variation below ±5% * $P_{start\ max}$ during this time
10	End of test

The system power is considered stable here if the average power of two consecutive intervals of 60sec does not differ by more than (±2% P_{nom})



Example of profile obtained in available-range-protocol

The average Electrical Power Input of the system in step 5 is defined as $\mathbf{P_{max\ system}}$ (use the arithmetic average of the system power during step 5).

The average Electrical Power Input of the system in step 9 is defined as $\mathbf{P_{min\ system}}$ (use the arithmetic average of the system power during step 9).

In case that rectifier power and BOP/system power are measured separately, the average value of both powers during step 5 and during step 8 are to be determined.

Protocol for Determination of Minimum-Maximum-Dynamics

At the beginning of this test the system should have been at minimum power state ($P_{min\ system}$) for at least 15 min.

Protocol for identification of the dynamics

Step	Description
1	Continue operation at minimum power for 15 min
2	Set system to maximum power with maximum H_2 production output as defined as

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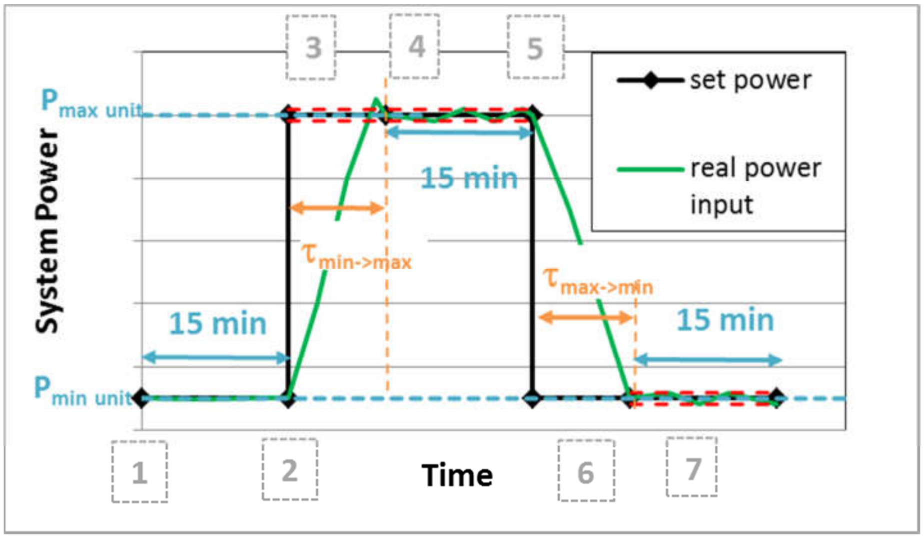
	$P_{max\ system}$ state in the test "protocol for identification of the power range available for grid services"
3	Wait for system power to stabilize to ±5%* $P_{max\ system}$
4	Hold at $P_{max\ system}$ for 15 min
5	Set system at 0% H_2 production output (or minimal continuously attainable output) as defined as $P_{min\ system}$ state the test "protocol for identification of the power range available for grid services"
6	Wait for system power to stabilize to ±5%*$P_{max\ system}$
7	Operate at minimum power for 15 min



Example of profile obtained in Min-Max-Dynamics protocol

The Total Response Time Minimum Power to Maximum Power $\tau_{min\text{->}max}$ is defined as the time from beginning of step 2 to end of step 3.

The Total Response Time Maximum Power to Minimum Power $\tau_{max\text{->}min}$ is defined as the time from beginning of step 5 to end of step 6.

Protocol for Determination of Nominal-Maximum-Dynamics

This protocol is only relevant for those systems for which maximum power that can be continuously operated (for at least 15 minutes) is higher than nominal power.
At the beginning of this test the system should have been at nominal power state for at least 15 min.

Protocol for identification of the dynamics nominal - maximum

Step	Description
1	Continue operation at nominal power for 15 min
2	Set system to maximum power with maximum H_2 production output as defined as $P_{max\ system}$ state in the test "protocol for identification of the power range available for grid services"
3	Wait for system power to stabilize to $P_{max\ system}$ ±(5%*$P_{max\ system}$)
4	Hold at $P_{max\ system}$ for 15 min
5	Set system at nominal system power depending on the type of system control

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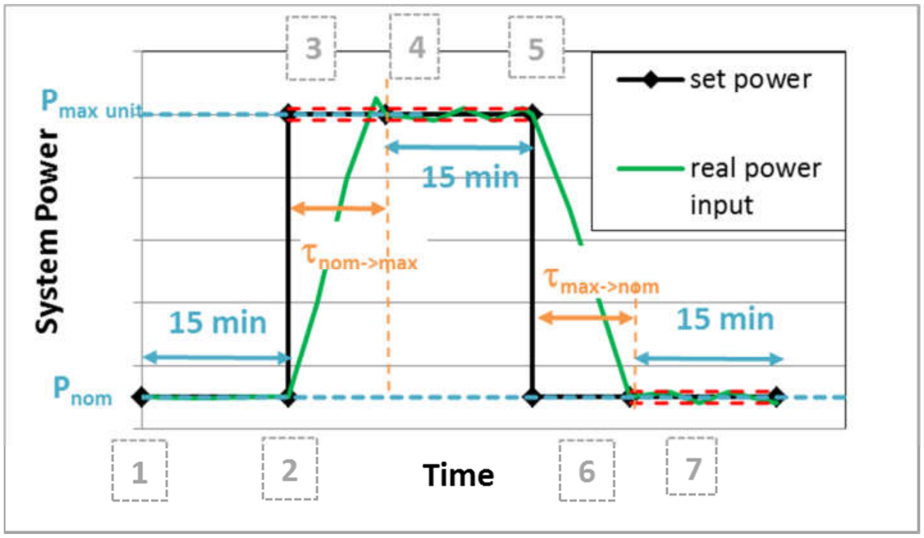
6	Wait for system power to ±5%*$P_{max\ system}$
7	Operate at nominal power for 15 min



Example of profile obtained in nominal-maximum-dynamics protocol

The Total Response Time Nominal Power to Maximum Power $\tau_{nom->max}$ is defined as the time from beginning of step 2 to end of step 3.
The Total Response Time Maximum Power to Nominal Power $\tau_{max->nom}$ is defined as the time from beginning of step 5 to end of step 6.

Protocol for determination of power down to standby time and minimum duration between reaching standby state and reaching the subsequent nominal power state

At the beginning of this test the system should have been at nominal power for at least 1 hour.

Down to standby and restart to nominal protocol

Step	Description
1	Set system at 0% H_2 production output (or minimal continuously attainable output) as defined as $P_{min\ system}$ state in the test "protocol for identification of the power range available for grid services"
2	When 0% H_2 production or minimum continuously attainable output is reached switch the system to standby state as defined by the manufacturer
3	Wait for standby state to be reached
4	Start the system from the standby state. Set the system power control to nominal power
5	Wait for system power constant by ± 5% in a 15 min interval

Identify the moment t_{down} during step 3 when the system power reaches the range $\mathbf{P_{standby}}$± (5% $\mathbf{P_{max\ system}}$) for the rest of step 3 (with $\mathbf{P_{standby}}$ as defined in the "Protocol for determination of start-up time from standby mode" and $\mathbf{P_{max\ system}}$ as defined in "protocol for identification of the power range available for grid services").

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Time from nominal to standby power: $\tau_{down\_to\_standby}$=Time from Step 1 started to t_{down}. If different types of standby mode are available for this electrolyser, the test should be repeated for each of the standby modes.

Time between reaching standby state and reaching the subsequent Nominal Power state $\tau_{down \rightarrow up}$ = Time from Step 3 finished to Step 5 minus 15 min.

Describe the status of the system in "standby state".

Protocol for Determination of Duration of Maximum Power

This protocol is only relevant for those systems for which maximum power that can be continuously operated (for at least 15 minutes) is higher than nominal power.
At the beginning of this test the system should have been at nominal power state for at least 15 min.

Protocol for identification of the duration of maximum power

NOTE: to avoid damage to the system run this test in close collaboration with the system manufacturer.

Step	Description
1	Continue operation at nominal power for 15 min
2	Set system to maximum power with maximum H_2 production output as defined as $P_{max\ system}$ state in the test "protocol for identification of the power range available for grid services"
3	Wait for system power to stabilize to $P_{max\ system}$ ±(5%*$P_{max\ system}$)
4	Hold at $P_{max\ system}$ for 4 hours or until system specifications are requiring power reduction.
5	Set system at nominal system power depending on the type of system control
6	Wait for system power to stabilize to $P_{max\ system}$ ±(5%*$P_{max\ system}$)
7	Operate at nominal power for 15 min

Identify the moment t_{down} during step 3 when the system power reaches the range $\mathbf{P_{standby}}$± (5% $\mathbf{P_{max\ system}}$) for the rest of step 3

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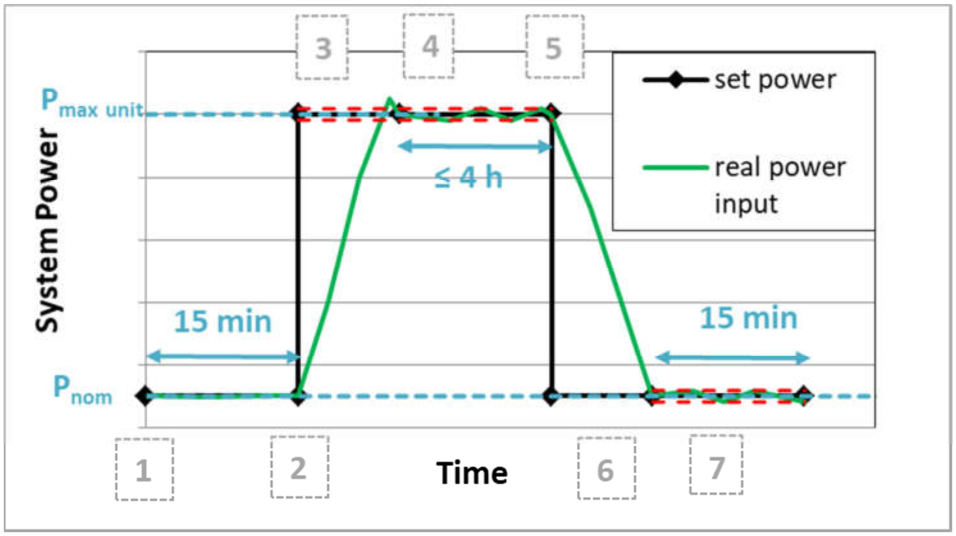

Example of profile obtained in nominal-maximum-dynamics protocol

The duration time of maximum power τ_{max} for which the system can remain in maximum power is determined by the duration of step 4. If the system does not need to terminate step 4 before the end of the 4 hours, give the value τ_{max}>240 min.

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