October 2018

EUTurbines Statement on Frequency Requirements

Foreword

During the development of the Commission Regulation (EU) 631/2016 – Network Code Requirements for Generators (NC RfG), frequency related topics have led to long discussions among stakeholders. These discussions have continued during the consultation and preparation of IGDs (Implementation Guidance Documents) and the first steps of implementation into National Regulation in the EU Member States (MS).

The ENTSO-E IGDs try to fill the gap between the non-exhaustive requirements of the NC RfG and the need for clarity during national implementation, but the current wording and interpretation may bear the potential of prohibiting grid access to some technologies without proper technical justification.

For EUTurbines, the association representing the gas and steam turbine manufacturers, it is crucial that the information provided in these documents consider the technical limitations of Synchronous Power Generating Modules (SPGM).

This paper aims to clarify the facts and status of discussions on a selected number of technical subjects and gives clear recommendations from manufacturers side for the national implementation to consider both the needs of the TSOs and their obligation to ensure stability of the electrical system on one hand, and the inherent constraints of some generation technologies on the other hand.

The areas addressed are:

- **Maximum Admissible active power reduction at low frequencies** covered under NC RfG Article 13 (4) and (5)
- **Requirements for frequency limits** as described in NC RfG Article 13 (1)
- **Rate of change of frequency** (RoCoF) capability described under NC RfG Article 13 (1.b)

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Maximum admissible active power reduction at low frequencies

Technical facts

During the development of NC RfG and the IGD[1], there has been an intensive exchange of knowledge on this subject with a common understanding on the following points.

System view:

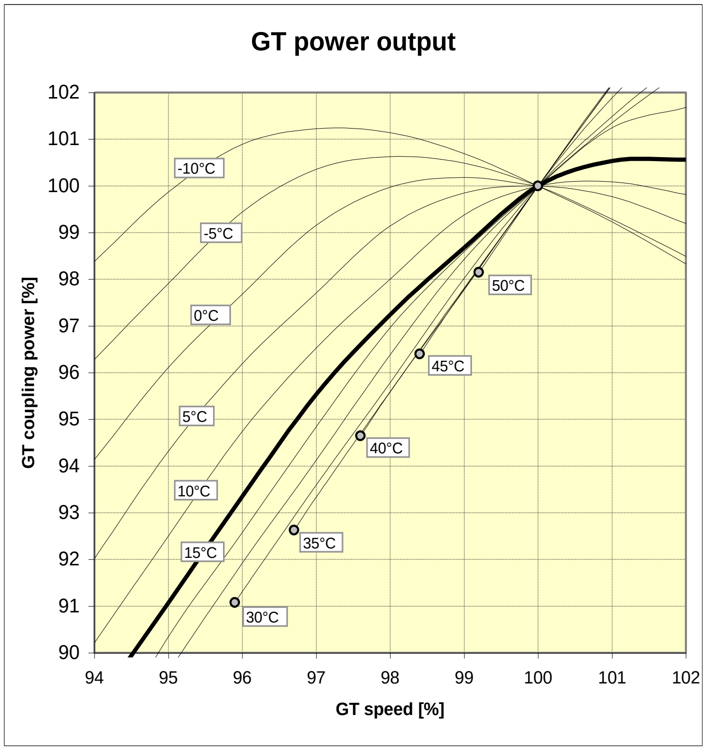
- In the moment of and short after a sudden and large mismatch between generation and demand, the need for quick recovery of this balance is crucial in order to arrest the change in frequency before it reaches the operational limits with a consequent black-out. Reaching the balance between generation and demand is visible as the point in time where the frequency nadir occurs (in case of under-frequency).
- The available timeframe for this action is only a few seconds – in case of a system split and large load imbalance levels, this can come down to only 2 s. From the point of stabilisation onwards, other mechanisms are in place to contain and then bring back the frequency to nominal value within a timeframe which is not time critical anymore.
- The activation of fast reserves and – if this is not sufficient – the disconnection of loads according to the system defence plan, are crucial for this stabilisation in case of falling frequency during the first few seconds.
- Any additional loss of generation during this highly dynamic process, e.g. due to the physical output loss of SPGMs due to falling frequency is not helpful for the system, because it can increase further the frequency transient.

Generation view:

- There are synchronous technologies, in particular gas turbines, which have the inherent characteristic of losing some output at a lower frequency, i.e. at a lower rotational speed of the synchronous machine. This is not caused by a controller action but purely due to the physical fact that a lower rotational speed comes along with a reduced mass flow, which translates immediately into a reduced power output.
- This behaviour is strongly dependant on the ambient conditions. The ambient temperature has especially an impact: the higher the temperature, the higher the inherent and immediate output loss.
- This effect is virtually invisible during normal frequency control actions within the normal frequency band of a few hundred MHz Due to its non-linear nature, intrinsic to this technology, the effect has more impact during large disturbances that cause the frequency to drop by 0,5 Hz or more.

[1] ENTSO-E IGD on Maximum Admissible active power reduction at low frequencies. Available here.

Figure: Typical behaviour of Gas Turbines (source: EUTurbines)



It is important to note that this picture, provided by EUTurbines during previous discussions, does not present the minimum capability achievable at state-of-the-art basic design for all manufacturers (as mistakenly presented in the IGD). The figure presents typical behaviours of gas turbines – meaning that some will perform above and some below the behaviour presented in the graph. We fear that this picture can be misinterpreted, considering that the majority of gas turbines will perform above the values presented in the picture, which is not necessarily the case.

- Compensation of this output loss would require activation of reserve power, which is withheld only for this extremely rare purpose and activated without any time delay. Due to the physics of those technologies and the constraints of any real control action, there is no compensation possible within the first few seconds even if the reserve would be available. Therefore, only the inherent characteristic of the SPGM is relevant for the system behaviour during the first seconds.
- There is no possibility to test and evaluate the behaviour or any countermeasure under real conditions, since neither the real range of system frequencies nor the range of ambient conditions can be established during a test. The behaviour only can be calculated and simulated.

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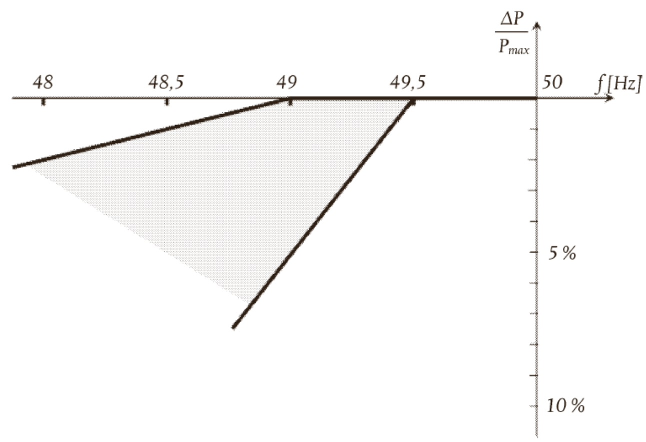
Current status of discussion and documentation

The NC RfG acknowledges the principle constraints of generation technologies and the effect of ambient conditions to it. Therefore, NC RfG Article 13 (4) gives a range of admissible power output reduction (shaded area) in its Fig. 2, where each MS can place its individual requirement:

Figure: Maximum power capability reduction with falling frequency (Art. 13 (4) NC RfG)



Furthermore, NC RfG Article 13 (5) addresses the subject of ambient conditions:

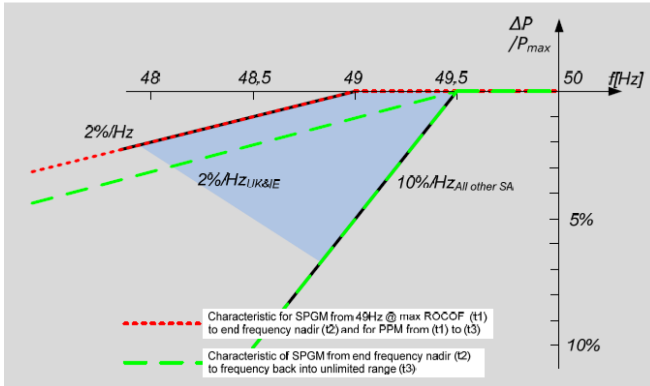
"The admissible active power reduction from maximum output shall:

(a) clearly specify the ambient conditions applicable;

(b) take account of the technical capabilities of power-generating modules."

However, the dynamic aspect has not been addressed in the NC RfG. Articles 13 (4) and (5) can be either understood as steady state, as transient, or as both. The topic has been further discussed during the preparation of the IGDs, mainly during some workshops organised by ENTSO-E until October 2017. It was understood that a split into two-time domains is helpful: a first "transient" domain (until the frequency nadir, i.e. between 2 s and 30 s) and a second "steady state" time domain:

Figure: Maximum power capability reduction with falling frequency (ENTSO-E IGD on Maximum Admissible active power reduction at low frequencies (2018), p. 8))



In order to take into account those facts and, at the same time, to stay within the area given by the NC RfG, the proposed values in the IGD for the transient domain (limited by the red dotted lines) are more stringent than the steady state values (green interrupted lines).

Ambient conditions discussion

The IGD suggests a temperature of 25°C as the reference condition to meet the requirement. While a more suitable temperature of 0°C had been proposed by ENTSO-E for gas turbines during an expert workshop in October 2017, according to the UK TSO, the 25°C as the reference ambient condition has been in place in UK for many years, which is met by Combined Cycle Gas Turbines through developing “efficient and cost-effective solutions”.

The explanation, however, does not take into account that the UK requirement is not a dynamic requirement and that there was no test procedure in place (because the requirement cannot be tested under real conditions). Any kind of counteraction, if any available, would lead the activation of the power reserve, which could be too slow for the critical transient domain identified in the IGD. It could also add some risks, as such counteraction could lead to flame out, a condition that cannot be excluded since the countermeasure cannot be tested in advance. Installing and maintaining a separate system for this purpose, which almost never will be used, cannot be considered cost-effective, as stated in the IGD.

Therefore, in the turbine manufacturers’ view, the reference temperature of 25°C, as stipulated in the IGD, is not acceptable and would inherently lead to non-compliance with the transient domain requirement. Even in case of derating of the plant, the activation of the reserve would take too long for the transient domain.

During the implementation process of the NC RfG in Germany, there was also some further discussion on this subject. It has been accepted that there is no suitable technical solution to overcome the inherent characteristic during the critical transient requirement, resulting in a transient allowance of 3% reduction for gas turbines down to 49 Hz. Manufacturers are further required to state the range of ambient conditions, where the steady state power drop requirement is met, i.e. there is no fixed ambient condition stated any more.

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Similar discussions have taken place in France, in NC RfG transposition forum, and have now provided proposals to the energy regulator and government. For generating units, whose behavior is dependent upon ambient condition (such as in the case of gas turbines turbines), the compliance is not expected for all ambient temperatures. It is expected that the inherent site-specific power vs. frequency characteristic be provided with the plant owner/manufacturer to the grid operator, so that the grid operator can analyse impacts.

Recommendations for national implementation

Based on the above presented facts, the turbine manufacturers recommend considering the following approach during the implementation of RfG Articles 13 (4) and (5) into national rules:

- The need for a minimum possible output loss in the transient domain and the consequent IGD recommendation to make use of the stringent end of the range allowed in the RfG (i.e. 2%/Hz below 49 Hz) is understood and accepted, as well as the more relaxed allowable loss in the steady state domain.
- Instead of fixing a reference temperature, which will always be arbitrary and without real justification, we recommend requiring from SPGMs, on a project-specific basis, the inherent power vs. frequency characteristics (i.e. without any power compensation control measures) with the ambient temperature as a variable parameter, to be used for system stability studies and design.
- Manufacturers can therefore state compliance with the requirement by means of a project specific manufacturer's compliance declaration, without the need of any test which, for this specific requirement, would never be a reliable proof of compliance.

This recommendation offers compliance with the NC RfG, taking into account the constraints of SPGM technologies and allows a feasible compliance process based on clear requirements with minimum complexity, applicable to all MS.

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Requirements for frequency limits

Technical facts

Frequency limits are a concern for rotating machines, since deviation from the typical frequency ranges can affect consistently the lifecycle or can damage the generating unit. The frequency limits are described in the NC RfG in the form of a table.

It is important to note that the frequency upper limits are indicated as "exhaustive requirements", which means that MS shall adopt them as they are; higher limits than the ones indicated in the table cannot be adopted. These limits are already considered upper limits for gas and steam turbine technology. Some of the intermediate values, though, have to be specified by MS.

Table 2

Minimum time periods for which a power-generating module has to be capable of operating on different frequencies, deviating from a nominal value, without disconnecting from the network.

Synchronous area	Frequency range	Time period for operation
Continental Europe	47,5 Hz-48,5 Hz	To be specified by each TSO, but not less than 30 minutes
	48,5 Hz-49,0 Hz	To be specified by each TSO, but not less than the period for 47,5 Hz-48,5 Hz
	49,0 Hz-51,0 Hz	Unlimited
	51,0 Hz-51,5 Hz	30 minutes
Nordic	47,5 Hz-48,5 Hz	30 minutes
	48,5 Hz-49,0 Hz	To be specified by each TSO, but not less than 30 minutes
	49,0 Hz-51,0 Hz	Unlimited
	51,0 Hz-51,5 Hz	30 minutes

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Great Britain	47,0 Hz-47,5 Hz	20 seconds
	47,5 Hz-48,5 Hz	90 minutes
	48,5 Hz-49,0 Hz	To be specified by each TSO, but not less than 90 minutes
	49,0 Hz-51,0 Hz	Unlimited
	51,0 Hz-51,5 Hz	90 minutes
	51,5 Hz-52,0 Hz	15 minutes
Ireland and Northern Ireland	47,5 Hz-48,5 Hz	90 minutes
	48,5 Hz-49,0 Hz	To be specified by each TSO, but not less than 90 minutes
	49,0 Hz-51,0 Hz	Unlimited
	51,0 Hz-51,5 Hz	90 minutes
Baltic	47,5 Hz-48,5 Hz	To be specified by each TSO, but not less than 30 minutes
	48,5 Hz-49,0 Hz	To be specified by each TSO, but not less than the period for 47,5 Hz-48,5 Hz
	49,0 Hz-51,0 Hz	Unlimited
	51,0 Hz-51,5 Hz	To be specified by each TSO, but not less than 30 minutes

Clarification on maximum capability associated to the generating unit

Article 13 1(a) (iii) of the NC RfG, states that "the power-generating facility owner shall not unreasonably withhold consent to apply wider frequency ranges or longer minimum times for operation, taking account of their economic and technical feasibility".

EUTurbines understanding is that this refers to the capability of the generating unit, i.e. the design capability of the components part of the generating unit (prime mover, generator, etc.). The design capability is the maximum frequency limits at which the generating is permitted to run.

Recommendations for national implementation

To help MS setting the intermediate values, ENTSO-E created the relevant IGD[2], where these limits are emphasised, while providing some guidance on how to select such values as well.

EUTurbines recommendation is to adopt values that are limited in time to the expected needs, for the system to recover to the normal frequency range. Specifying longer timeframes can lead to unnecessary cost increases related to possible oversizing.

Rate of change of frequency

Introduction

SPGMs are not generally capable of withstanding a RoCoF of 2 Hz/s as stated in the RoCoF IGD[3] and the 2016 SPD Report [4],– this value has not been provided by manufacturers. The turbine manufacturers urge grid operators to consider a more adequate grid event.

The ±2 Hz/s scenario as defined by CE grid operator in the 2016 SPD Report and now widely spread as a "shall be" requirement in the relevant IGD can be qualified as the "RoCoF give-up scenario".

The impact of extreme and not well-set requirements could result in a generation trip, due to the technology's limitations, which are impossible to overcome, and to the difficulties to demonstrate ability to withstand a true grid event like this.

The ±2 Hz/s extreme values are the natural consequences of an extreme assumption taken by grid operators, where operators would not have a role in the operation of the grid. Grid operators should actively consider what they could do and what shall be put in place to avoid such RoCoF event to happen: if the appropriate action is taken during the implementation of the Connection and the System Operation Codes, the RoCoF event would not happen.

[2] ENTSO-E IGD on Frequency ranges. Available here.
[3] ENTSO-E IGD on Rate of Change of Frequency. Available here.
[4] 2016 SPD Report (RG - CE System Protection & Dynamics Sub Group): Frequency Stability Evaluation Criteria for the Synchronous Zone of Continental Europe –Requirements and impacting factors. Available here.

Setting remedies such as connection and operation requirements for fast frequency response (synthetic inertia) on synchronous and non-synchronous generators, or operational stop gap lines to avoid extreme load imbalance (>40%) in each region (2016 SPD Report) are the responsibility of grid operators. Assuming these actions are taken, continental Europe would come back to more reasonable scenarios as depicted below.

Technical facts: possible root causes leading to abnormal RoCoF

On meshed electrical system, the frequency is always fluctuating– being a balance between generation and loads. The RoCoF during normal operation is very limited. There are some major events that can lead to abnormal RoCoF. Typically, they can be classified in two major categories:

- **Major Load Imbalance,** such as loss of big generation, loss of big loads, or loss of interconnection between synchronous areas. These events can lead to high load mismatch in the grid and, as a consequence, they can result in a high RoCoF.
- **Grid splits**, leading to formation of separate grid with high level of load imbalance and leading the different split areas to variate their frequency to accommodate their load imbalance.

Short-term acceleration on synchronous generator's shaft line during a grid (voltage) fault is NOT considered a RoCoF event. This phenomenon is considered and understood under Fault-Ride Though Requirement, since the associated frequency variations of the shaft correspond to variation of the electrical angle between the generator and the grid during the fault. Voltage dips may cause localized Rate of Change of Frequency values and in these cases, the Fault-Ride Through clause supersedes the Clause of RoCof.

The Irish Example - Joint study of RoCoF phenomenon by grid operators, manufacturers and industry stakeholders

The Irish case has some specific peculiarities: the Irish system has a high system non-synchronous penetration target (above 75%) of inverter based (such as variable RES, HVDC interconnector imports) generation. Such target created some concerns in terms of system stability. For this reason, the study was a cooperation between System Operator, manufacturers and industry stakeholder (most similar studies are typically carried out by System Operators only). The Irish system is not a very extended one and it is an isolated synchronous area with HVDC interconnectors connected to the Great Britain network.

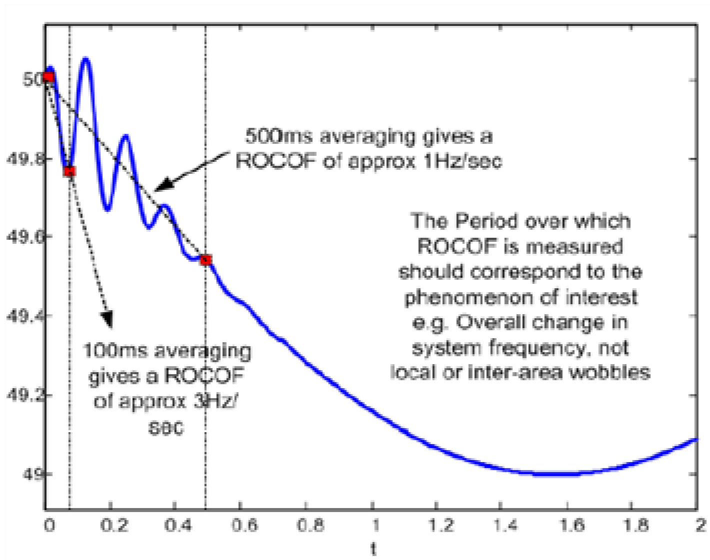
One of the biggest worries was to analyse the impact of a sudden imbalance on the grid, like losing the interconnection to Great Britain or losing a big portion of the generation. In fact, these are typical impact studies for islands.

TSOs, by defining the reference incident in terms of maximum imbalance and maximum RoCoF withstand, grid topology and minimum system synchronous inertia – through for example maximum System Non-Synchronous Penetration (SNSP) –, have ways to manage RoCoF. Since the initial RoCoF is directly proportional to the size of a single contingency relative to the net load and inversely proportional to the system inertia.

Under the DS3 banner [5] the following studies and key results have been achieved:

- Case study of sudden imbalance due to loss of large production/demand/interconnection unit is seen as priority.
- The reference incident considered led up to ±1 Hz/s RoCoF.
- The result of the study shows that a high RoCoF can be expected at the beginning of the event for a very short transient and, in general, an average RoCoF of 1 Hz/s along the event (see figure below).
- Based on this, the way the frequency is measured becomes very important, leading to the following conclusions:
    - Frequency measurement used for studies shall be averaged over 500 ms or more rolling window.
    - If the RoCoF is defined on a lower timeframe, one is exposed to erroneous assumptions and results: in the first instants after a grid event, the inter-area wobbles can end up measuring a high RoCoF value (although the system average RoCoF is lower).

Figure – Illustration of Frequency Measurement Stakes (Source EIRGRID and SONI)



[5] DS3 Programme: http://www.eirgridgroup.com/how-the-grid-works/ds3-programme/

Recommendations for national implementation

SPGM and, in particular, gas and steam turbines cannot withstand a High RoCoF (2 Hz/s[6] or higher). Frequency deviation can be detrimental for a generating unit and its components, resulting in possible trips of the unit itself due to technology limitations impossible to overcome. The definition of the RoCoF is complex and it shall be associated to a defined value and its correspondent window of time upon which the frequency is measured.

EUTurbines recommends using **1 Hz/s on a rolling window of 500ms as reference values to define the requirements with the provision of frequency versus time profile as suggested in the IGD.** This recommendation is based on the experience gathered during the study in Ireland, where it had been proposed to adopt the same values (see below).

RoCoF withstand limit shall be based on a CBA. EUTurbines recommends MS to develop such methodology.

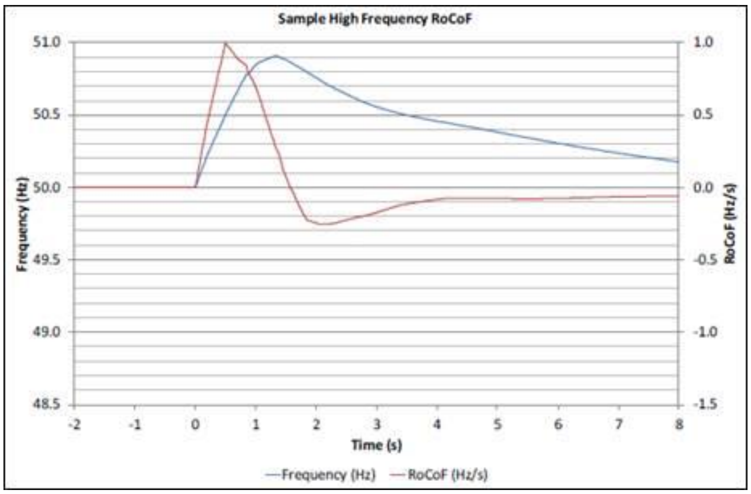


Figure 1 - Sample High Frequency RoCoF (Source EIRGRID and SONI)

[6] KEMA-DNV RoCoF for Eirgrid, An independent analysis on the ability of Generators to ride through Rate of Change of Frequency values up to 2Hz/s, available here.

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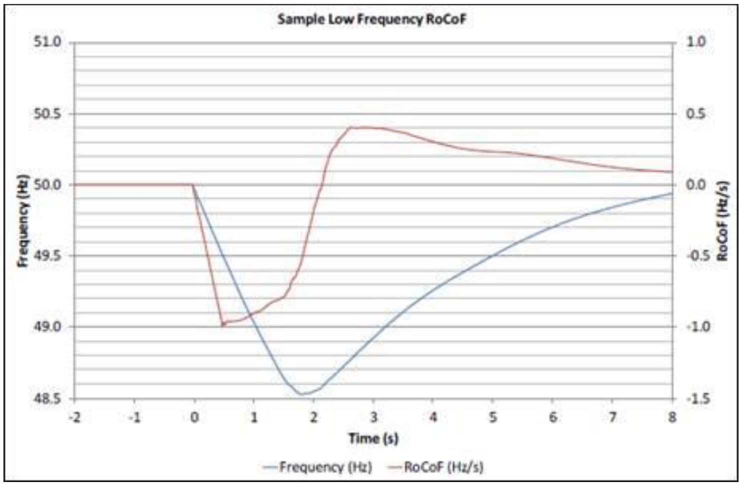

Figure 2 - Sample Low Frequency RoCoF (Source EIRGRID and SONI)

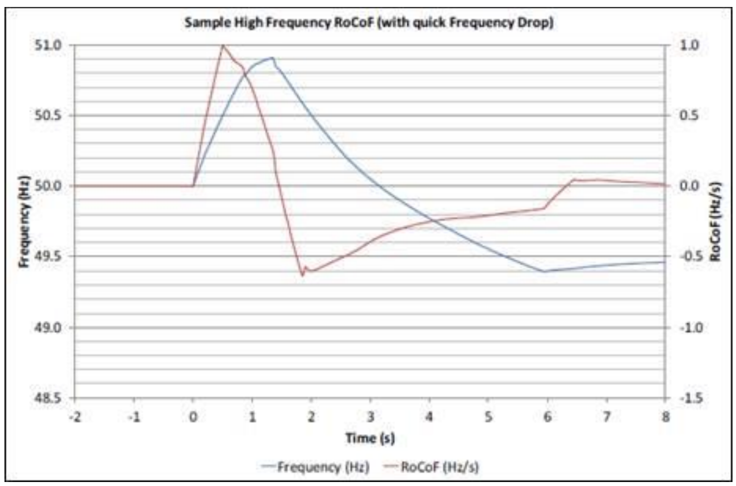

Figure 3 - Sample High Frequency RoCoF (with quick Frequency Drop) (Source EIRGRID and SONI)

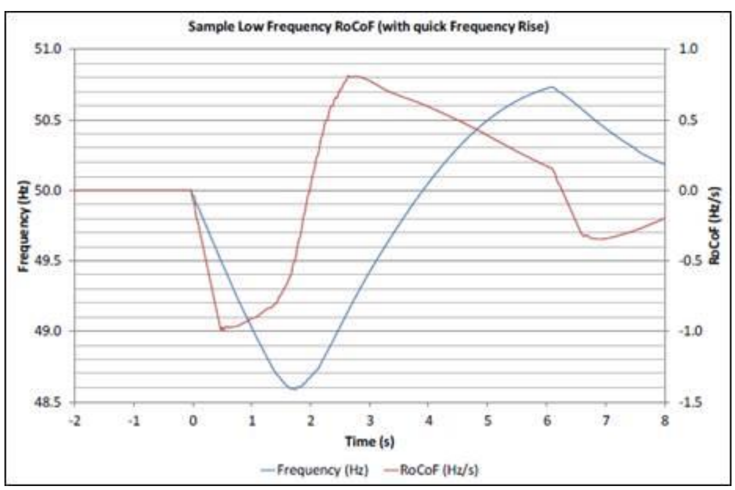

Figure 4 - Sample Low Frequency RoCoF (with quick Frequency Rise) (Source EIRGRID and SONI)

EUTurbines considers that these frequency traces could represent the system frequency changes expected, as the time with a RoCoF contained between 0.5 Hz/s and 1 Hz/s is higher than 1 s in each of the traces, and several seconds with RoCoF values less than 0.5 Hz/s. In general, EUTurbines considers that RoCoF requirements shall be based onto a credible set of scenarios of contingency events. For the sake of safe grid operation, extreme RoCoF values shall first and foremost be avoided and counter measures evaluated to avoid such case.

EUTurbines urges the EU Grid Operators to implement proper countermeasures – which shall be taken in consideration, including defence plan reactions – to avoid high RoCoF (NC RfG (25)), for example:

- **fast frequency response** requirements applied to units, such as inverter-based generators
- imposed operational limits to **avoid large load imbalance** between regions/countries on the same grid
- Special protection schemes, smart transmission devices, etc.

Verification of capability

For generating units above 1-2 MW, it is not possible in practice to verify the requirements, since there is no laboratory that can provide a virtual grid to be tested, not even taking in consideration all the issues related to logistics. The following are some possible alternatives to evaluate the requirement:

- **Simulation:** the test shall consist of verifying the behaviour of the gas turbine controller, generator and its protection and plant equipment when a frequency variation according to the defined RoCoF is applied. The manufacturer will define the reference conditions used to initialise the controller relevant for the simulation. **Acceptance of compliance, hence, must be limited to stability of the model (e.g. no disconnection) during such simulation.**

- **On-site testing:** due to the impossibility to perform a full RoCoF test under real conditions, an alternative proposal is the **on-site verification that the unit remains connected under the required RoCoF by means of injecting a simulated frequency in the gas turbine controller when this option is available**. Artificial positive and negative frequency changes could be injected and check the reaction of the unit that should not trip. When the unit is capable of load rejection, RoCoF during a load rejection test can be also measured; in this case, the unit shall remain at full speed no load after the test.

It is very difficult, if not impossible to predict and simulate the stability and the limitations of a complex technology like a gas turbine under the extreme conditions of a high RoCoF, due to the complexity of, for example, the combustion process. Additionally, there is almost no operational experience with high RoCoF due to the very limited occurrence of such extreme event and the impossibility of testing it under real conditions.

Therefore, it shall be understood that the above described evaluation criteria will provide a possible expected behaviour. The SPGM cannot be made liable for any unpredictable effects under such severe conditions. Taking the frequency profile as a boundary profile in a real event (like for FRT) might cause conflicts with the requirements for frequency ranges. Therefore, it must be made clear that such profile is just the input for the simulation compliance test.

About EUTurbines

EUTurbines is the only association of European gas and steam turbine manufactures. Its members are Ansaldo Energia, Doosan Skoda Power, GE Power, MAN Energy Solutions, Mitsubishi Hitachi Power Systems Europe, Siemens and Solar Turbines.

EUTurbines advocates an economic and legislative environment for European turbine manufacturers to develop and grow R&I and manufacturing in Europe.

EUTurbines promotes the role of turbine-based power generation in a sustainable, decarbonised European and global energy mix and contributes to the political and regulatory discussions by continuous exchanges with the European institutions and other stakeholders.

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