European Network of
Transmission System Operators
for Electricity

Maximum Admissible Active Power Reduction at Low Frequencies

Draft 1 | 16 November 2020

From: StG CNC

TABLE OF CONTENTS

Description

Introduction

The objective of this implementation guidance document is to determine the main criteria for the national level specification of the capability of PGMs to avoid the reduction of active power output more than an admissible value due to the decrease of frequency decrease following a disturbance.

For the implementation of the relevant parameters it is essential to stress the objective of this requirement and to clarify how it interacts with other frequency stability requirements and external factors such as power plant technology and ambient conditions.

For each synchronous area, proposals for national choices for the non-exhaustive requirement on admissible active power reduction at low frequencies are provided through this IGD.

NC frame

The non-exhaustive requirements are those for which the European level connection network codes (CNCs) do not contain all the information or all parameters which are necessary to apply the requirements immediately. These requirements are typically described in the CNC as “TSO / relevant system operator shall define” or “defined by / determined by / in coordination with the TSO / relevant TSO”.

Regardless of choices that need to be made at national level for this requirement, the frequency-related issues normally require an equitable system-wide response and therefore the collaboration between TSOs at synchronous area level.

The implementation of article 13 (4) of the NC RfG shall establish at least a $P_{max}(f)$-characteristic which falls within the acceptable range defined by the NC RfG. Article 13(5), complementing Article 13(4) clarifies that ambient conditions, for which the characteristics are defined shall be given clearly as these have an important influence on the capability of power generating modules to comply with the requirement. Furthermore, article 13(5) draws specific attention to the fact that some technologies are very sensitive to the value chosen when specifying this requirement. It could make sense to harmonize ambient conditions at EU level and maybe further with existing standards.

For some technologies the compliance with the most onerous possible specification of the requirement may be challenging. Furthermore, system needs also highly depend on the time domain (transient or steady-state) for which the requirement is defined. Both of these aspects would lead to the definition of multiple $P_{max}(f)$-characteristics for different time domains.

Harmonization of the requirement at synchronous area level is needed, especially for the system dynamics driven part of the requirement (transient/dynamic time domain). Harmonization of the technology dependent part of the requirement (steady-state time domain) at synchronous area level would be beneficial to support a level playing field for all grid users.

Finally, the harmonization of the requirement at European level, even if numerical values differ for each synchronous area, should be reached in order to facilitate harmonised technology development and compliance verification as well as comparison and monitoring of the network code implementation.

Further information

Beside the present implementation document, the reader could follow the following implementation guidance documents as given below:

- IGD on parameters related to frequency stability
- IGD on frequency ranges
- IGD on RoCoF
- IGD on FSM

Interdependencies

Between the CNCs

The implementation of the requirement of this article is strongly linked to other frequency parameters in the connection codes, especially to rate of change of frequency (RoCoF), frequency sensitive model (FSM) and frequency range withstand capabilities.

In other CNCs

The characteristic nationally defined for this requirement has a strong impact on the sizing of synchronous area FCR, FRR and UFLS schemes as defined in the System Operation Guidelines[1] (SOGL).

System characteristics

A system frequency drop is always linked to a power imbalance between generation and demand in the system. In order to support the frequency stability and to not impair the system response, it is important that at low frequencies during power imbalances the active power output of PGMs is reduced as little as technically possible from its pre-disturbance operating point. It is worth

[1] *COMMISSION REGULATION (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation*

mentioning that large frequency deviation (i.e. frequency below 200mHz) is expected to be very rare. Nevertheless, the consequence of not having a sufficient support from the running generating units can be significant for the system frequency stability. This justifies the major importance of such requirement to ensure system security and stability.

Such continuous support to the system from the PGMs is needed in different time frames. As mentioned above the exhaustive description of these time frames increases transparency of the requirement and aims at taking technology limitations into account while meeting system needs

Frequency support is needed during the initial frequency transient (immediately after the power imbalance in the network) and until frequency is stabilized. This is addressed by the expected short-term characteristics. This requirement allows the system to remain stable without activating load shedding schemes for a normative incident (e.g. loss of 3 GW for CE). The frequency nadir during the frequency transient response shall not be lower than 49 Hz. The initial time (t_1) of the transient behavior is defined as the minimum time at which the system could reach 49Hz starting from 50 Hz. This is linked to the maximum expected RoCoF (Hz/s), for which the withstand capability is defined (See IGD on RoCoF). The final time (t_2) of the transient behavior is the maximum time needed to stabilize system frequency. This is typically linked to the full deployment time of the FCR.

In addition, this system support is also needed just after frequency has been stabilized and until it is restored to a normal frequency range. This is addressed by the expected steady-state characteristics. This requirement allows the slower automatic and manual action to be well sized and efficiently activated to restore a normal power system operating state. The initial time of the expected medium behavior is aligned with the final time (t_2) of the short-term behavior while the final time (t_3) of the expected medium term behavior is aligned with the expected minimum duration for frequency withstand capability of the power plant as defined by national implementation of the NC RfG article 13(1).

It is important to note that any decrease of active power at low frequencies is detrimental to system security and therefore each generator shall reduce it's active power output as little as technically feasible in such a situation. Therefore, the requirement shall define the maximum admissible active power reduction at low frequencies but no intentional decrease of active power to align the NC requirement will be accepted.

PPMs (and many typologies of SPGM) do not have specific technology limitation within the range defined in the NC for both articles 13(4) and 13(1). Therefore, the maximum admissible active power reduction at low frequencies should be avoided. Taking into account the range defined by the NC, no active power reduction is considered admissible above 49Hz. Below 49Hz, the most stringent value in line with the NC would consider a maximum active power reduction of 2%/Hz to be admissible although it is not expected, as PPMs have no specific technology limitation within this range. This maximum admissible active power reduction at low frequencies would be required from a time (t_1) after the beginning of the frequency transient and until time (t_3) which is aligned with the minimum duration for frequency withstand capability of the power plant as defined by national implementation of the NC RfG article 13(1). The time t_1 is linked to the maximum speed at which the system can reach 49Hz. This is therefore related to the maximum RoCoF which can be expected and linked to the defined withstand capability of PGMs. In line with the IGD on RoCoF where, for the normative incident a value of 2Hz/s could be expected, the recommended value for t_1 is then 0.5s.

No voluntary active power reduction is accepted if the PGM does not have inherent technology constraints, duly demonstrated by the PGM owner.

Differently from PPMs, some SPGMs may have technological limitations to maintain their maximum active power at low frequencies, based on technology-dependent limitations and existing practices reflecting system needs, it is proposed to define two time domain based characteristics as maximum admissible active power reduction at low frequencies: the **transient behavior** and the **steady-state behavior**:

1. For the **transient characteristics**, an approach as already applied in DE and HR is technically reasonable but is hardly reflected by the non-exhaustive requirement defined in NC RfG. Furthermore, no requirements are defined for frequencies below 49Hz. Therefore, it is proposed to develop a similar technical requirement but adapted to the NC framework.
    a. No active power reduction is considered admissible during the observed power system transients for the normative incident above the load shedding frequency threshold. The main aim is to maintain active power output constant until the stage of load shedding is potentially activated.
        i. In presence of a significant amount of SPGM (low PPM penetration), the shortest duration time at which the system can reach 49Hz is expected to be 0.5s. This is in line with the IGD of RoCoF which recommends a withstand capability of 2Hz/s for SPGM, having for consequence that 49Hz could be reached after 0.5s for the normative incident. The desired system value for t_1 would then be 0.5s. However, taking into account current reaction and response limitations of SPGM technologies, a value of $t_1 \leq 2s$ could be acceptable in line with the time defined for similar facts in the context of FSM capabilities2[2].
        ii. The maximum duration of the transient at 49Hz is expected to be linked to the end of the frequency nadir in the worst case incident not leading to load shedding. (e.g. for CE based on SPD simulation and existing national code requirement t_2 equals 30s). For some synchronous areas this time could also be linked to the full deployment time of the FCR (e.g. 30s).
    b. Below 49Hz, the active power reduction is admissible, because load shedding will counteract to further frequency decrease. The slope of the maximum admissible active power reduction at low frequencies should be designed to be less constraining than load shedding equivalent slope (in order to keep a positive system balance). Load shedding is typically designed to reach 45% of load shed at 48Hz. The upper slope (i.e. 2%/Hz) is therefore proposed not to weaken the efficiency of load shedding scheme.

2. Concerning the **steady-state characteristics**
    a. It would make sense to align with the current grid codes where no active power reduction is considered admissible above 49.5Hz. The slope of the maximum

[2] *The initial activation of control actions needed to maintain active power output in case of frequency deviation shall not be unduly delayed. If the delay in initial activation of control actions needed to maintain active power output in case of frequency deviation is greater than two seconds, the power- generating facility owner shall provide technical evidence demonstrating why a longer time is needed.*

admissible active power reduction at low frequencies is limited. Current grid codes are considered admissible, at maximum, an active power reduction of:

DE	(47,5Hz; 20%)	Slope: 10%/Hz
DK	(47.5Hz; 15%)	Slope: 6.0%/Hz
UK	(47Hz; 5%)	Slope: 2%/Hz

b. It would also make sense to have different requirements per synchronous areas, but harmonized within a synchronous area. (e.g. UK, IE = 2%/Hz, CE, Nordic & Baltic = 10%/Hz). However, for countries within the synchronous area which are exposed to a higher risk of islanding (e.g. peninsular area), a more stringent slope of the maximum admissible active power reduction at low frequencies could be defined at time of national implementation of the NC article 13(4) & 13(5). It must be noted that to facilitate the compliance of a PGM with both transient and steady-state characteristics, the latter should be always less constraining than the first ones. This is also in line with the system need for a stronger frequency support in case of transient conditions.

c. Concerning the steady-state domain, it would be desirable to request the active power performance until a time (t3) which is aligned with the minimum duration for frequency withstand capability of the power plant as defined by national implementation of the NC RfG article 13(1). However, in case of limited maximum admissible active power reduction at low frequencies (e.g. 2%/Hz) some technologies, mainly CCGT, have time limitations which should be taken into account. Therefore, in UK and IE, it is recommended to request CCGTs to be able to provide the capability for as long as technically feasible but for a minimum of 5min (t3=5min).

As a summary, for SPGM, the recommended maximum admissible active power reduction at low frequencies for national implementation is:

	parameters	**CE**	**Nordic**	**UK**	**IE**	**Baltic**
transient domain	frequency threshold	49Hz	49Hz	49Hz	49Hz	49Hz
	slope	2%/Hz	2%/Hz	2%/Hz	2%/Hz	2%/Hz
	t1	≤ 2s	≤ 2s	≤ 2s	≤ 2s	≤ 2s
	t2	30s	30s	30s	30s	30s
steady-	frequency threshold	49.5Hz	49.5Hz	49.5Hz	49.5Hz	49.5Hz

state domain	slope	10%/ Hz	10%/Hz	2%/Hz	2%/Hz	10%/Hz
	t3	30min	30min	90min*	90min*	30min

* Except for CCGT where a minimum of 5min is requested

Figure 3 summarizes the proposed characteristics for the maximum admissible active power reduction at low frequencies where the red curve defines the PPM characteristics from t_1 to t_3 and the capability of SPGMs from t_1 to t_2.

The two green curves define the capabilities of SPGMs from t_2 to t_3 for the different synchronous areas (UK&IE on one side and all other SA on the other side)

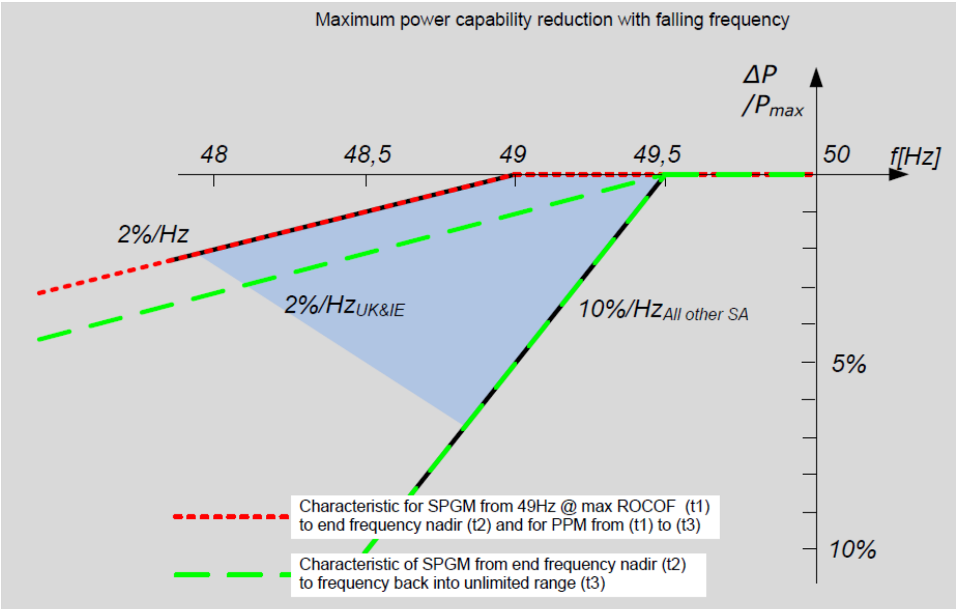

Figure 1 Proposed characteristics for the maximum admissible active power reduction at low frequencies

Concerning the national implementation of article 13(5), it is recommended to require 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 to be shown in the range between -10 to 40ºC. This shall not say that the above requirement is to be met for the whole set of temperatures but rather that this information is important for TSOs to be able to size FCR, FRR, and RR as well as the load shedding scheme and eventually minimum system inertia. Furthermore, the provision of this information will support the verification of compliance of the PGM with the defined requirement.

Furthermore, it is recommended for the national implementation of the NC and for the compliance verification process that these define the following:

- initial voltage defined within the normal operation range. It must be acknowledged that deviation of the voltage outside of the FRT profile or steady-state voltage range could lead to PGM disconnection.

- initial reactive power output at which the capability needs to be proven

- mainly for PPM, the acceptability by the Network Operator of a P over Q priority control scheme at low frequencies.

The UK Grid code defines 25° C as reference ambient temperature to meet the requirements. It is proposed to apply this reference to all technologies. It must be highlighted that CCGTs have been complying with the UK requirement for many years and have developed therefore efficient and cost-effective solutions. The capabilities of these CCGT designs should not be confused with the capability of existing CCGT based on a basic design as illustrated in the Technology Characteristics section below. Altitude between 400 m to 500 m and humidity between 15 to 20 g H_2O/1 kg of air should also be defined.

In addition to the above description of the recommended national implementation of the requirement of maximum admissible active power reduction at low frequencies, a clarification is deemed valuable to understand the interaction between this requirement and the requirements on LFSM-U and FSM. The IGDs on LFSM-U and FSM are defining net additional active power output[3] at low frequencies compared to the active power output delivered by the PGM at 50Hz. This net additional active power output should be demonstrated at the connection point and therefore it is expected that the control system acting on the power of the primary energy source should, in addition to the increase of this power compared to the 50Hz value, further increase this power to compensate for any active power reduction at low frequencies discussed within this IGD.

Technology characteristics

It is important to recall that this requirement defines the capability to maintain the rated active power output of a PGM in case of low frequency with relevance for plant design. It is not an operational requirement and therefore the impact of the availability/unavailability of the primary energy source (e.g. water for hydro power plants) shall not be considered while assessing the compliance of a PGM with this requirement.

Furthermore, as mentioned in the system characteristics sections, the frequency of occurrence of large frequency deviation (i.e. frequency below 200mHz) is expected to be rare. Therefore, it is not recommended to take into account a significant impact on the lifetime and maintenance intervals of the PGM in order to define the technical capability of the PGM when implementing the network code or assessing potential derogation requests.

[3] "where the "net active power output" is the active power exchange between the PGM and the network at the connetion point"

Concerning the requirement itself, the relationship between frequency and active power output capability depends on the generation technology. It is particularly relevant for gas turbines. Gas turbines commonly operated in the power system include a shaft driven air compressor at the turbine inlet. When the CCGT is synchronously connected to the grid any disturbance in the system resulting in decrease of frequency will cause the compressor to slow down. This results in a reduction of the mass flow of air through the turbine and reduction of the active power output of the CCGT. This effect is much stronger at high ambient temperatures. Thus due to this physical phenomenon, gas turbine output drops significantly with falling frequency. To mitigate active power reduction, depending on the machine type and plant configuration different measures can be used (e.g. increasing the gas turbine flame temperature, increasing the air mass flow (by opening fully the compressor valves or by injection of water mist into the air intake of compressor)).

This phenomenon of decreased maximum power capability at low frequencies can be observed as well for other technologies used in the power sector especially if the low frequency is combined with low voltage. Due to reduction in efficiency of auxiliaries, the power generating units are not able to produce maximum power under these conditions. To mitigate this problem an appropriate choice of the auxiliary devices shall be considered at plant design.

In May and June 2017, ENTSO-E has conducted a consultation[4] directed to European stakeholders in order to collect the most up-to-date information concerning the capabilities (present and future) of generating units.

According to the wind industry, wind farms based on full converter technology have very limited reduction of active power at low frequencies. Impact on active power is mainly due to auxiliary equipment and change of losses in step-up transformers.

Additionally, wind farms based on DFIG technology do need to reduce slightly more the active power at low frequencies to compensate the increase of current related to the decrease frequency.

These limitations for wind technology do not prevent wind generation to comply with the most onerous specifications allowed by the RfG. Furthermore, the initial reactive power output and the acceptability of a P over Q priority control scheme at low frequencies could further increase the wind farm capabilities keep constant active power with falling frequencies. Some challenges have also been reported for other technologies, namely internal combustion gas engines or hydro units without that, taking into account the guidance provided in this document, the capability to fulfill the proposed implementation of this network code requirement.

[4] ENTSO-e, "Consultation of Stakeholders on Guidance for Connection Code Implementation of frequency related parameters", May 23rd – June 25th 2017.

The most onerous specifications allowed by the RfG could however be a concern for gas turbines, especially at high temperature. Thermal overloading of the engine at lower frequencies is the main constraint for gas turbine and if the frequency set-point is kept for a longer time, power reduction must be performed below 49 Hz in order to avoid overloading of the engine. The hotter the ambient temperature, the lower the capability to maintain power output at falling frequency. For gas turbines, the decrease of active power is much less at low temperature. Typically, the engines start derating with a rate of 10 %/Hz and operate for unlimited time.

The gas turbine rating is typically specified at ISO condition (15°C).

For existing gas turbines, the following set of steady state curve could be considered as the minimum capability achievable at state-of-the-art basic design for all manufacturers.

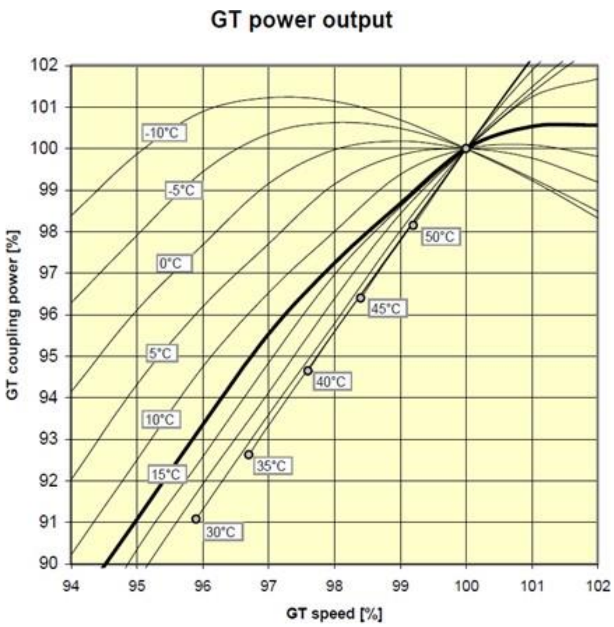

Figure 2 Minimum capability for basic design of existing gas turbines

Collaboration

TSO-DSO

As mentioned above, the transient characteristics should be coordinated at synchronous area level as this impact the sizing of the FCR, UFLS scheme and eventually minimum system inertia. Strong benefits have been highlighted if structure of the requirement, ambient condition and steady state characteristics are also coordinated.

As per the NC RfG, this requirement is defined by the relevant TSO. It must be recalled that it is not an operational requirement.

For DSO connected PGM the operational counterparts should be defined in coordination between TSO and DSO.

RSO-Grid User

Specific attention should be given to the fact that some technologies are very sensitive to the specifications, in particular gas turbines. Discussion between RSO and power generating facility owner is strongly encouraged to ensure better understanding of technical limits of the generating module with taking into account the system needs.

Furthermore, the verification of compliance might be complex and shall be agreed with the power generating facility owner case by case.

Abbreviations

FCR	Frequency Containment Reserve	**PGM**	Power Generating Module
FRR	Frequency Restoration Reserve	**PPM**	Power Park Module
RR	Replacement Reserve	**RfG**	Requirements for Generators
DSO	Distribution System Operator	**RoCoF**	Rate Of Change Of Frequency
FSM	Frequency Sensitivity Mode	**RSO**	Relevant System Operator
IGD	Implementation Guidance Document	**SPGM**	Synchronous Power Generating Module
UFLS	Under-Frequency Load Shedding	**TSO**	Transmission System Operator

Annex 1: Link between GT characteristic and NC RfG non-exhaustive requirement.

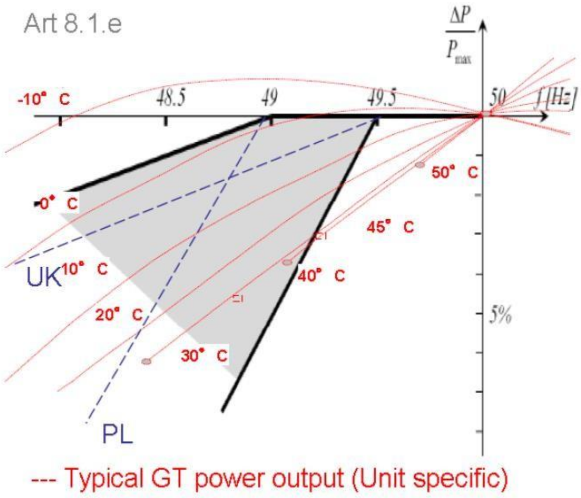

Figure 3 Example of active power output of a typical gas turbine with falling frequency (EU turbines year 2011)