European Network of
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Rate of Change of Frequency (ROCOF) withstand capability

ENTSO-E guidance document for national implementation for network codes on grid connection

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DESCRIPTION

Code(s) & Article(s)	NC RfG: Articles 13 (1) (b) and 15 (5) (b) (iii) NC DCC: Articles 28 (2) (k) and 29 (2) (g) NC HVDC: Articles 12 and 39 (3)
Introduction	The requirement aims at ensuring that power generating modules (NC RfG), demand units offering Demand Response (DR) services (DCC), HVDC systems and DC-connected power park modules shall not disconnect from the network up to a maximum rate of change of frequency (df/dt). A large rate of change of frequency (RoCoF) may occur after a severe system incident (e.g. system split or loss of large generator in a smaller system). The facilities shall remain connected to contribute to stabilize and restore the network to normal operating states.
NC frame	NC RfG and DCC require that the Relevant TSO shall define/require the df/dt (RoCoF), which a power generating module (RfG) or a Demand Unit (DCC) shall at least be capable of withstanding. <u>NC HVDC</u> • Article 12: An HVDC system shall be capable of staying connected to the network and operable if the network frequency changes at a rate between – 2,5 and + 2,5 Hz/s (measured at any point in time as an average of the rate of change of frequency for the previous 1 sec). • Article 39 (3): DC-connected power park module shall be capable of staying connected to the remote-end HVDC converter station network and operable if the system frequency changes at a rate up to +/– 2 Hz/s (measured at any point in time as an average of the rate of change of frequency for the previous 1 second) at the HVDC interface point of the DC-connected power park module at the remote end HVDC converter station for the 50 Hz nominal system. NC DCC, Article 28 (2) (k): • Demand units with demand response active power control (...) shall have the withstand capability to not disconnect from the system due to the rate-of-change-of-frequency up to a value specified by the relevant TSO. With regard to this withstand capability, the value of rate-of-change-of- frequency shall be calculated over a 500 ms time frame.
Further info	Further implementation guidance on NC RfG, NC DCC and NC HVDC: Supporting documentation of HVDC network code: • Network Code for HVDC Connections and DC-connected Power Park Modules - Requirement Outlines (30. April 2014) External supporting documents: • All Island TSO Facilitation of Renewables Studies(see attachment)

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	• Summary of Studies on Rate of Change of Frequency events on the All-Island System (Aug 2012) (see attachment) • Chapter 4 of GB ETYS 2012 diagram on severe reduction in total system inertia 2012 to 2030 (see attachment) • Loss of Mains Protection (see attachment) • RoCoF Alternative Solutions Technology Assessment (see attachment) • Increased Wind Generation in Ireland and Northern Ireland and the Impact on Rate of Change of Frequency[1] • Frequency Stability Evaluation Criteria for the Synchronous Zone of Continental Europe[2] • IGD on High Penetration of Power Electronic Interfaced Power Sources

INTERDEPENDENCIES

Between CNCs	The selection of the maximum (df/dt) values to be withstood needs to be chosen by collaboration between the connection codes in order to ensure equitable behaviour of the relevant system users in case of rapid frequency changes bearing in mind the different scope of application of the CNCs. NC HVDC introduces an explicit limit for HVDC systems (2.5 Hz/s), which is above the limit for DC-connected power park modules (2.0 Hz/s). The rationale behind these choices is to have a margin between the capability of HVDC systems and power generating modules to ensure that HVDC systems will disconnect last in order to enable power generating modules and demand units to contribute to stabilize and restore the network to normal operating states as long as possible.
With other NCs	COMMISSION REGULATION (EU) …/… of XXX establishing a Guideline on Electricity Transmission System Operation, adopted by the EC on 04.05.2016, Article 39 ("Dynamic stability management ")
System characteristics	Rate of change of frequency (ROCOF) is the time derivative of the power system frequency (df/dt). This quantity was traditionally of minor relevance for systems with generation mainly based on synchronous generators, because of the inertia of these generators, which inherently counteract to load imbalances and thus limit RoCoF in these cases. It however becomes relevant now during significant load-generation imbalances (caused by disconnection of either large loads or generators, or by system splits), when larger ROCOF values may be observed because of low system inertia caused by (amongst others) disposal of synchronous generation in case of high instantaneous penetration of non-synchronously connected generation facilities. In the absence of any control, inverter-based generation does not possess such inherent characteristics and high inverter penetration could therefore lead to

[1] http://www.eirgridprojects.com/site-files/library/EirGrid/Increased Wind Generation in Ireland and Northern Ireland and the Impact on Rate of Change of Frequency.pdf
[2] https://www.entsoe.eu/Documents/SOC%20documents/RGCE_SPD_frequency_stability_criteria_v10.pdf

higher ROCOF in a power system. The relationship between inverter penetration and ROCOF is, however, not straightforward, and countermeasures – mostly in the form of control algorithms – need to be implemented carefully.

Large ROCOF values may endanger secure system operation because of mechanical limitations of individual synchronous machines (inherent capability), protection devices triggered by a particular ROCOF threshold value or timing issues related to load shedding schemes.

Initial ROCOF is the instantaneous ROCOF just after the disconnection of either a generator or load from a power system, before any controls become active. This is theoretically the highest system ROCOF. Its average for an interconnection of N synchronous loads and generators can be computed as follows:

$$\left.\frac{d\Delta f}{dt}\right|_{t=0^+} = \frac{f^0 P_k}{2\sum_{i=1,i\neq k}^{N} H_i S_i}$$

wherein Δf is the deviation of the frequency f from its nominal value f^0, 0^+ is the moment just after disconnection of the load/generation P_k is the lost generation/load (the machine carrying the index k), and H_i and S_i are the inertial constant and apparent power rating of synchronous machine i, with i ranging from 1 to N[3].

Additional frequency oscillations may occur locally on top of the average behavior. It should be noted that any system that relies on measuring frequency and ROCOF will most likely not detect a ROCOF as high as the theoretical maximum. This is due to the inevitable filtering involved in frequency measurement[4]. As a result, ROCOF relays with measurement windows of several hundred ms may not be triggered if the initial ROCOF breaches their threshold, but ROCOF is lower subsequently.

To define the RoCoF withstand capability correctly, the characteristics of an entire synchronous area must be considered. The capability shall be determined based on analysis of a normative incident for the network concerned. Such a normative incident could be a defined system split of a large synchronous area with a significant change of inertia and power imbalance in the resulting subsystems (e.g. historic events like the Italy blackout in 2003 and the Continental Europe 3-way split in November 2006). With regard to smaller synchronous areas with low inertia the loss of the largest power generating module or HVDC link may define the normative incident instead (e.g. increase of loss of a single unit up to 1800 MW in GB which would commonly exceed the until recent existing GB threshold level of RoCoF-based Loss of Mains (LOM) protection [0.125 Hz/s][5]).

Since one main concern is the decrease of system inertia, chosen scenarios should reflect situations with low inertia, e.g. high share of non-synchronous

[3] M. Chan, R. Dunlop, F. Schweppe: "Dynamic Equivalents for Average System Frequency Behaviour Following Major Disturbances," IEEE Transactions on Power Apparatus and Systems

[4] S. Engelken, C. Strafiel, E. Quitmann: "Frequency Measurement for Inverter-based Frequency Control," in Wind Integration Workshop, Vienna, 2016

[5] Frequency Changes during Large Disturbances WG ppt (see attachments)

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	renewable generation or high import/export scenarios in case of system splits. For example, on 23rd of August 2015, renewable energy generation in Germany covered 84% of domestic demand[6]. The RoCoF withstand capability should be assessed on not only the present network but also account for the expected capability that will be required over the asset life of concerned installations accounting for future changes in the network and its demand and generation portfolio. Also the capability of existing connected generators will be taken into account. The RoCoF withstand capability should ideally be provided as a change in frequency over a defined time period which negates short term transients and therefore reflects the actual change in synchronous network frequency). However, in practice this may interfere with protective controls of generators or LOM schemes. Hence, changes relevant to protections, e.g. LOM, using RoCoF but driven by other needs can be considered. Other LOM protection systems (e.g. inter-tripping, satellite protection and load shedding[7]) might also be considered as alternative measures. Finally, All-Island studies show large df/dt deviation between different bus-bars for the first few cycles, eventually converging to one value, pointing to the importance of the length of the measurement time window for calculation of df/dt[8].
Technology characteristics	Given the uncertainty on system characteristics and their future evolution, power generating modules need to be robust against changes to the system and shall provide RoCoF withstand capability which accounts for these varying system conditions (e.g. in Ireland, analysis has shown that there will be on average a 25% reduction in on-line synchronous inertia by 2020 which has significant implications for the RoCoF) The scenarios which define the minimum RoCoF withstand capability requirements have to reflect technological changes (e.g. share of generation in operation contributing to system inertia) on the network. Hence, it is important that the RoCoF withstand capability requirement accounts for reduced network strength due to higher penetration of converter-connected components like PPMs, HVDC systems, and demand, when defining these scenarios. The identified minimum RoCoF withstand capability shall apply to all installations regardless of technology. Although the inherent capability may vary for different generation technologies, a single minimum RoCoF withstand capability needs to be required to ensure stability of the network. A common value of RoCoF withstand capability of a synchronous area shall not inhibit a TSO requiring further inherent withstand capabilities not to be unreasonably withheld e.g. to manage system operation of parts of its network which may be exposed to a higher risk of islanding.

[6] https://energy-charts.de/power_de.htm
[7] see attachment on Loss of Mains Protection
[8] see attachment (Summary of studies on Rate of Change of Frequency events on the All-Island System)

DNV KEMA studies for Irish TSOs[9] also show the dependency of individual unit stability on time window size, which higher df/dt values are bearable by generators if the time window is small enough and vice versa. This again indicates the importance of time window size. In addition, leading power factor of generators will increase their vulnerability to high RoCoF values.

According to CENELEC TS50549-1/-2 generating units connected to LV networks with rated current above 16A as well as those connected to MV networks shall be able to operate with rates of change of frequency up to 2,5 Hz/s[10] [11].

Loss of Mains RoCoF type protection & settings, although not explicitly part of Article 13 (1) (b) of NC RfG, are covered in Article 14 (5) (b) on Protection Coordination. These requirements should be carefully set by collaboration.

COLLABORATION

TSO – TSO

Although not explicitly requested in the connection network codes, it would be reasonable to consider collaboration for the RoCoF withstand capability criteria (including) within each synchronous area. This includes the maximum RoCoF value to be withstood, the size of measurement rolling window but also frequency and RoCoF measurement technique. Therefore, TSO – TSO collaboration within a synchronous control area would ensure that a minimum RoCoF withstand requirement is applied to all relevant system users.

TSO – DSO

Based on article 13 (b), a power-generating module shall be capable of staying connected to the network and operate at rates of change of frequency up to a value specified by the relevant TSO, unless disconnection was triggered by rate-of-change-of-frequency-type loss of mains protection. The relevant system operator, in coordination with the relevant TSO, shall specify this rate-of-change-of-frequency-type loss of mains protection.

RSO – Grid User

The relevant system operator needs to take care, that the parameters of RoCoF withstand capability defined by the relevant TSO are applied to system users.

[9] https://thales.entsoe.eu/sites/al/ImplementationGuidances/XIGD09_8.pdf?Web=1

[10] https://www.cenelec.eu/dyn/www/f?p=104:110:1376998791841501::::FSP_ORG_ID,FSP_PROJECT,FSP_LANG_ID:1258595,53799,25

[11] https://www.cenelec.eu/dyn/www/f?p=104:110:1376998791841501::::FSP_ORG_ID,FSP_PROJECT,FSP_LANG_ID:1258595,45870,25

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