

Demand Response – System Frequency Control

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

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Description

Code(s) & Article(s)

COMMISSION REGULATION (EU) 2016/1388 of 17 August 2016 establishing a Network Code on Demand Connection.

- Article 29 (2) – Specific provisions for demand units with demand response system frequency control

Introduction

The objective of this implementation guidance document is to support the definition of the main criteria/motivation for the recommended settings as well as the applications of the demand response system frequency control (DR SFC) capabilities of demand units of a synchronous system on a national level.

For the specification of the relevant parameters it is essential to be aware of the objective of DR SFC, the deployment strategies that can be applied and to understand its interaction with other frequency stability related requirements and assumptions for a system defence plan.

In order to implement comprehensively the DR SFC capabilities, this implementation guidance document will look beyond the DR SFC in the NC DCC, considering the proposed settings for LFSM outlined in other guidance documents.

For each synchronous area, proposals for national choices of the non-exhaustive DR SFC parameters are provided in this IGD.

NC frame

The non-exhaustive topics are those for which the European level CNCs do not contain all the information or 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”.

Although choices need to be made at national level, for frequency-related issues this normally requires a system wide response and therefore collaboration between TSOs at synchronous area level is necessary.

See also the general IGD on parameters related to frequency stability.

Further information

- IGD on parameters related to frequency stability
- IGD on frequency ranges
- IGD on Frequency Sensitive Mode (FSM)
- IGD on Limited Frequency Sensitive Mode (LFSM)
- IGD on admissible power reduction at low frequencies

Interdependencies

Between CNCs

Response to frequency variations requires a coordinated response from all parts of a synchronous network and all users who provide frequency response. Therefore there must be a coordinated frequency response across the network extending to not only the different interconnected countries, but across the interconnected network within the country i.e. DSOs, CDSOs and the users themselves. Also there must be collaboration between all of these parties as we move typically from:

- an early response (i.e. FSM, DSR SFC) even to small frequency variations to,
- a response (i.e. LFSM, APC, DSR SFC) to larger frequency variation, and;
- Finally a last response (LFDD or generator over frequency disconnection) as a last response to avoid network collapse

Related Network Code sections:

- RfG, Article 13(2) [LFSM-O]
- RfG, Article 15(2)(c) [LFSM-U]
- RfG, Article 15(2)(c) [FSM]
- HVDC, Article 13(3) [LFSM-O/-U, FSM]
- HVDC, Article 39(4) [LFSM-O]
- HVDC, Article 39(7) [LFSM-U]
- HVDC Article 51(2)(a)(viii) [LFSM-O/-U, FSM]
- HVDC Article 52(b) [LFSM-O/-U, FSM]

In other NCs

SO GL Part IV Title 5 [FCR] sets out the principle and operation of containment reserve. These will need to be considered when selecting settings for DR SFC as the predicted scale of and settings applied to DR SFC will provide a contribution to addressing the need for containment reserve.

Consequently the need for alternative sources will reduce and modelling of adequacy of the defence plan will also need to take DR SFC into account. As FCR will change over time dependent on system configuration and loading in future years, it will not define the DR SFC settings, but rather need to be reflective of DR SFC quantities and settings.

System characteristics

System frequency typically deviates from its nominal value when an imbalance occurs between load and generation. Such a deviation occurs under normal operating conditions as a result of a mismatch between the actual system load and load forecasts, on which dispatchable generation is scheduled. Another source of load imbalance is the loss of generation or demand due to a failure in the customer installation or the network or changes in intermittent generation (i.e. most non-synchronous units). System frequency increases in case of a generation surplus and decreases in case of lack of generation, because of an acceleration or deceleration of the rotating masses of synchronously connected generators.

In order to cope with and compensate such frequency deviations, frequency containment reserves (FCR) are deployed by generators running in frequency sensitive (FSM) mode. According to NC RfG type C and D power generating modules shall be capable of providing of FCR. Within a synchronous area FCR is dimensioned to keep the system frequency within a defined operational range based on a reference incident. For example, the relevant design criterion, for the Continental Europe (CE) synchronous area, is to keep the steady state system frequency within 50.0 Hz +/- 200 mHz in case of a load imbalance of +/- 3.000 MW.

Nonetheless more severe disturbances exceeding this FSM reference incident cannot be excluded. These disturbances may occur in particular, if an interconnected system splits into separate parts each with a high load imbalance, due to a high-power exchange between these parts before the disturbance. In such cases frequency deviations larger than 50.0 Hz +/- 200 mHz could be expected in the CE synchronous system.

LFSM-O and LFSM-U are to be activated, when the system is in an emergency state after a severe disturbance, which has resulted in a major generation surplus and the frequency deviation cannot be mitigated by the FCR resources only. In such cases FCR resources has been fully deployed, but system frequency cannot be stabilized and increases further triggering LFSM to respond.

The active power decrease or increase of all power generation modules according the LFSM-O or LFSM-U specifications shall support stabilizing the system at a frequency after FCR has been exhaustively deployed to avoid a system collapse and gain time for further operational measures for frequency modulation.

The rate of change of frequency (RoCoF) and the magnitude of the deviation due to a load imbalance are highly dependent on the transient dynamic behaviour of the interconnected system in the case of loss of either generation or demand. This transient behaviour is determined by the system inertia, which is typically lower for small synchronous areas such as Ireland or GB, where a single loss of a generator or HVDC interconnector can result in a change in system frequency that is markedly greater than what could be in CE synchronous area.

However, given the elevated complexity and risk for the larger more integrated networks of system splits these are considered a reasonable design case to be taken into account. For system splits large transients in frequency need to be withstood and mitigated as well. Furthermore, the opposition to the size of frequency shift from system inertia tends to continuously decrease with the increasing instantaneous penetration of renewable energy sources (RES). This is due to the progressing displacement of synchronous generators by non-synchronously connected power park modules.

This leads naturally to the need for a faster and/or larger response in future to arrest a change in frequency and restore the nominal frequency. It is therefore evident, that response time is a crucial factor of the operation of any and all frequency response resources.

An alternative to adjusting generation output to address the load and generation balance is to adjust demand using DR SFC. In principle DR SFC could contribute to simulate either or both FSM, LFSM or a combination of both.

Every power demand unit that has a latent thermal store, for example refrigeration, space heating/cooling, water heating/cooling and any other heating/cooling device could be used to provide DR SFC. Given the normal percentage of load that these devices make up, it is conceivable for all system requirements for frequency response provided by FSM and/or LFSM could be provided by DR SFC.

Frequency sensitivity increases at low system inertia and at these times frequency support activation is more frequent. Therefore there is an increasing need for greater capability to adequately respond in such situations as the level of non-synchronously connected generation increases. DR SFC has the potential to provide any increased capability.

Technology characteristics

In principle, a DR SFC service can be provided by every power demand unit that has an inherent thermal store, for example refrigeration, space heating/cooling, water heating/cooling and any other heating/cooling device.

The CNCs describe only the necessary functionality of this requirement, as innovative technical solutions are to be made possible. The use of an external signal to trigger the DR-SFC function is not permitted in order to ensure that the required triggering time is achieved without delays. This is due to the need to ensure the necessary speed and reliability of such a function to control the system frequency and to avoid cascade losses in generation and load which would lead to system failures and potentially a blackout.

The trigger for this function is a threshold value of the system frequency deviation from the nominal value. The value of the system frequency can be measured at the connection point of any device within the demand system facility. This makes it possible to integrate the entire control and operation of the DR-SFC into the corresponding device, thus minimizing costs and effort. In fact, devices with a built-in DR-SFC controller, based on plug and play solutions, are already available on the market.

Given the way this service can be provided and the availability of series products, factory tests for the DR- SFC shall be accepted. Tests on the system itself shall only be performed for larger modules demand units as part of the commissioning test. For small demand units/modules a certificate of NC compliant functioning of the DR SCC by the manufacturer within the conformity process should be sufficient.

The reason that a factory test could be acceptable approach is with the predicted failure rates of the devices. When performing factory tests, failure rates of the units are also determined based on the construction reliability. This data can be used to estimate the full potential of the frequency response of the entire integrated equipment in operation.

The deployment strategy of this technology is also important before discussing recommendations for DR SFC non-exhaustive parameters settings.

DR SFC can be considered a 'new' service from demand units. In the past demand response services have made use of the thermal store of some demand units. However, these have not provided an automated individual unit designed through aggregation to provide a proportional controlled respond to frequency deviations.

Consequentially it is recommended that the utilisation of the capability has a phased introduction to develop assurance of its performance and develop tools and techniques to maximise the operational capability that the service provides. An added desirable outcome of this approach would be the time provided to industry and markets to develop a reflective market to stimulate, whilst finding the lowest cost market model to administrate and fairly recompense the service.

The unique automated aggregated nature of the individual responses allows this phased introduction to be more flexible than traditional services. Traditionally the capital commitment in purchasing and installing generation makes later modification to its capabilities expensively and practically prohibitive. However, the cost of conversion of demand devices to DR SFC is by comparison modest with the demand unit being bought for other purposes. Many of these devices are also demand units that are built with the expectation of a much shorter operational life, and high replacement rate than generation units (c.10 years to 40 years respectively). Also, these smaller demand units can be fitted for operation from energisation (i.e. plugged in) without the necessity of commissioning of the controller or its settings.

Therefore, it is recommended that settings that mimic those of LFSM-U and LFSM-O applied to generator units are initially selected for DR SFC operation. This will allow real life experience,

modelling tools and operational practice to develop as the number of units rise within a system. As this experience develops more reactive frequency response settings could then be selected for the non-exhaustive parameters moving DR SFC reducing the dead-band range (see below) and thereby making DR SFC provide an earlier response within the FSM response range.

To be clear this does not require (although nor does it inhibit) existing units to be modified to move to these new settings. The move to the new DR SFC frequency response settings globally in a system will be achievable through the combination of natural replacement of demand units and new units being installed. Given that most users already have demand units that could provide this response and these units will have an assumed 10 year replacement cycle, at least 10 years would be required to replace the fleet of demand units. Therefore periodic updates at 3 yearly periods (based on review period foreseen in the network codes) would allow for at least 3-4 changes in settings in that period.

This offers the opportunity to make ongoing adjustments to DR SFC frequency response settings without the need for a logistically difficult replacement of settings of installed and operational demand unit equipment.

Concerning the DR SFC frequency response settings the NC DC requires that the following non-exhaustive parameters are defined at a national level:

- Be equipped with a control system that is insensitive within a deadband around the nominal system frequency of 50,00 Hz, of a width to be specified by the relevant TSO in consultation with the TSOs in the synchronous area.’ DCC Article 29(2)(d)
- The maximum frequency deviation from nominal value of 50,00 Hz to respond to shall be specified by the relevant TSO in coordination with the TSOs in the synchronous area.’ DCC Article 29(2)(e)
- The demand unit shall be capable of a rapid detection and response to changes in system frequency, to be specified by the relevant TSO in coordination with the TSOs in the synchronous area.’ DCC Article 29(2)(g)
- For demand units connected at a voltage level below 110 kV, the non-exhaustive parameters for Article 29(2) (d) and (e) as set out above shall, prior to approval in accordance with DCC Article 6, be subject to consultation with the relevant stakeholders in accordance with DCC Article 9(1)

Due to the system-wide effect of frequency-related issues a harmonised setting of these parameters to be installed into demand units within a synchronous area is desirable and maybe essential¹. If these responses are not harmonised adverse impacts can occur, which may

¹ Noting that these parameters may be adjusted periodically over time for the reasons discussed above

aggravate the changes in system frequency the response is trying to rectify. For example, diverging frequency thresholds between control blocks may result in unwanted load flow patterns, if in one control block generators already change active power output while generators in another control still remain “silent”. A comparable effect may occur in case of diverging droop settings. Hence it is recommended to align these parameters at synchronous area level. However, it is recognised that as DR SFC is an aggregated response over many units the likely spread and scale of the unit involved will assist in dampening the risk of these undesirable outcomes.

In order to best coordinate active power response by DR SFC with the provision of FCR, it is recommended to activate it at full deployment of FCR, i.e. to set the frequency threshold such, that there is no overlap or gap between FCR and the initiation of DR SFC. Hence, the following frequency threshold are recommended to define the width of the non-exhaustive dead-band parameter for each synchronous area:

Synchronous area	Under frequency threshold	Over frequency threshold
Continental Europe	49.8 Hz	50.2 Hz
Nordic	49.5 Hz	50.5 Hz
Great Britain	49.5 Hz	50.5 Hz
Ireland	49.5 Hz	50.2 Hz
Baltic	49.8 Hz	50.2 Hz

The full capability of DR SFC as selective shedding of non-essential loads should be activated by frequency before LFDD is operated as non-selective load shedding also affecting essential loads. This will ensure that non-essential loads offered for DR SFC are disconnected before the need to shed essential loads. In this context essential load means an electricity consuming device which the final user directly utilizes and will notice any reduced operation, whereas the non-essential load has an internal buffer which decouples the energy consumption from the practical use. This sets the under frequency non-exhaustive maximum frequency deviation parameter for each synchronous area.

The recommended parameters for the over frequency non-exhaustive maximum frequency deviation for each synchronous area should be set to raise demand to avoid unnecessary loss of generation due to over frequency. This will ensure that generators remain available for short term frequency fluctuations giving time for adjustments to their and HVDC circuits output power to restore frequency within a normal operating range. Failure to do so has the potential to create secondary problems, for example with the loss of inertia and reactive power management which may be instrumental in being able to manage this situation. This sets the over frequency non-exhaustive maximum frequency deviation parameter for each synchronous area.

Consequential the recommended non-exhaustive maximum frequency deviation parameters for each synchronous area are:

Synchronous area	Under frequency maximum frequency deviation	Over frequency maximum frequency deviation
Continental Europe	49,00 Hz	51,50 Hz
Nordic	48,70 Hz - 48,80 Hz	51,50 Hz
Great Britain	48,80 Hz	52,00 Hz
Ireland	48,85 Hz	52,00 Hz
Baltic	49,00 Hz	51,50 Hz

Finally, one of the key determinates in ensuring DR SFC is commercially implementable was the cost of the sensor of the system frequency. This was particularly important for smaller units (for example domestic white goods). The accuracy limits of 50mHz in NC DC Article 29(2)(g) was selected after discussion with manufacturers to avoid unnecessary increased costs. This means that every unit will measure frequencies with an offset of up to +/-50mHz, so that for example the reference 50Hz of the system with an offset between 49.95Hz or 50.05Hz. However once this offset is accounted for each device will be accurate to within the 10mHz accuracy level across its response as set out also in Article 29(2)(g). As a result a variation of +/- 50mHz in the reading of individual DR SFC units will be balanced out applying the rules of probability for a high number of units. This means that these accuracy levels should not have a material bearing on the setting selection.

Admissible frequency offset of sensor from the nominal frequency is +/-50 mHz. Insensitivity of frequency measurements is +/-10 mHz.

Collaboration

TSO-TSO

DR SFC in combination with all non-exhaustive frequency settings shall be coordinated at synchronous area level. The main motivation is to set a coordinated activation of frequency response in case of frequency deviation. The frequency threshold and droop shall be explicitly coordinated among countries of the same synchronous area.

TSO-TSO

Activation of DR SFC is considered as an automatic function. In specific cases the increasing or decreasing of active power it could cause a overloading of lines due to change of power flow in local area.

However the reduction of load should not present an unforeseen event as all DSOs have to design and plan their network to account for periods of extremely low and at times zero demand. However increased load, depending on the scale of DR SFC embedded into a network, may exceed the diversification factor of load used in the design of the network.

The diversification factor is the proportion of the maximum contracted load demand which is considered to necessary to plan for. This level is set considering a balance between the cost of network development and risk of occurrence.

Therefore it is anticipated that the DSOs will monitored the increasing levels of DR SFC to ensure that any local constrains in their own area are known and a suitable strategy for managing these can be sought.

RSO – Grid User

The setting parameters will not normally need to be discussed with the demand facility owners as most applications should be installed at source by manufacturers. However in some instances for large scale facilities consideration it may be prudent to consider and discuss the interaction of DR SFC with other protection and control strategies onsite. This may be more relevant where other DR services are to be provided.

Abbreviations

Abbreviations			
APC	Active Power Control	LFDD	Low Frequency Demand Disconnection
CDSO	Closed Distribution System Operator	LFSM	Limited Frequency Sensitivity Mode
CDS	Closed Distribution System	PGFO	Power Generating Facility Owner
DCC	Demand Connection Code	PGM	Power Generating Module
DF	Demand Facility	PPM	Power Park Module
DR	Demand Response	RfG	Requirements for Generators
DU	Demand Unit	ROCOF	Rate Of Change Of Frequency
DSO	Distribution System Operator	RPC	Reactive Power Control
FSM	Frequency Sensitivity Mode	RSO	Relevant System Operator
HVDC	High Voltage Direct Current	SFC	System Frequency Control
IGD	Implementation Guidance Document	TSO	Transmission System Operator

References

- [1] Frequency Stability Evaluation Criteria for the Synchronous Zone of Continental Europe, RG-CE System Protection & Dynamics SubGroup, March 2016. Available:
https://eepublicdownloads.entsoe.eu/clean-documents/SOC%20documents/RGCE_SPD_frequency_stability_criteria_v10.pdf
- [2] Ddispersed generation impact once region security, dynamic study 2014 report update, 11-12-2014. Available:
https://www.entsoe.eu/Documents/Publications/SOC/Continental_Europe/141113_Dispersed_Generation_Impact_on_Continental_Europe_Region_Security.pdf
- [3] Technical background and recommendations for defence plans in the continental europe synchronous area, system protection and dynamics- regional group continental europe, 26.10.2010. Available:
https://eepublicdownloads.entsoe.eu/clean-documents/pre2015/publications/entsoe/RG_SOC_CE/RG_CE_ENTSO-E_Defence_Plan_final_2011_public.pdf