European Network of
Transmission System Operators
for Electricity

Demand Response – System Frequency Control

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

11 October 2017

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DESCRIPTION

Code(s) & Article(s)	• Demand Response System Frequency Control (DR SFC): o NC DCC – Article 29(2)
Introduction	Demand response is an important instrument for increasing the flexibility of the internal energy market and for enabling optimal use of networks. It should be based on customers' actions or on their agreement for a third party to take action on their behalf. A demand facility owner or a closed distribution system operator ('CDSO') may offer demand response services to the market as well as to system operators for grid security. In the latter case, the demand facility owner or the closed distribution system operator should ensure that new demand units used to provide such services fulfil the requirements set out in this Regulation, either individually or commonly as part of demand aggregation through a third party. In this regard, third parties have a key role in bringing together demand response capacities and can have the responsibility and obligation to ensure the reliability of those services, where those responsibilities are delegated by the demand facility owner and the closed distribution system operator. The objective of this guidance document is to help to determine the main criteria/motivation for the recommended settings and applications of the DR SFC capabilities of demand units at a synchronous system and national level. For adequate specifications 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 how it interacts with other frequency stability requirements and assumptions for a system defence plan. In order to implement comprehensively the DR SFC capabilities, this implementation guidance will look beyond only 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 for 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 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.

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Further info	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 the 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, RPC, 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 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 defense 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 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 control methodology for the devices is only limited to functionally in the network codes to permit innovation in the implementation of the requirements. However it is recognised in the functionality that the necessary operation time prohibits the use of an external signal to trigger the DR SFC response. This is due to the importance, speed and reliability which are required to manage system frequency and avoid cascading loss of generation or demand leading to system blackouts. The trigger for this service is a change in system frequency which may be measured at the supply point of any device connected within a demand facility. This may be achieved by measuring the frequency from its electrical supply. Therefore the entire control and operation of DR SFC can be built into the device, minimising cost and complexity. In effect a device can be bought with a DR SFC controller built in and simply ‘plugged in’ to become operable. A typical response of DR SFC is to turn a device, connected within a demand facility, on or off. Given the nature of the way this service can be provided, and the aggregated nature of the response of all demand devices, it should be acceptable for factory testing of the DR SFC completed by the manufacturer. Therefore tests of this service should only be considered for larger facilities which are already subject to commissioning tests for other network code connection requirements. The reason that a factory test could be acceptable approach is with the predicted failure rates of the devices (based on their design reliability) a correction based on the number of units shown can be made to estimate the full potential of the installed devices in service. 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 operationally 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 deadband 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 DCC requires that the following non-exhaustive parameters are defined at a national level:

- *'be equipped with a control system that is insensitive within a* ***dead band*** *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 essential[1]. If these responses are not harmonised adverse impacts can occur, which may 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	50.4 Hz
Ireland	49.5 Hz	50.2 Hz
Baltic	tbd	Tbd

For the same reasons to avoid the need to implement arbitrary loss of demand customers with Low Frequency Demand Disconnection the full capability of DR SFC should exhausted before LFDD is operated. This will ensure that non-essential load offered for DR SFC by demand users is disconnected before their essential load. 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 parameter for each synchronous area are:

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

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Synchronous area	Under frequency maximum frequency deviation	Over frequency maximum frequency deviation
Continental Europe	tbd	Tbd
Nordic	tbd	Tbd
Great Britain	tbd	Tbd
Ireland	48.9 Hz	51.1 Hz
Baltic	tbd	Tbd

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 DCC Article 29(2)(g) was selected after discussion with manufacturers to avoid unnecessarily increased costs. This means that every unit will measure frequencies with an offset of up to +/-50 mHz, so that for example the reference 50 Hz of the system with an offset between 49.95 Hz or 50.05 Hz. However once this offset is accounted for each device will be accurate to within the 10 mHz accuracy level across its response as set out also in Article 29(2)(g). As a result a variation of +/- 50 mHz 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.

COLLABORATION

TSO – TSO	*DR SFC in combination with all non-exhaustive frequency settings shall by 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 – DSO	*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.*

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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**	Regional System Operator
HVDC	High Voltage Direct Current	**SFC**	System Frequency Control
IGD	Implementation Guidance Document	**TSO**	Transmission System Operator

Reference

[1] Frequency Stability Evaluation Criteria for the Synchronous Zone of Continental Europe, RG-CE System Protection & Dynamics Sub Group, March 2016. Link: https://www.entsoe.eu/Documents/SOC%20documents/RGCE_SPD_frequency_stability_criteria_v10.pdf

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