CONTINENTAL EUROPE SIGNIFICANT FREQUENCY DEVIATIONS – JANUARY 2019

European Network of
Transmission System Operators
for Electricity

entsoe

ABOUT ENTSO-E

ENTSO-E, the European Network of Transmission System Operators for electricity, represents 43 electricity transmission system operators (TSOs) from 36 countries across Europe.

ENTSO-E was established and given legal mandates by the EU's Third Legislative Package for the Internal Energy Market in 2009, which aims to further liberalise the gas and electricity markets in the EU.

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CONTENT

EXECUTIVE SUMMARY

From 9 to 11 January, the Continental Europe Synchronous Area faced a significant frequency and time deviation due to the convergence of the following two main events:

- The Deterministic Frequency Deviation (DFD) during the evening peak-load at the hourly schedule transition;
- A long-lasting frequency deviation (average – 30 mHz) caused by a technical failure given by a frozen measurement on four tie lines between TenneT Germany and APG grids, which affected the Load Frequency Controller (LFC) of both the TenneT Germany Control Area and the Germany Control Block.

MAVIR control centre

After ex post analysis, the recorded data identified hour 13:25 on 9 January as the triggering moment of the long-lasting frequency deviation. Even though it was difficult to detect, the deviation was identified on the morning of 10 January at 10:00 by the Region Continental Europe Coordination Centres (TSOs responsible for scheduling, accounting coordination and system frequency monitoring, Amprion for the Northern part of Europe and Swissgrid for the Southern part).

An extensive analysis was carried out on 10 January but it was not possible to determine clearly the cause based on the available information. The sum of the Area Control Error (ACE) for Continental Europe North and Continental Europe South was even positive, which contradicted the low frequency observations. The Coordination Centres decided at 12:30 on 10 January to contact TSOs, pointing out that there was a long-lasting frequency deviation, and asked TSOs to investigate the reasons.

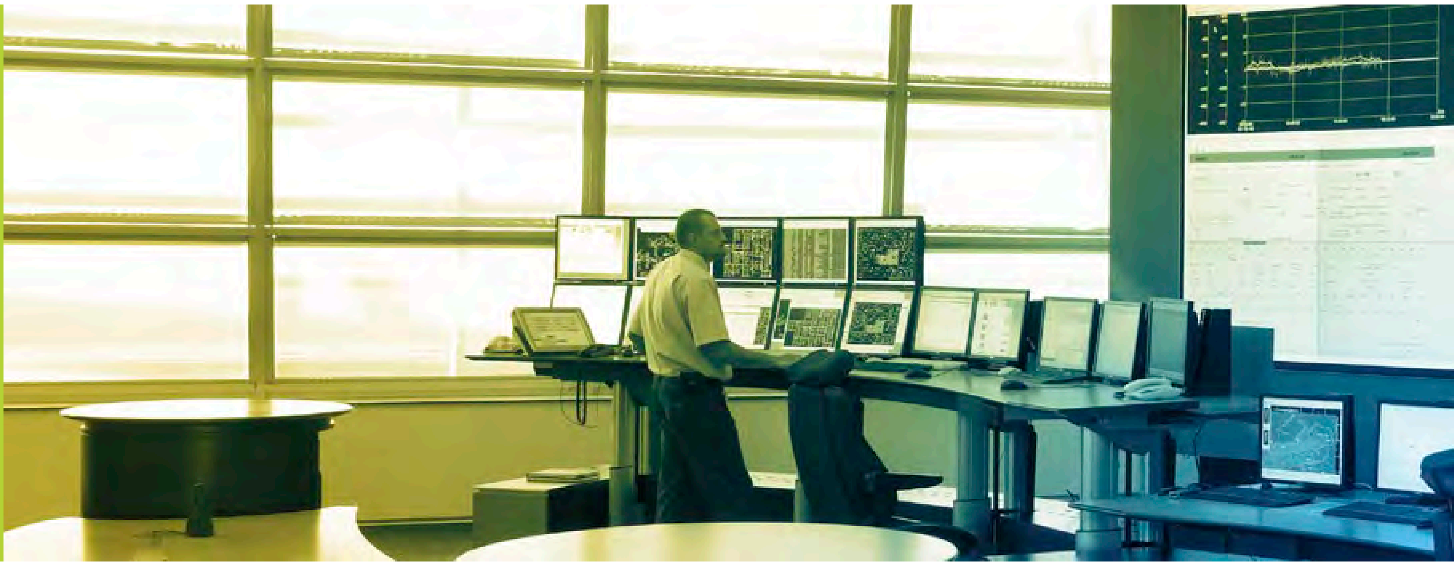
The cumulative effect of the permanent frequency deviation due to the frozen measurement on the four tie lines, in addition to the significant evening DFD, culminated on 10 January at 21:02 when the steady-state frequency in the Continental European system reached 49.808 Hz. This was a significant frequency deviation where the frequency entered the alert state range, as defined in the System Operation Guideline (SO GL), for 9 seconds (the criteria for emergency state was not reached). However, the frequency was low enough for RTE to automatically reduce approximately 1.7 GW of load through the Industrial Interruptible Service, which, in addition to activated Frequency Containment Reserves (FCR) across all control areas, quickly supported the restoration of the frequency to within the normal frequency range. The activation of the Industrial Interruptible Service and of FCR made it possible to stop the frequency drop, without entering the “emergency range” of frequency, for which additional schemes exist. The superposition of DFD and the long-lasting frequency deviation on the 10 January led to the largest absolute frequency deviation in the Continental European Power System since 2006 (when the frequency dropped to 49.0 Hz).

In order to prevent further significant frequency deviations TSOs held a number of coordination teleconferences in which mitigation measures were agreed. These teleconferences where held regularly until the measurement error was detected and corrected by TenneT Germany on 11 January at 09:37.

The Sequence of Events between 9 January to 11January are detailed in this report and an in-depth analysis of those events from ENTSO-E perspectives has been completed by a dedicated Task Force.

This incident is classified as per the Incident Classification Scale as a scale 1 incident for Frequency (F1) as the Continental Europe steady-state system frequency was violated by more than 100 mHz for 5 minutes and 9 seconds.

Further in-depth analyses of the causes and impacts of Long-Lasting and Deterministic Frequency Deviations are completed and solutions to reduce and/or eliminate their effects have been identified.



THE FOLLOWING CAUSAL FACTORS HAVE BEEN IDENTIFIED BY THE TASK FORCE:

1. No efficient incentives in place for market participants or control tools/processes in place to avoid significant DFDs;

2. Frequency Containment Reserves are designed to stabilise the system frequency and are effective for other imbalance patterns than those causing DFDs. Hence, Frequency Containment Reserves are not dimensioned to prevent significant DFDs;

3. A single point of failure in processing nominal and backup values in a specific case of four interconnector lines;

4. The current monitoring tools and alarming systems are not applicable for this kind of error;

5. Current process and procedure for detecting long-lasting frequency deviations does not have criteria for deviations below 50 mHz.

The Task Force recommends that the CE DFDs are addressed by TSOs, Market Parties and other external stakeholders to mitigate the occurrence and impact of stressed situations. The Task Force further recommends that an analysis is carried out to determine a step-by-step approach in order to implement solutions to DFDs (for example, including how much additional reserves should be procured in CE until additional solutions to DFDs are in place). TSO's Tools, Processes and Procedures should be further improved to detect measurement errors more quickly and to mitigate the effects of long-lasting frequency deviations.

APG CONTROL ROOM

THE TASK FORCE RECOMMENDS THE FOLLOWING ACTIONS:

1. Analysis to be completed to determine how much additional reserves should be procured until Market or TSO based Solutions to DFDs are implemented;

2. Consultation document to be developed by ENTSO-E to consider Market and/or TSO proposals to mitigate DFDs;

3. Set Frequency Quality Targets which define acceptable levels of DFD;

4. Check the existing Definition and Implementation of fail-safe measurement and telecommunication standards, for all interconnectors values used by LFC across CE and identify follow-up actions as necessary. Define and implement control system functionality standards to detect "frozen" LFC values across CE;

5. Centralised process and tools to facilitate the timely resolution of frequency deviation incidents to be reviewed and improved.

1. INTRODUCTION

A long-lasting steady-state frequency deviation of 0 to maximum −60 mHz (average −30 mHz) began on Wednesday, 9 January 2019 at 13:25 and persisted until 11 January 2019 at 09:37. The synchronous time deviation increased from −14 seconds on 9 January to −84 seconds on the 11 due to this low steady-state frequency deviation in Continental Europe (CE). At 21:02 on 10 January, this long-lasting steady-state frequency deviation coincided with a Deterministic Frequency Deviation (DFD) which quickly caused the frequency to decrease to a value of 49.808 Hz.

APG CONTROL CENTRE

RTE automatically reduced approximately 1.7 GW of load through the Industrial Interruptible Service, which in addition to activated Frequency Containment Reserves (FCR) in all other control areas helped the frequency to return quickly within the normal frequency range. At 09:37 on 11 January, the origin of the long-lasting frequency deviation was detected and solved, returning the frequency to its normal pattern. It should be highlighted that, in all cases, the frequency values did not reach the Emergency state as defined in the System Operation Guideline (SO GL) [1].

The long-lasting steady-state frequency deviation was caused by the drop of a telecommunication line between substation St. Peter (APG, Austria) and substation Simbach (TenneT Germany), which stopped the measurement value transmission to TenneT Control Center South. The frozen measurement values in the load frequency controller of TenneT DE led to an error in the calculation of Area Control Error (ACE) for TenneT DE and subsequently in the German LFC block. The ACE error produced an incorrect imbalance of up to 1,000 MW. There was no problem on the APG side as APG LFC used measurement values from a different source.

The phenomena of DFD occurs daily in the CE Power System for many years. These market driven imbalances occur during the morning and evening ramping periods. During the period between 9 and 11 January, there were five DFDs, which in addition to the TenneT DE measurement error, caused frequency deviations greater than 100 mHz from nominal (50 Hz).

DFDs usually occur around the change of the hour and the related peak to peak change of frequency can reach up to 200 mHz. During the period of the frequency excursion, lasting usually 15 – 20 minutes, a large amount of Frequency Containment Reserves (FCR) and automatic Frequency Restoration Reserves (aFRR) are activated. The superposition of DFD and the long-lasting frequency deviation on the 10 January led to the largest absolute frequency deviation in the CE Power System since 2006 (when the frequency dropped to 49.0 Hz [2]). Almost all the FCR was fully activated per product specifications and the CE Power System at that moment was not able to withstand an additional large disturbance without affecting the availability of supply to all consumers, i.e. without further measures such as the use of further Industrial Interruptible services or load-shedding.

The permanent long-lasting deviation of the Serbia, Macedonia and Montenegro (SMM) control block also affected the frequency between 9 and 11 January, the average hourly ACE of the SMM CB being –83 MW. However, SMM CB did not participate in the large frequency deviation at 21:02 on 10 January as the EMS Control Centre observed the low frequency and took preventive action and did not disconnect, as planned, a 300 MW pump-storage unit that was running in generation mode.

2. SEQUENCE OF EVENTS FROM 9 JANUARY TO 11 JANUARY

After ex post analysis, the recorded data marked hour 13:25 on 9 January as the triggering moment of the event. The frequency decreased slightly and the CE time deviation started slowly to increase from this time. Even though it was difficult to detect, the Continental Europe Coordination Centres identified this deviation on the morning of 10 January at 10:00. The frequency deviations continued until a measurement error was detected and corrected by TenneT DE on 11 January at 09:37. Five frequency deviations > 100 mHz (due to DFDs and TenneT DE measurement error) occurred during this period, the largest occurring on 10 January at 21:02 when the steady state frequency in the CE system reached 49,808 Hz.

The following section is a factual sequence of events listed chronologically.


PICTURE COURTESY OF TENNET

EVENT OPERATIONAL TIMESCALES

9 JANUARY

13:25 CET

A technical failure of measurement on four tie-lines connecting German and Austrian networks triggered a frequency deviation within the Continental Europe Synchronous Area.

This mismeasurement affected the following tie-lines: OHL 220 kV St.Peter (APG) – Altheim 230 – 1 & 2 (TenneT DE), OHL 220 kV St.Peter (APG) – Pleinting 258 (TenneT DE) and OHL 220 kV St. Peter (APG) – Pirach 256 (TenneT DE).

10 JANUARY

10:00 CET

On 10 January between 10:00 and 11:00, the long-lasting frequency deviation was observed by Amprion (Coordination Centre North and current Synchronous Area Monitor). The deviation was traced back by using frequency curves in the SCADA System and it was determined that it had already started on 9 January. Due to the fact that the frequency deviation increased slowly, it was difficult to detect the situation and not possible to identify the exact starting time.

The time deviation at 10:00 was –43 seconds.

11:00 – 15:30 CET

Amprion informed Swissgrid (Coordination Centre South) and both CCs performed some common analyses. The CCs analysed the calculated values ACE CE-North and ACE CE-South and the individual ACE of each TSO in ENTSO-E Awareness System (EAS) in order to find the impacting parties. The CCs also checked the scheduled and physical power flows in the EAS Generation Map. The CCs compared the values from their local systems (LFC, SCADA, Scheduling System) with the values from the other CC and with the values from EAS. It was not possible to find a dependency between the ACE values and the frequency deviation. The sum of ACE CE-North and ACE CE-South was even positive, so it seemed illogical that these values would have resulted in an under frequency for the CE synchronous area. The only explanation was that one or more TSOs used incorrect LFC-Input data such as wrong control programs or wrong measurements for physical and virtual power flows.

The existent SMM deviation was within the permanently reported levels (average –83 MW) and, therefore, it only contributed to a similar extent as in the previous months.

Several control blocks were contacted by the CCs to ask for their support in the identification of the long-lasting frequency deviation root causes. The CCs informed CE TSOs of the long-lasting frequency deviation and to perform actions in order to investigate and identify the new source of frequency and time deviation.

10 JANUARY

15:46 CET

CC South sent an email to all CE TSOs and ENTSO-E Operations Secretariat informing them about the long-lasting deviation of the system frequency and synchronous time degradation, and asking for possible reasons for this. All CE TSOs were asked to check their control systems which have an impact on active power balance. The time deviation due to the long-lasting frequency deviation was −58 seconds.

16:00 CET

CE TSOs were asked by the CCs to check their control systems which have an impact on active power balance. Feedback of technical and operational investigations between RG CE Control Centres and CCs was ongoing from 16:00.

17:00 CET

Amprion called TenneT DE asking to check TenneT DE ACE and controller values. TenneT DE checked the controller values, especially the LFC input values. The TenneT DE ACE also appeared to be normal. This is discussed further in Event Analysis section 3.1 and 3.2.

19:00 CET

DFD of –120 mHz occurs
(including TenneT DE measurement error).

19:04 CET

The need for urgent technical investigations by all TSOs within RG CE is escalated within CE TSOs and all TSOs were asked to perform the above checks within their grids.

19:00–20:00 CET

Amprion again called all CE North TSOs and CC South. In these calls the ACE values, the scheduled and the measured exchange were queried and compared with the values in the EAS System.

20:00 CET

DFD of –109 mHz occurs
(including TenneT DE measurement error).

21:02 CET

The cumulative effect of the long-lasting frequency deviation (approx. 60 mHz at this time) and a large evening peak-load DFD, culminated on 10 January at 21:02 when the steady-state frequency in the CE system reached 49.808 Hz, triggering the automatic activation of the RTE Industrial Interruptible Service. As a consequence, the French Load decreased by 1,250 MW within 5 seconds and up to 1,700 MW after 30 seconds. The frequency quickly returned to within the normal frequency range (–50 mHz were violated for less than 8 minutes). The time deviation at 21:00 was –71 seconds.

The CCs got in touch again to analyse the situation. A phone call with RTE took place where RTE informed them about the automatic activation of its Industrial Interruptible Service.

21:06 CET

Amprion activated mFRR and shed one contractual load of 124 MW manually (activation at 21:06) to stabilise the frequency. No further control measures of the CCs were necessary, as the frequency had stabilised.

22:14 CET

CE TSOs arranged a teleconference for Friday 11 January, 12:00 CET. All the representatives were asked to take their own actions as aforementioned and to immediately inform the CCs in case of any findings. The teleconference was intended to review all the actions taken around the CE network and to identify the cause of the frequency deviation.

23:00 CET

TenneT DE called all neighbours to check interconnectors power values. TenneT DE checked all tie-line values with neighbours by comparing the measured values by phone. The comparison of tie-lines power values between TenneT DE and neighbours appeared to match. This is discussed further in Event Analysis section 3.1 and 3.2.

11 JANUARY

00:00 CET

DFD of −142 mHz occurs
(including TenneT DE measurement error).

Time deviation is now −76.8 seconds.

01:15 CET

Teleconferences between five CE TSOs (Amprion, Swissgrid, REE, RTE, Terna) where held regularly through 11 January in order to be prepared for the next potential frequency drop. The following decisions and countermeasures were agreed in the call:

1. The five TSOs will observe the frequency and try to avoid big changes in their control programs;

2. In case of further large frequency deviations, all five TSOs will each activate 200 MW additional reserve power to restore the frequency (1,000 MW in total);

3. Amprion will start further telephone conferences during the day to stay in contact and assess the situation until the permanent frequency deviation is resolved.

08:00 CET

TenneT DE started a closer investigation of measurement values and, by comparing the LFC input values to the tie-line load flow values, the difference taken from different measurement locations was detected and corrected at 09:37 when the grid time deviation was −84 seconds.

11:15 CET

Further telephone conference in which it was verified that the steady state frequency deviation is no longer observable.

12:00 CET

CE TSO TELECONFERENCE:

TenneT DE informed CE TSOs of the measurement failure and that the problem was solved at 09:37 CET. TenneT DE presented its first rough estimation about power exchange implications due to the frozen measurement. The initial data presented by the Coordination Centres was also analysed.

All TSOs reported the output of their mutual checks and investigations within their systems and it was concluded that the only cause of the long-lasting frequency and time deviations between 9 and 11 January was the TenneT DE measurement failure. The larger observed deviations during the period were the cumulative effect of the long-lasting frequency deviation and the DFDs during the hourly schedule changes.

3. EVENT ANALYSIS

This section analyses the contributing factors to the frequency and time deviations between 9 January and 11 January.

3.1 FALSE MEASUREMENT VALUES FROM TenneT DE TIE-LINES TO APG

On 9 January at 13:25, the drop of a telecommunication line between substation St. Peter (APG) and substation Simbach (TenneT DE) stopped the measurement value transmission to TenneT Control Center South (Control Center South = Control Center of TenneT DE). These values remained frozen for 4 interconnectors.

The frozen values were split off into two values before being used as input for Telecommunication devices at TenneT DE Control Centre South. This artificial doubled single measurement value was now accepted as first and second value and transmitted to the TenneT DE Load Frequency Controller (LFC). This misleading split of one input value into first and second value used by LFC led to the wrong assumption of having a fail-safe processing for measurement and telecommunication.

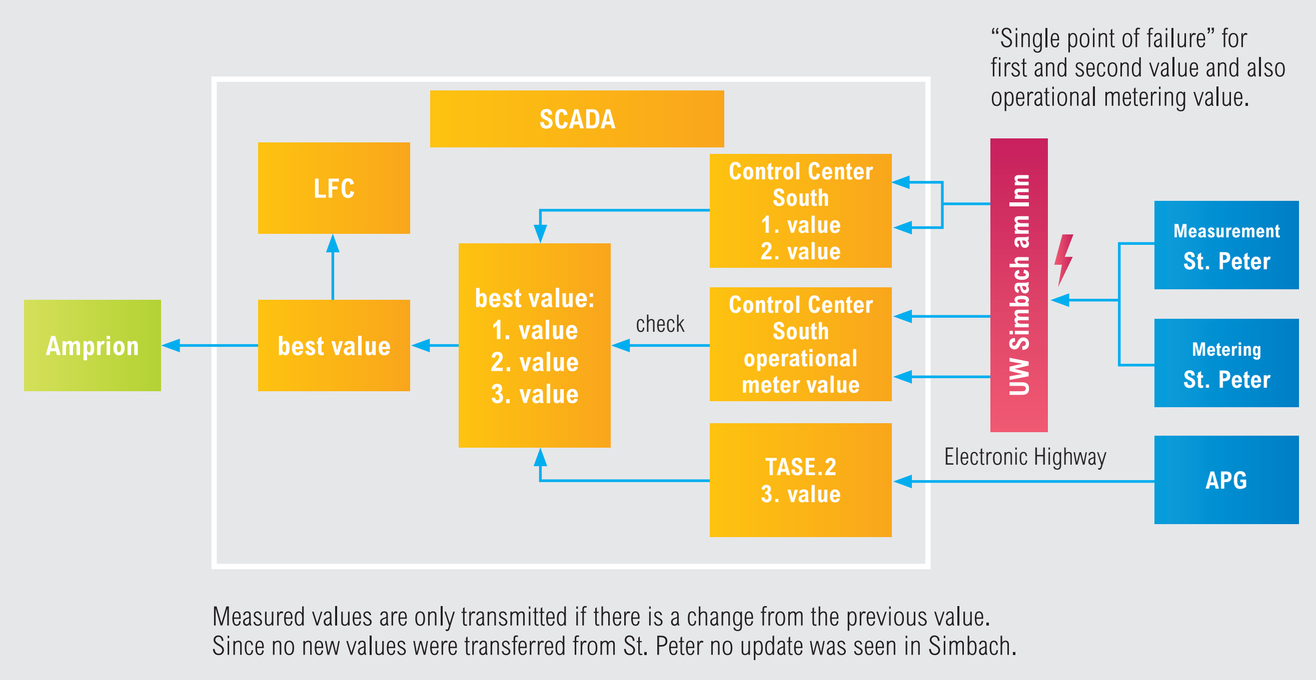


Fig. 1: TenneT DE Data Transmission Failure

The SCADA system of TenneT DE used several more input values which were measured and transferred correctly from separate measurement and telecommunication systems, e.g. from UW Simbach. This caused correct results within the state estimation and for load flow calculations of the tie-lines.

During the investigation of the frequency response deviation, the wrong assumption of fail-safe measurement and double telecommunication lines delayed the detection of the fault. At 17:00 on 10 January, TenneT DE checked the controller values, especially the LFC input values. Since the first LFC input value and second LFC input value (both wrong) at the Austrian border were identical, the mismeasurement at the Austrian border was not identified. TenneT DE ACE also appeared to be normal. At 23:00 on 10 January, TenneT DE called all neighbours to check interconnector power values. TenneT DE checked all tie-line values with neighbours and compared measurements. The comparison of tie-line power values between TenneT DE and neighbours matched. TenneT DE power flow measurement values were taken from other measurement locations (not St. Peter) and were therefore not the wrong and frozen LFC input values.

3.2 EFFECT OF WRONG LFC INPUT ON FREQUENCY DEVIATION

At the start time of the telecommunication failure (9 January, 13:25), wind energy generation in Germany was very high, reaching 34 GW, which resulted in an export of 723 MW via the four interconnectors between TenneT DE and APG. Afterwards, the measurement values were no longer transferred correctly to the Load Frequency Controller (LFC) of TenneT DE. The readings remained frozen at the last correct value (total 723 MW).

On late 9 and during 10 January, the wind energy production in Germany decreased significantly (down to 4 GW), so that the export to Austria was strongly reduced and even led to an import from Austria of up to 330 MW on the four tie-lines with TenneT DE.

The difference between real import/export (Fig. 2 – yellow curve) and wrong measurement (Fig. 2 – green line) values caused an “unreal additional power flow” from the TenneT control area towards APG. The impact of this “unreal additional power flow” to the other correct exchange values performed by TenneT DE LFC was a wrong calculated surplus for the TenneT DE control area. Consequently, the LFC applied negative control power, which caused in reality a shortage in the TenneT DE control area. Due to incorrect values, this shortage was seen as a properly balanced situation.

The wrongly calculated (too high) export led to positive ACE (wrong) and, as a result, to negative control power demand (also wrong). A wrongly balanced control area was in reality a shortage.

Export(schedules) = Export(measurement)
= Export(true) + Error

This error “MW-value” which was missing in the TenneT DE control zone caused a proportional frequency deviation of about 0 to −60 mHz between 9 January, 13:25 and 11 January, 09:37 (average of about −30 mHz).

The same frozen and incorrect values were transmitted by TenneT DE to Amprion where they were used to calculate the import/export of control block Germany with the same result for the control block as for the control area. German energy demand and German ACE was also falsely calculated as balanced.

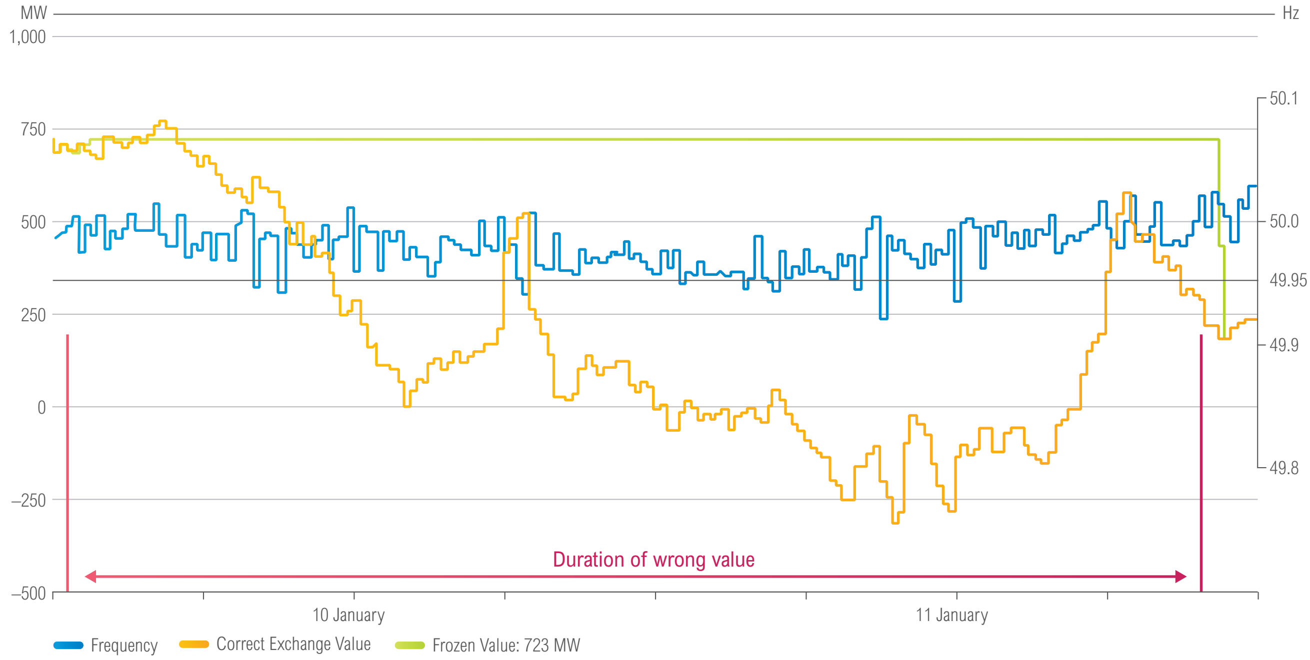
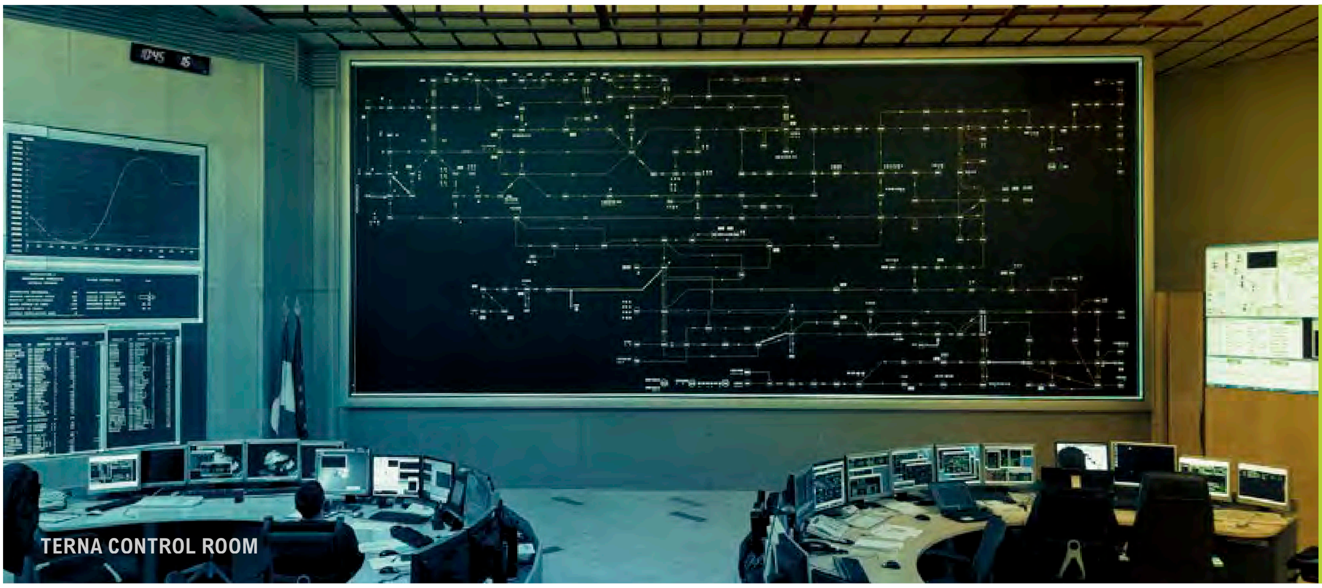


Fig. 2: Frequency Deviation 9 January 2019, 13:25 – 11 January 2019, 09:37



3.3 PERMANENT INTENTIONAL FREQUENCY DEVIATION DURING 9 JANUARY TO 11 JANUARY

The permanent long-lasting deviation of the SMM control block also affected the frequency between 9 January to 11 January where the average hourly ACE of the SMM CB was −83 MW. However, SMM CB did not participate in the large frequency deviation at 21:02 on 10 January, as EMS Control Centre observed the low frequency trend and took preventive action to not disconnect, as planned, a 300 MW pump-storage unit that was running in generation mode.

3.4 DETERMINISTIC FREQUENCY DEVIATION 21:02 ON 10 JANUARY

Several significant DFDs (leading to total frequency deviations of > 100 mHz from the setpoint of 50.0 Hz) occurred during the period of the long-lasting frequency deviation between 13:25 on 9 January and 09:37 on 11 January. DFDs were observed on the

- 9 January −106 mHz at 20:00
- 10 January −120 mHz at 19:00, −109 mHz at 20:00, −192 mHz at 21:00 and −142 mHz at 24:00.

Table 1 shows the ACE values of Continental Europe Control Blocks during the evening-peak DFD between 21:01 to 21:03 on 10 January when the CE frequency dropped to 49,808 Hz.

Table 1 and Fig. 3 on the following pages show the participation of the RG CE TSOs in the frequency deviation on the 10 January 2019 between 20:55 and 21:10. The red graphical representation in Fig. 3 corresponds to the ACE of the German Control Block. For ex-post analysis purposes, the contribution from the measurement error from TenneT DE has been removed from the ACE contribution in both Table 1 and Fig. 3. At the time of the event the real-time ACE in Germany as viewed by operators was up to 1,000 MW lower. In addition, all TSOs, including German TSOs, were trying to cover the large changes in the unit production programmes that directly correlate with the large changes in the cross-border exchange programs. Table 2 on the next page shows, at 21:00, the large changes in cross-border exchange programs. REN −2.2 GW, RTE 3.3 GW, REE −2.1 GW, Swissgrid −2.4 GW, German CB 1.3 GW, TenneT NL 0.9 GW, Elia 0.6 GW, Poland 0.6 GW and Transelectrica 0.6 GW.

Time CET	dF (mHz)	Total ACE (MWs)	AT	BE	BG	CH	CZ	DE	DK	ES
21:01:00	−117.9	−2,202	−102	−195	−111	16	−3	−953	−8	134
21:01:05	−123.8	−2,128	−86	−195	−81	−43	32	−972	−8	134
21:01:10	−132.6	−2,545	−111	−191	−45	−43	32	−1146	−6	57
21:01:15	−146.1	−2,810	−101	−191	−40	−3	−230	−1146	−6	−7
21:01:20	−158.2	−3,381	−118	−153	−76	6	−230	−1626	−11	−7
21:01:25	−159.2	−3,552	−101	−153	−66	1	−324	−1653	−11	−7
21:01:30	−175.4	−3,817	−98	−156	−63	−13	−324	−2007	−17	−99
21:01:35	−172.9	−3,907	−95	−156	−42	−29	−317	−2007	−17	−110
21:01:40	−175.8	−4,018	−104	−234	−78	−39	−317	−2103	−14	−110
21:01:45	−175.4	−4,034	−99	−234	−59	−60	−302	−2103	−14	−110
21:01:50	−172.1	−4,269	−106	−257	−75	−100	−302	−2010	−7	−129
21:01:55	−173.6	−4,413	−105	−257	−99	−122	−290	−2004	−7	−119
21:02:00	−167.7	−4,164	−85	−350	−55	−158	−290	−1760	−3	−119
21:02:05	−170.3	−4,345	−114	−350	−44	−218	−291	−1756	−3	−119
21:02:10	−179.8	−4,888	−123	−340	−44	−231	−291	−1644	−2	−129
21:02:15	−192.3	−4,766	−111	−340	−33	−215	−264	−1585	−2	−129
21:02:20	−184.9	−4,763	−149	−382	−83	−216	−264	−1633	0	−243
21:02:25	−164.1	−4,440	−191	−382	−88	−210	−273	−1638	0	−64
21:02:30	−151.2	−3,080	−185	−318	−79	−188	−273	−1546	17	−64
21:02:35	−139.5	−2,736	−166	−318	−52	−102	−239	−1546	17	22
21:02:40	−132.9	−3,202	−159	−289	−66	31	−239	−1424	29	22
21:02:45	−130.4	−3,039	−158	−289	−56	125	−193	−1421	29	−48
21:02:50	−127.8	−2,860	−153	−299	−56	133	−193	−1211	31	−48
21:02:55	−126.7	−2,856	−179	−299	−56	151	−185	−1211	31	−94
21:03:00	−128.2	−2,764	−155	−294	−83	173	−185	−1111	28	−94

Table 1: CE EAS Area Control Errors from 21:01 to 21:03 on 10 January (German ACE was ex post corrected by the mismatch / error within the TenneT DE controller)

Time CET	BE	DE +	NL	APG	PL & UA	CH	FR	IT	SHB	GR	SMM	RO	BG	AL	CZ	HU	SK	TR	ES +	SK
20 – 21:00	−1,627	5,004	1,155	2,037	16	2,470	−5,200	−4,177	−376	624	−1,068	−931	315	−583	2,234	−1,612	−619	96	−998	−3,242
21 – 22:00	−1,038	6,351	2,031	1,587	621	40	−1,916	−3,788	−423	378	−1,457	−369	411	−608	2,399	−1,449	−744	96	−3,086	966
Delta (MWs)	**589**	**1,347**	**876**	**−450**	**605**	**−2,430**	**−3,284**	**389**	**−47**	**−246**	**−389**	**−562**	**96**	**−25**	**165**	**163**	**−125**	**0**	**−2,088**	**−2,276**

Table 2: The change of RG CE TSOs realized control programs at 21:00 on 10 January (VulcanuS)

FR	GR	HU	IT	NL	PL	PT	RO	SHB	SMM	SK	TK	AL
−708	104	29	109	−15	−187	−211	−104	−69	3	−18	92	−5
−708	109	33	109	0	−160	−211	−104	−87	46	−23	87	0
−880	92	30	141	−6	−89	−371	−112	−33	84	−31	86	−3
−880	92	38	141	−4	−92	−371	−112	−45	97	−27	78	−1
−880	90	49	106	−3	−87	−383	−120	−35	58	−27	66	0
−880	111	33	106	−51	−77	−383	−120	−28	61	−40	28	2
−775	139	52	158	−64	−81	−383	−111	−29	90	−37	−1	2
−775	137	36	158	−99	−80	−383	−111	−26	87	−30	−49	1
−559	116	58	127	−127	−74	−383	−110	−32	74	−31	−82	4
−559	139	46	127	−152	−89	−383	−110	−16	52	−30	−85	7
−778	142	48	127	−151	−115	−383	−113	−19	69	−31	−86	7
−778	151	62	−76	−126	−119	−383	−113	−20	93	−38	−67	4
−577	163	40	−136	−160	−149	−383	−123	−33	98	−42	−42	0
−577	162	48	−183	−188	−155	−383	−123	−59	80	−51	−21	0
−725	176	55	−298	−194	−265	−637	−126	−44	45	−58	−13	0
−725	176	96	−317	−203	−338	−637	−126	−50	111	−63	−3	−8
−210	161	30	−230	−249	−404	−645	−121	−101	57	−82	12	−11
−210	140	42	−217	−241	−293	−645	−121	−84	85	−81	37	−6
833	175	49	−213	−226	−269	−645	−122	−71	76	−79	49	−1
833	185	53	−210	−159	−289	−645	−122	−61	88	−74	47	2
28	164	29	−201	−31	−297	−645	−125	−43	64	−68	16	2
28	148	39	−169	0	−297	−645	−125	−56	78	−60	28	3
−67	157	34	−142	18	−299	−645	−139	−53	72	−60	55	5
−67	171	31	−120	26	−285	−645	−139	−44	37	−59	72	8
−161	174	19	−50	14	−304	−596	−160	−66	56	−58	77	12

In Fig. 3 (page 20/21), the automatic activation of the Industrial Interruptible Service (1,700 MW) in France is visible as a blue peak in the middle of the graph that shows the period when RTE quickly helped to recover the frequency. After ten minutes, due to the natural behaviour of the frequency during DFD, the frequency deviation decreased to approximately −50 mHz. Note that in Fig. 3:

a) The German ACE was corrected by the 1,000 MW mismatch/error within the TenneT DE controller;

b) In order to convert the ACE contributions to frequency in mHz, a re-scaling was performed by dividing each Control Block ACE by the synchronous area K-factor.

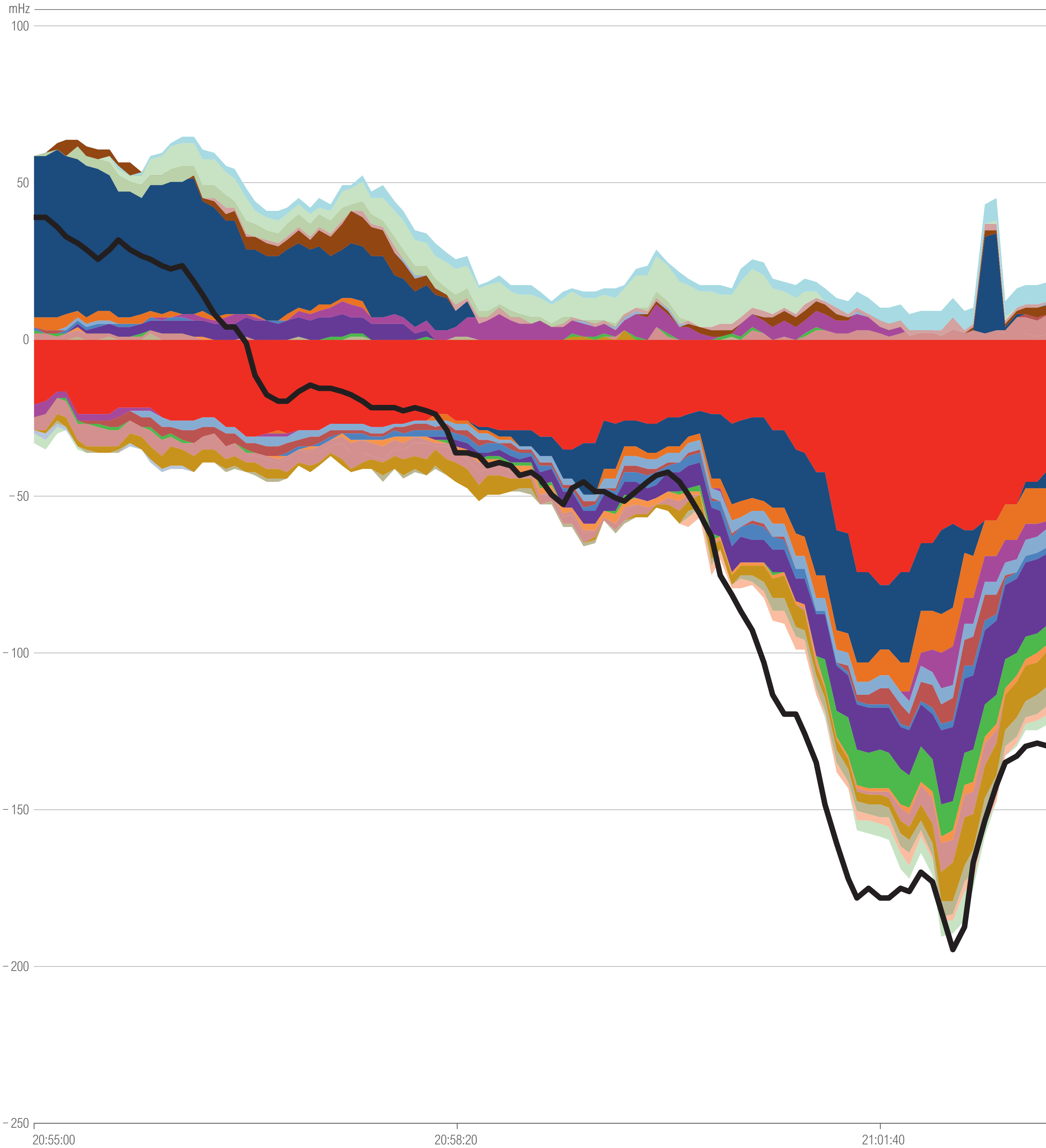
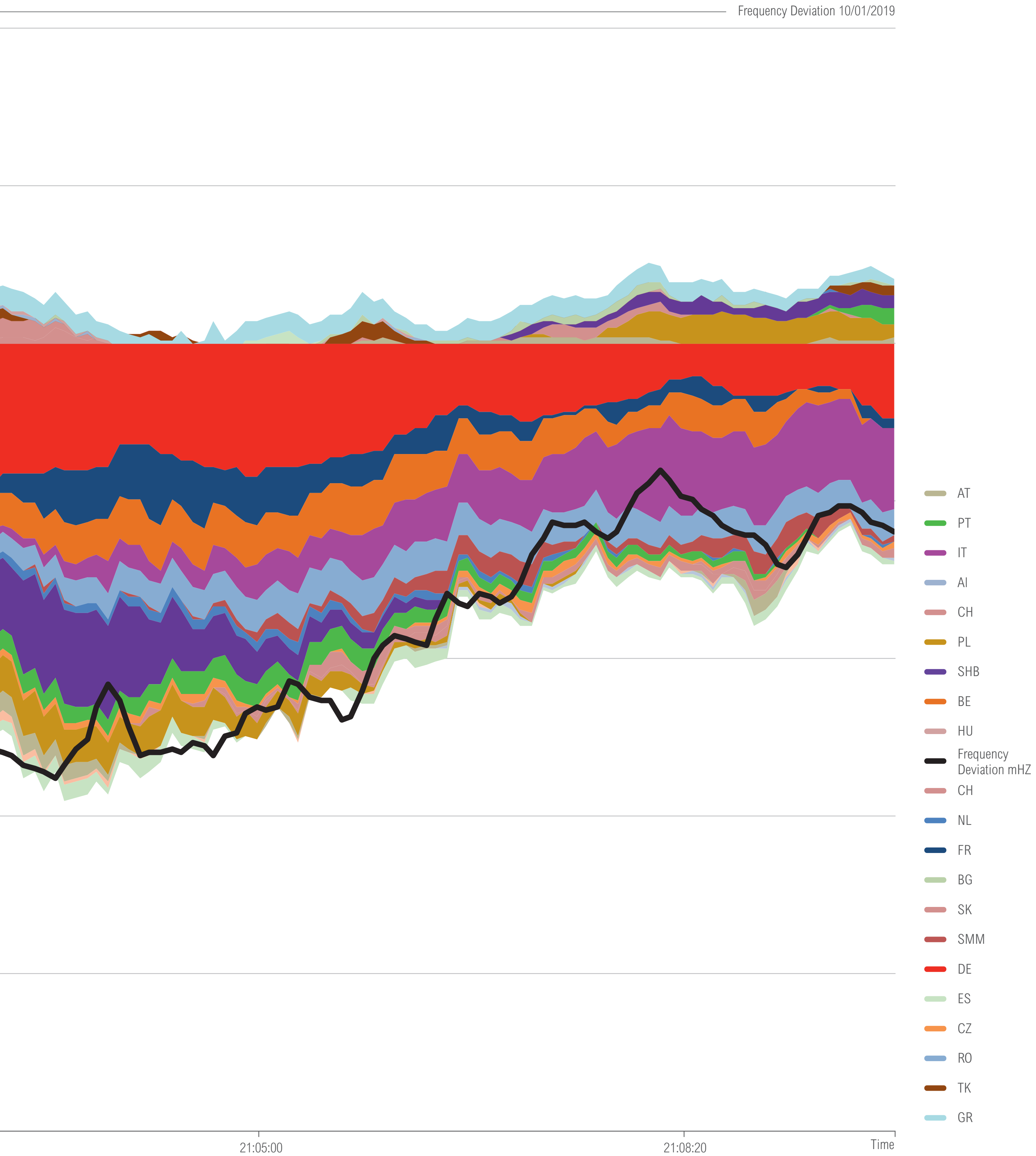


Fig. 3: Graphical Representation of CE Control Block individual ACE (source EAS; German ACE was ex post corrected by the mismatch/error within the TenneT DE controller) contribution from 20:55 to 21:10 on 10 January) contribution from 20:55 to 21:10 on 10 January



Due to their radial connection to the centre of the CE power system the interconnection of the Iberian TSOs, REN and REE, as well as Turkey experienced significance additional flows during the event at 21:02 on 10 January.

For the interconnection between REE and RTE there was a convergence of approx. 4 GW of change in schedules with an additional 400 MW of flow due to the activation of FCR from the region. Similarly, Turkey contributed with approx. 300 MW of FCR during the frequency deviation.

3.5 APPLICATION OF THE CE EXTRAORDINARY PROCEDURE AND OPERATION HANDBOOK[1)]

A procedure is in place in RG CE to avoid serious system disturbances, and especially large frequency deviations with the risk of the uncoordinated disconnection of generation or load. The aim of the procedure is to keep the steady-state frequency between 49.9 Hz and 50.1 Hz.

The "Extraordinary procedure for frequency monitoring and countermeasures in case of large steady-state frequency deviations" is triggered when the following criteria are fulfilled:

Stage 1:

- system frequency of 50.05 Hz or 49.95 Hz is exceeded for a time interval longer than 15 minutes
- system frequency of 50.1 Hz or 49.9 Hz is exceeded for a time interval longer than 5 minutes

Stage 2 (Activation of 5 TSOs Teleconference):

- system frequency of 50.05 Hz or 49.95 Hz is exceeded for a time interval longer than 20 minutes
- system frequency of 50.1 Hz or 49.9 Hz is exceeded for a time interval longer than 10 minutes
- Telephone Conference and discussion of measures by Amprion, Swissgrid, REE, RTE and Terna

On 10 January at 21:02 the criteria for Stage 1 were fulfilled for only 9 seconds (see Fig. 4 below) The criteria for Stage 2 was not reached. However, to be prepared for the next potential frequency drop, Amprion, as the responsible Synchronous Area Monitor, decided to launch proactively the 5 TSOs telephone conference (Stage 2 of the procedure). The following decisions and countermeasures were agreed in the call:

1. The 5 involved TSOs (Amprion, Swissgrid, REE, RTE, Terna) will observe the frequency and try to avoid big changes in their control programs;

2. In case of further huge frequency deviations, all five TSOs will each activate 200 MW additional reserve power to restore the frequency (1,000 MW in total);

3. Amprion will start further telephone conferences during the day to stay in contact and assess the situation until the long-lasting frequency deviation is resolved.

A process and procedure are in place (Operation Handbook) for the detection of long-lasting frequency deviations based on the monitoring of grid time deviation. However, the triggering criteria of 20 seconds for grid time correction and 60 seconds for taking additional measures is retrospectively considered as too long.

3.6 INCIDENT CLASSIFICATION

According to COMMISSION REGULATION (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation (SO GL [1]), Article 18.2. (c) the classification of system state as "Alert" state is as follows:

Frequency meets the following criteria:

i. *the absolute value of the steady state system frequency deviation is not larger than the maximum steady state frequency deviation;*

   - **fulfilled, as criteria "steady state frequency > 200 mHz" was not violated**

ii. *the absolute value of the steady state system frequency deviation has continuously exceeded 50% of the maximum steady state frequency deviation for a time period longer than the alert state trigger time or the standard frequency range for a time period longer than time to restore frequency;*

   - **criteria "100 mHz > 5 Minutes"**
     → fulfilled for approximately 9 seconds.
   - **criteria "Δf > 50 mHz > 15 minutes" was not fulfilled.**

[1)] Starting 14 April 2019, the Continental Europe Operation Handbook MLA terminated as the new Synchronous Area Framework Agreement was approved on 27 February 2019 and entered into force from 14 April 2019

Fig. 4: Frequency deviation and 50/100 mHz criteria

Therefore, the system was in "Alert" but not in "Emergency" state as per SO GL. Since alert state lasted less than 10 seconds it was not possible to set the System State to Alert in EAS (see Fig. 4 above).

ENTSO-E developed an Incident Classification Scale (ICS) Methodology in accordance with the SO GL requirements for system states. The ICS Methodology is used to develop the annual ICS report, as per SO GL Article 15.

According to the ICS Methodology, the 10 January 2019 frequency event was a Scale 1 – Noteworthy incident.

The prerequisite for Scale 2 – Extensive incident as per ICS Methodology, is that the "system is in Emergency state after the incident" and this was not the case. Even if an instantaneous frequency deviation of > 200 mHz occurs, the system is not considered to be in Emergency state as the evaluation criteria per SO GL is the "steady-state frequency deviation" and not the "maximum instantaneous frequency deviation".

As per SO GL, the frequency quality defining parameter of the CE region for maximum instantaneous frequency deviation is 800 mHz. The FCR full activation time for a frequency deviation of 200 mHz is defined as 30 seconds in SO GL.

In conclusion, according to the ICS Methodology, the CE significant frequency deviation on 10 January 2019 is classified as a scale 1 incident leading to frequency degradation (F1).

4. LONG-LASTING FREQUENCY DEVIATIONS

Long-lasting frequency deviations can be caused by errors in measurements or schedules in AGC or, sometimes, by known direct or indirect reasons (intentional deviations).

PICTURE COURTESY OF RTE

4.1 LONG-LASTING FREQUENCY DEVIATION ANALYSIS

ACE is defined in Art. 143 of the SO GL:

$ACE_{i,real} = \Delta P_{i,real} + K_{i,real} \cdot \Delta f$

With $\Delta P_{i,real} = P_{i,actual} - P_{i,scheduled}$

Physics guarantees that $\sum_i P_{i,actual} = 0$

Scheduling processes define that $\sum_i P_{i,scheduled} = 0$

This leads to $\sum_i ACE_{i,real} = \sum_i K_{i,real} \cdot \Delta f$

Any error in measurements or schedules in an AGC will create a frequency deviation in CE, which is governed by the total K factor of all TSOs (about 27,000 MW/Hz). Thus, an error of 500 MW will create approx. 20 mHz long-lasting frequency deviation.

Intentional deviations are not usual in CE Synchronous Area, but when they occur it is usually the result of non-technical causes. Intentional deviations also lead to long-lasting frequency deviations following the same rule as above. The permanent use of FCR to contain long-lasting frequency deviations can lead to less availability of FCR from limited energy sources. Typical examples of limited energy sources are batteries, pumped storage and coal power plants. Given that the average usage of FCR is non-zero during a long-lasting frequency deviation, the reserve of energy is systematically reduced until unavailable, unless it is replaced. This means that, sometime, there may be less than 3,000 MW of FCR available (total amount of FCR procured to cover the dimensioning event) in CE system unless the sources are substituted.

Long-lasting frequency deviations also lead to large compensation programs which need accounting and administration. In addition, these deviations lead to time deviations on electronic clocks which are sensitive to system frequency.

4.2 POSSIBLE MITIGATION MEASURES FOR LONG-LASTING FREQUENCY DEVIATIONS

The introduction of imbalance netting and forthcoming introduction of algorithms for cross border activation of active power reserves can reduce balancing costs but also present challenges in terms of measurement values in AGC. Therefore, ENTSO-E TSOs are developing algorithms that will seek to prevent possible errors in measurement values which affect the ACE calculation. Several independent measurements, independent telecommunication lines, algorithms that compare real-time measurements with metered values are necessary. Closer cooperation between neighbouring TSOs on the exchange of measurement values for integrity checking and a better quality of ACE calculation is very important.

5. DETERMINISTIC FREQUENCY DEVIATIONS

This chapter presents historic trends and analysis of market based Deterministic Frequency Deviations. Possible mitigation measures and next steps to resolve DFDs are discussed.

REE CONTROL ROOM

5.1 INTRODUCTION AND APPROACH

This chapter will provide an answer to the following questions:

1. Why is it a problem to have large deterministic frequency deviations at the change of the hour in the morning and in the evening?

2. Where are the deterministic frequency deviations coming from?

3. What does ENTSO-E consider to be acceptable as frequency deviations from System Security point of view for the Synchronous grid of Continental Europe?

4. Which solutions can be envisaged to reduce the size of the deterministic frequency deviations?

5. What is the action plan to make sure these solutions are implemented in reality?

5.2 DETERMINISTIC FREQUENCY DEVIATION HISTORIC TRENDS ANALYSIS

The quality of frequency in the Continental Europe Synchronous Area has decreased during the last years. Fig. 5 shows, monthly, the number and duration of periods when frequency deviation was greater than 75 mHz. The number and intensity of deviations increases during the winter period. For instance, on the 24 January 2019 at 06:00 CE Synchronous system experienced its largest positive DFD of maximum +173 mHz. Also, on 3 April 2019 at 21:00 CE Synchronous system experienced a pure DFD of maximum +157 mHz (in all cases, the duration of frequency deviation was not sufficient to enter the Alert or Emergency ranges defined in the SO GL). Between 2013 to 2016 measures (due to recommendations from ENTSO-E Eurelectric Joint Investigation Team [3]) were implemented to improve the frequency quality. For instance, a market time unit of 15 minutes was introduced in 2012 in Germany and unit ramping was also introduced in the Italian market. There were also relatively mild weather conditions in between 2013 and 2016.

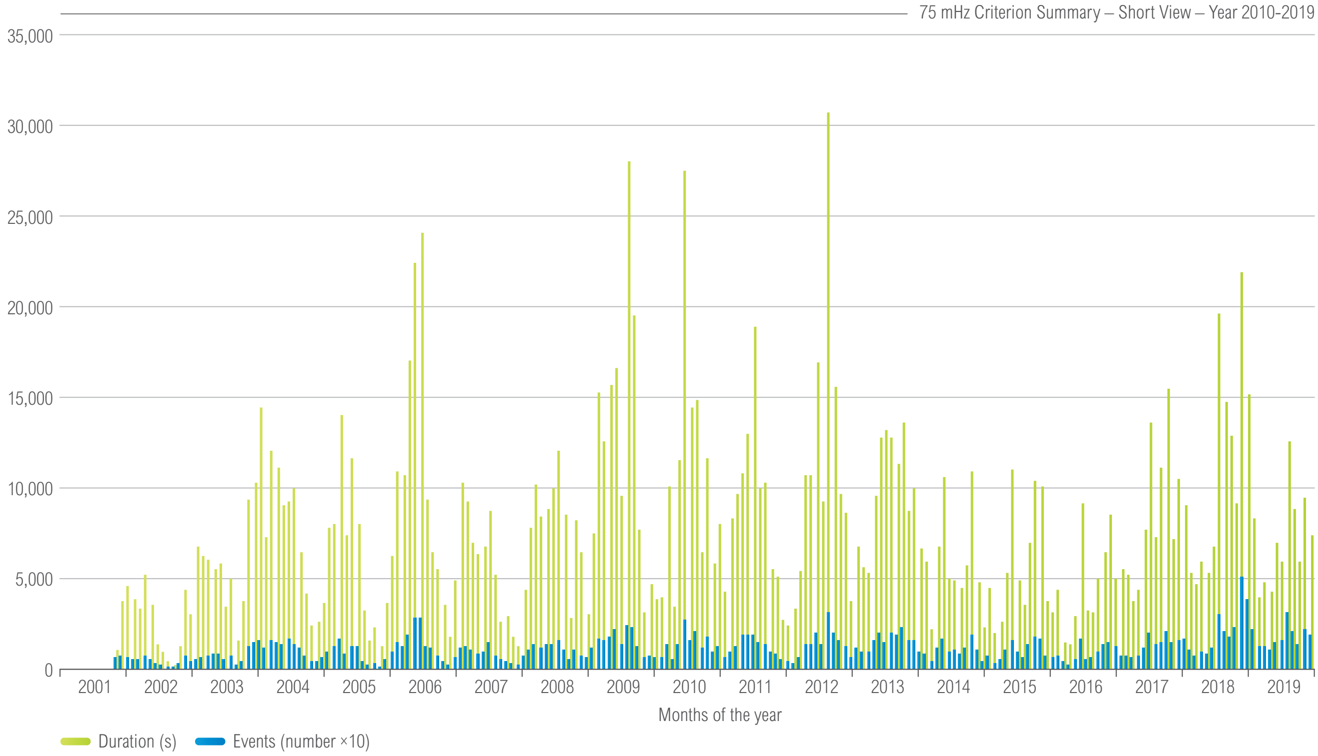


Fig. 5: Number and duration of ±75 mHz criteria violation

A very high percentage of the frequency deviations are caused by Deterministic Frequency Deviations (DFDs). Figures 6 to 9 illustrate the total number and period of duration in the frequency deviations higher than 75 mHz and 100 mHz, within the last two years and the participation of frequency deviations caused by DFDs in those values. Approximately 85 % of the deviations are deterministic with respect to the 75 mHz limit and more than 90 % with respect to the 100 mHz limit. In addition, the size of the absolute frequency deviations is permanently increasing during the last years.

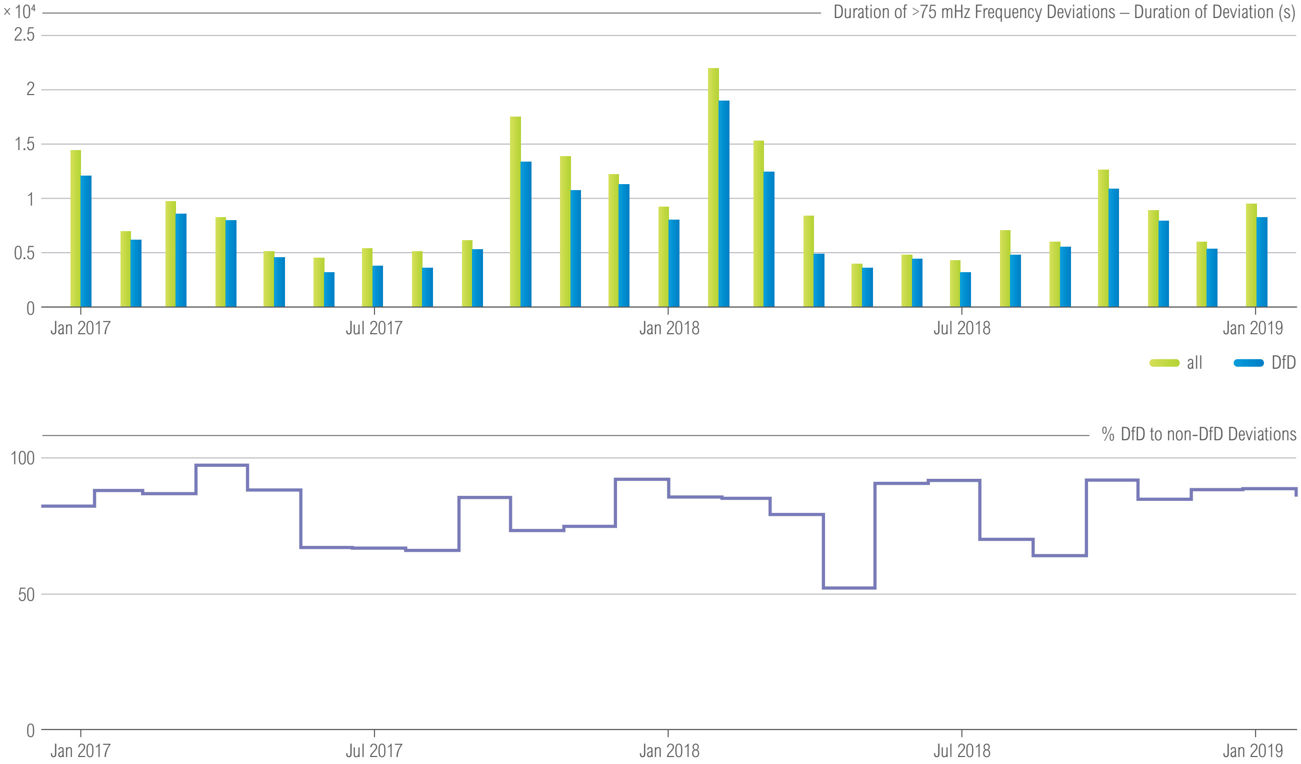


Fig. 6: Duration of DFDs and % of DFD to non-DFD deviations in the last 2 years (> 75 mHz)

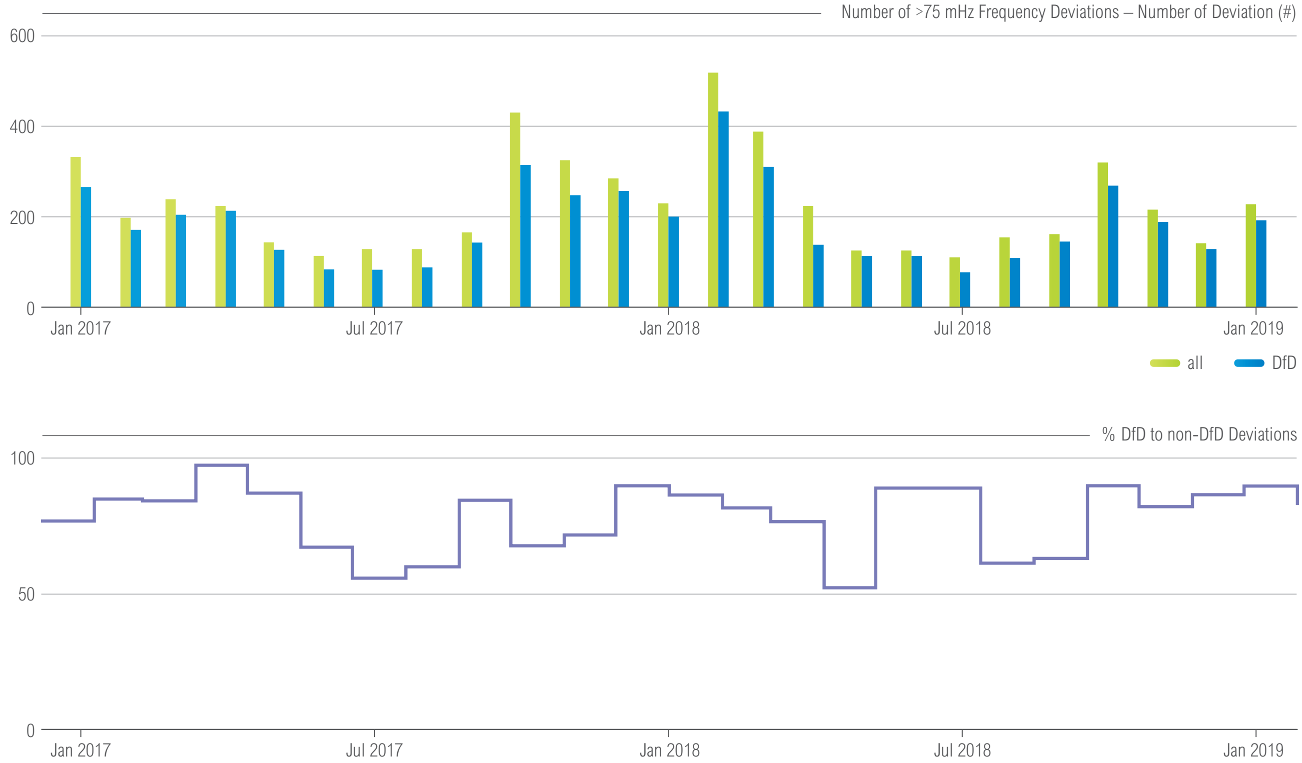


Fig. 7: Number of DFDs and % of DFD to non-DFD deviations in the last 2 years (> 75 mHz)

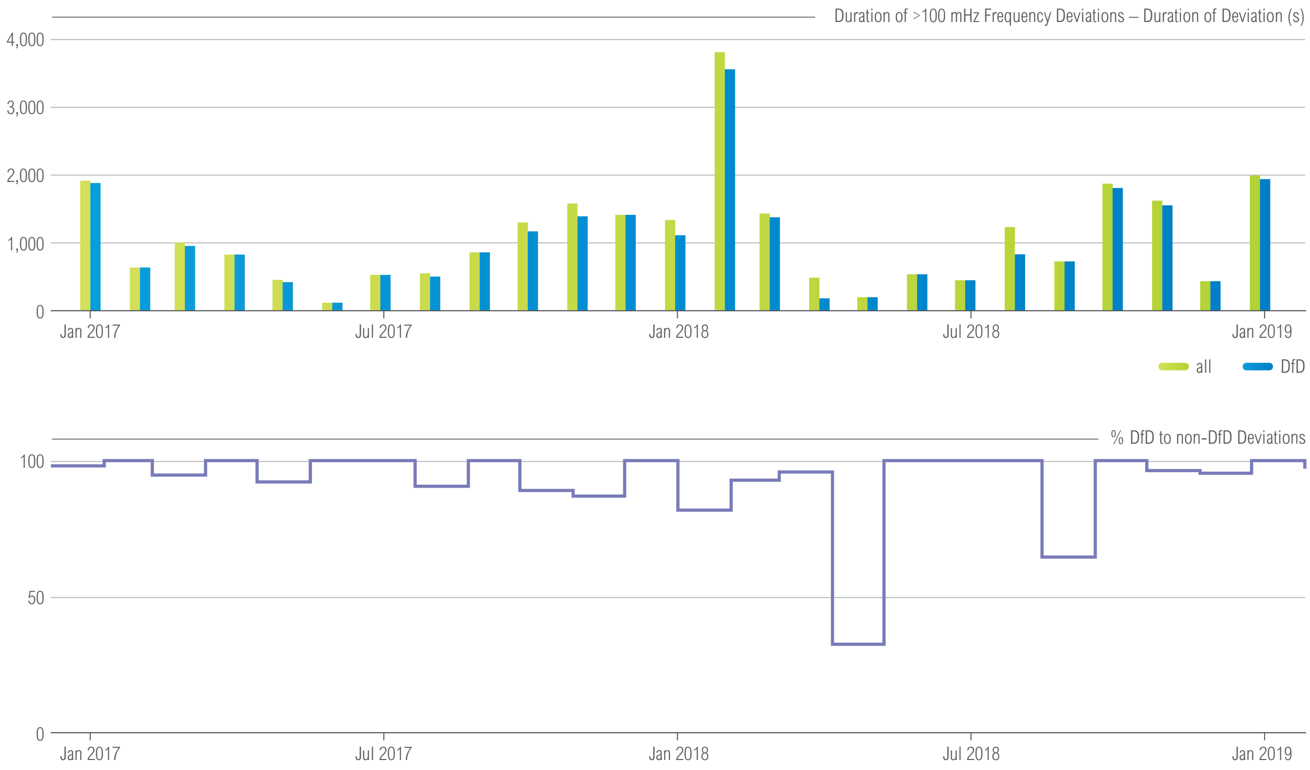


Fig. 8: Duration of DFDs and % of DFD to non-DFD deviations in the last 2 years (> 100 mHz)

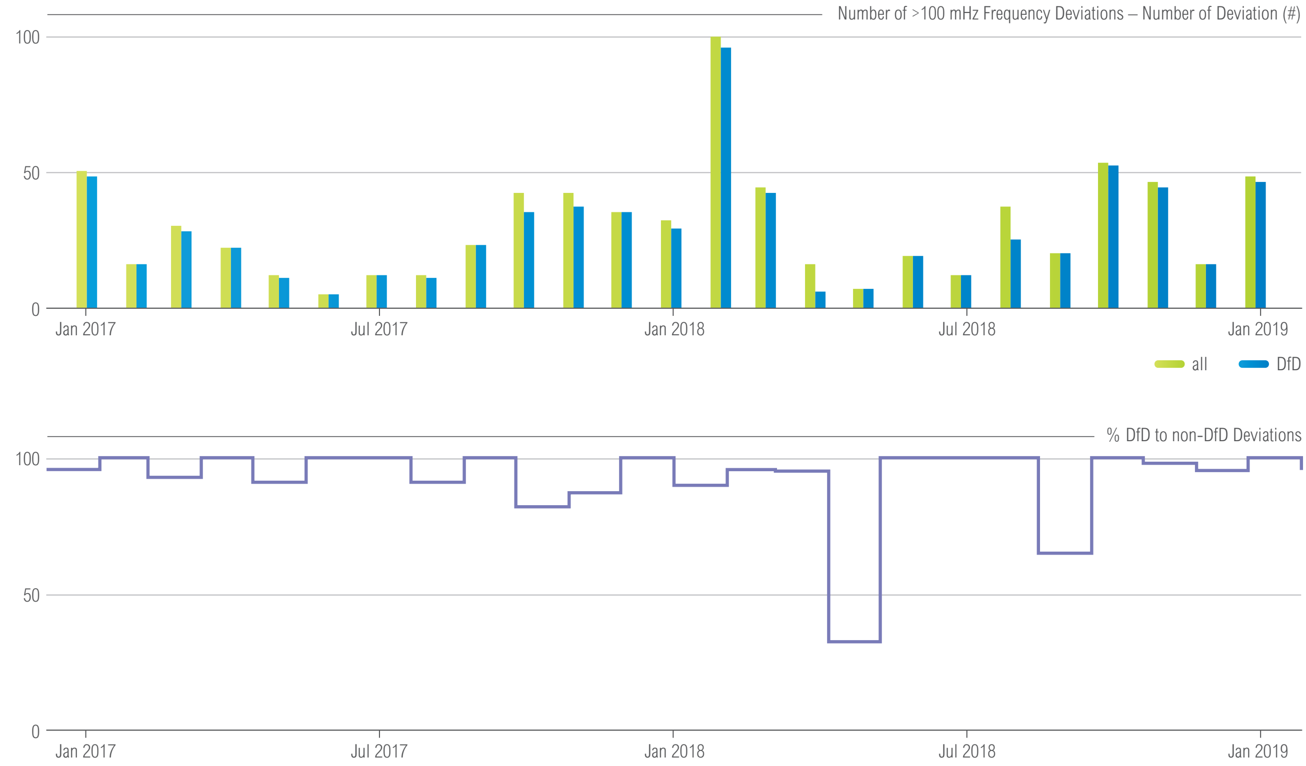


Fig. 9: Number of DFDs and % of DFD to non-DFD deviations in the last 2 years (> 100 mHz)

The problem has remarkably increased during the winter months of 2018 and 2019, with DFDs reaching values higher than 100 mHz daily, and even several times a day. Furthermore, very high values of deterministic frequency deviation have been reached, e.g. maximum of −168 mHz on 6 of February 2018 at 20:00 and maximum −166 mHz on 14 February 2018 at 22:00. Before that, only two frequency deviations (stochastic, in 2010 and 2011 with values of around 160 mHz) have reached similar values since the incident in November 2006, which was caused by the split of CE network. Fig. 10 illustrates the average values of frequency during all days at the same time of day for January 2019.

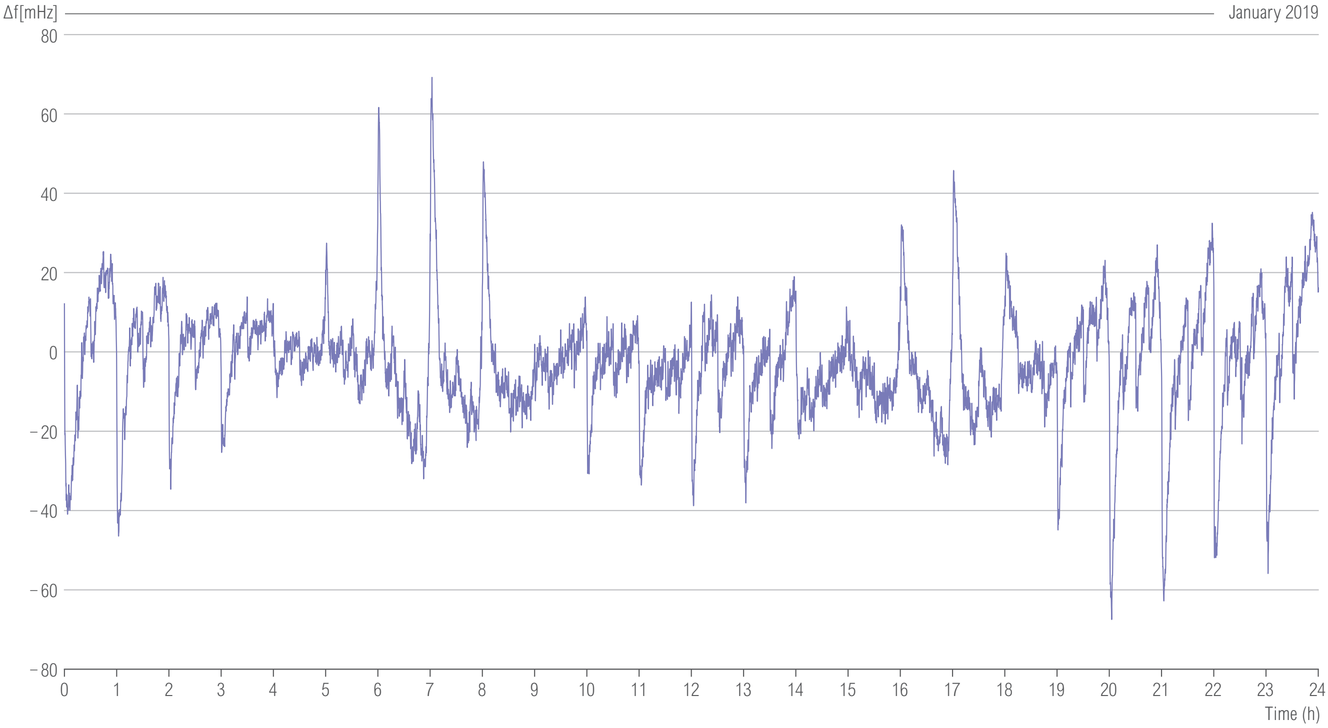


Fig. 10: Average values of Frequency per time of day during January 2019

It is also observed from regular sampling of the DFD over the past years, that the speed at which the frequency changes is increasing and is now sometimes reaching critical values of 5 mHz per second. This is getting close to the maximum speed at which FCR is expected to react. Further increases in the coming years could result in more serious DFDs and lower frequency values.

5.3 MAIN CAUSES OF DETERMINISTIC FREQUENCY DEVIATION

The causes of the DFDs were identified to be:

a) Weakening in the strong link between power consumption and power generation dynamics. The current market rules between generation and consumption are based on energy blocks of fixed time periods, the existing market rules require development.

b) The hourly transit period for generation schedule is currently not explicitly defined between all market participants. The resulting imbalances are reflected in the frequency deviations.

c) There is also the rule for BRP to be balanced over the whole Imbalance Settlement Period (ISP), which leads to effects that BRPs will adjust their production at the latest point in time, by the fastest gradient possible.

DFDs take place around the hour mark, caused by fast changes in the power output of generating units or big consumption units (e.g. pump storage units) initiated by BRPs in order to meet the energy schedules for the ISP which currently has a duration between 15 minutes and one hour (depending on the country). The corresponding almost stepwise variation differs remarkably from the continuous shape of the load curve and induces imbalances between generation and load, which lead to corresponding sharp frequency deviations. This is illustrated in Fig. 11. The sign of these frequency deviations typically depends on whether the load is increasing or decreasing.

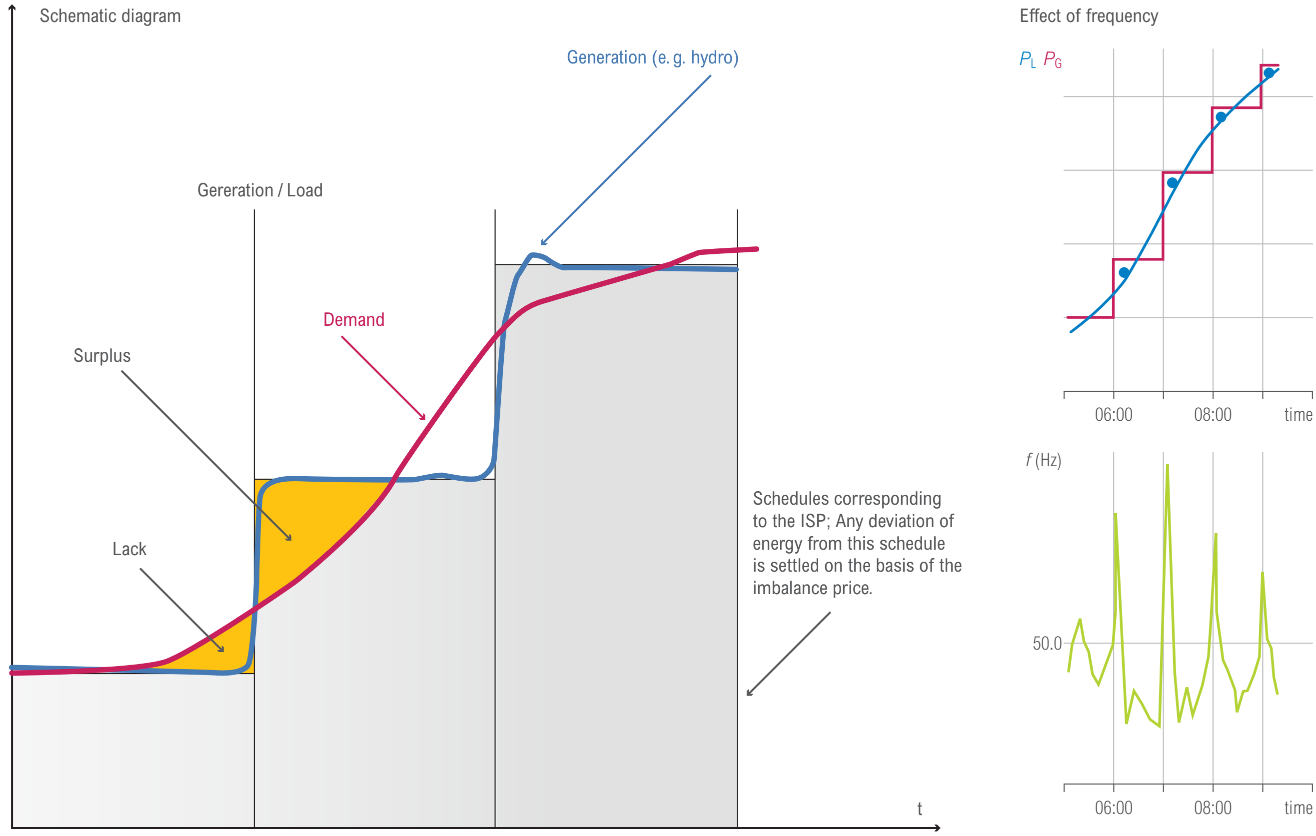


Fig. 11: Impacts of fast changes in the output of generation/consumption on frequency (Source: University of Stuttgart)

Additionally, DFDs also occur if generation is shifted between units with different ramp rates, e. g. between coal-fired power plants and hydro units. Such shifts typically happen at the change of the Market Time Unit (MTU) of day-ahead and intraday markets. The increase in the number of changes in generation mix is directly linked to the increase in the number of changes of schedules.

In addition, there is also an imbalance due to mismatch of ramps as one generation unit reacts faster than another and this directly impacts the frequency. Fast units' behaviour is practically a power step without correspondence in real load and, in this manner, the hourly behaviour of many fast units is quite similar to a system incident (e. g. Loss of a large demand sink or generation unit). Slow units are faced with opposite requirements: technical requirements which impose the natural ramp and the commercial requirements which require delivery of scheduled energy in a set time frame. Usually two mechanisms are adopted:

a) Energy compensation from fast units – other BRP;

b) Ramp compensation by the unit itself, with power modification in the market time frame.

Both behaviours contribute to frequency deviations. The solution could be to find a set of market rules capable of adapting the market model to the behaviour and needs of real load.

The cause of frequency deviations can be found in the incompatibility between load / production ramping and imbalance settlement on (large) fixed blocks.

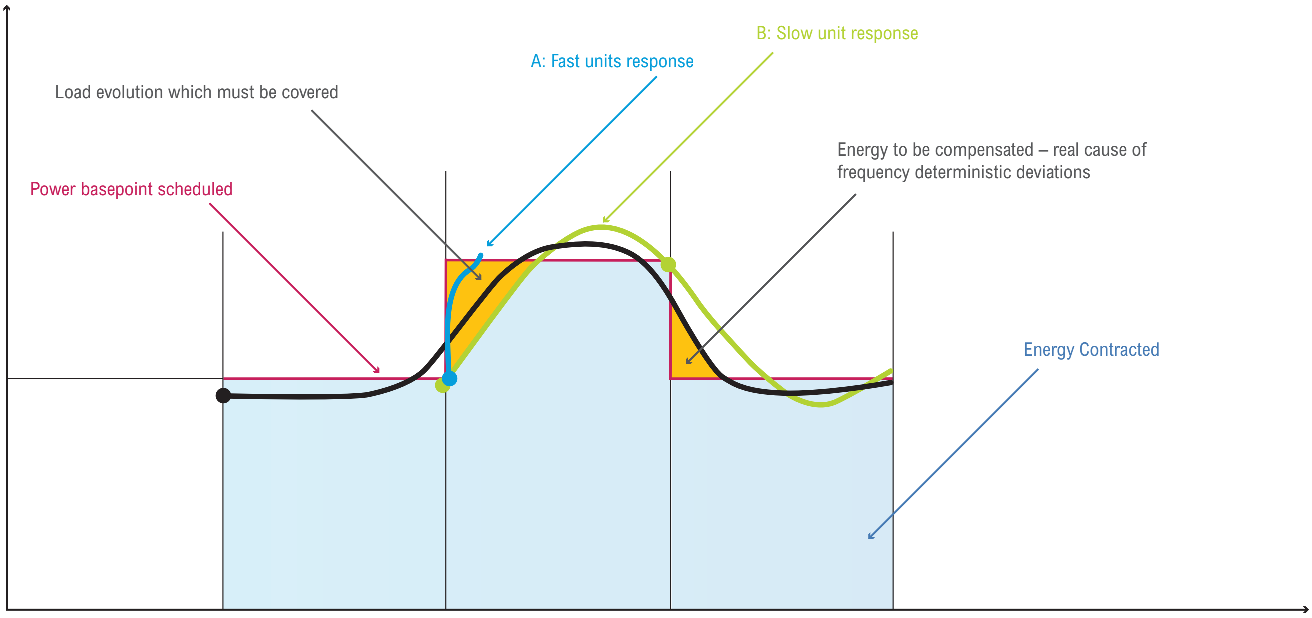


Fig. 12: Unit behaviour in Scheduled Time frames [3]

During the morning ramp, the stepwise increase in generation followed by the slower continuous increase in load results in a power imbalance. This "stepwise" imbalance cannot be balanced by control energy at any reasonable cost; this results in the frequency rising instantly and dropping again below 50 Hz over the hour.

5.4 IMPACT OF DETERMINISTIC FREQUENCY DEVIATIONS

5.4.1. IMPACT ON SYSTEM OPERATION

Flow changes: Frequency deviations result in unscheduled power flow due to activation of FCR that was not foreseen in the reference flow. This could result in a circuit overload of more than 5 minutes.

This means that the remaining capacity of the lines (as foreseen in the reliability margins TRM or FRM) is used more frequently than only during system outages, for instance, every hour during the DFD and must be guaranteed to be available at all times.

Misuse of Frequency Containment Reserves: The actual reserves sizing of 3,000 MW allows to cover a maximum of up to 125 mHz frequency deviation. This means that practically the dimensioning incident is not adequately covered for any deterministic frequency deviation below 49.925 Hz, the contracted reserves to cover the possible incidents would not be sufficient. The DFDs diminish the capability of TSOs to ensure the reliability of the system as FCR is activated to maintain frequency stability.

Simply put, during the time that the DFD occurs, the system of continental Europe is weaker and could not have sufficient reserves to cover the loss of 3,000 MW without dropping below the level of 49.8 Hz.

System Damping issues: In situations of low availability of FCR, the damping of inter-area oscillations is also reduced [3]. Figure 13 shows clearly an increase in the amplitude of the oscillation at a higher frequency deviation from the setpoint. This could require additional operational measures and, in some cases, could lead to challenging operational situations such as loss of generating units and/or system separations. In other words, during the DFD, the electricity system of Continental Europe has a slower reaction in responding to oscillations, which may occur at any time, thereby increasing the risk that such oscillations cause additional issues (e. g. possible additional outages) in the system.

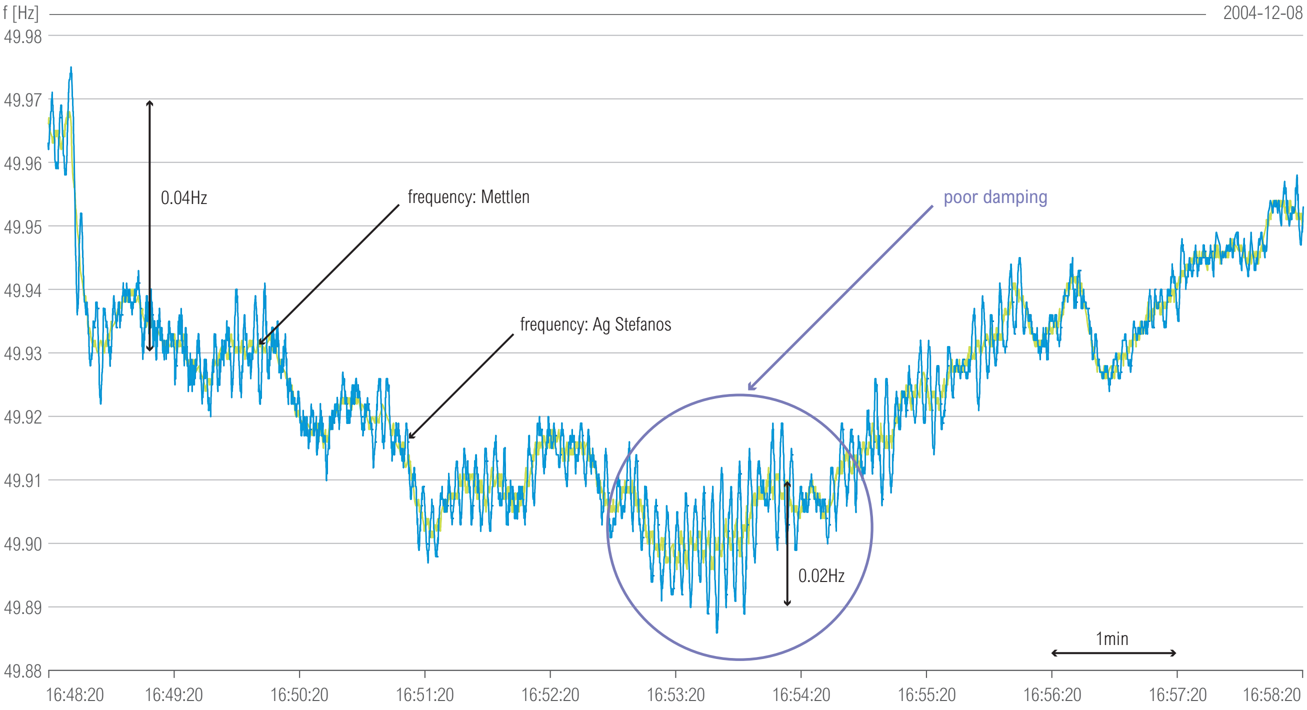


Fig. 13: Recording of poor damping of inter-area oscillations during frequency excursion

5.4.2. IMPACT ON MARKET PARTIES

a) Synchronous generation

Synchronous generation are designed and tuned to operate efficiently and safely within a limited operational domain defined mainly by frequency and voltage. Frequency limits are a concern for rotating machines, since deviation from the typical frequency ranges can affect generation lifecycle or can cause damage.

The Network Code on requirements for grid connection of generators [4] enables units to reduce their active power injection due to technical limitations associated with under-frequency deviations as illustrated in Fig. 14. This is mainly due to the inherent characteristic of losing some output at a lower frequency (particularly Gas Turbines), 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, with a lower rotational speed comes a reduced mass flow, which immediately translates into a reduced power output. To maintain the same output power under the same rotational speed a higher mass flow is required.

Maximum power capability reduction with falling frequency

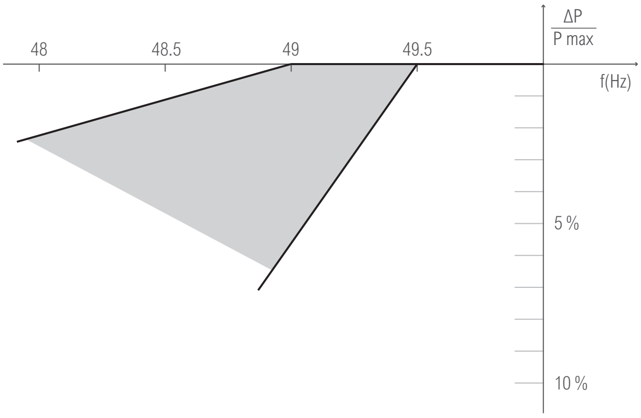


Fig. 14: Admissible Power Reduction under falling Frequency [4]

b) Non-synchronous generation

Frequency quality usually does not have a substantial impact on non-synchronous generation (e.g. full-converter wind turbines, PV installations connected via converter or Storage facilities) as these generation types often cover a large frequency band.

Activation of FCR in large quantities for more and longer periods leads to higher wear and tear of production units. Structural activation, i.e. not only in case of outages, could increase the wear and tear of production units and increases the cost of delivering FCR.

5.5 DETERMINISTIC FREQUENCY DEVIATION TARGET

5.5.1. EXPECTED FREQUENCY QUALITY

One of the solutions that could be envisaged at European level is to establish which size of DFD is detrimental to the security of the grid, and which DFD size can be considered as acceptable. The target could be used to check if the proposed solutions are adequate to reduce the size of DFD to the acceptable level.

The proposal of an acceptable DFD size comes from the realization that it will be virtually impossible to completely eliminate the DFD as there will always be a remaining mismatch between the accounting schemes of balancing which are related to minimum counter period (usually 10 or 15 minutes) and the load curve which changes constantly and smoothly.

First Target: Maximum Frequency Deviation

A DFD should allow the occurrence of the defining incident of FCR without going below 49.8 Hz, which means the frequency deviation should always be smaller than 200 mHz.

The dimensioning incident (double outage of power plants) of FCR is 3,000 MW which causes a frequency deviation of (3,000 MW / 27,000 MW / Hz) approx. 115 mHz for standard conditions. However, sometimes load/production is higher or lower and regulating power of the grid is also sometimes higher and lower.

So, expected frequency deviation would be in an interval of 100 to 125 mHz

Total margin therefore should be 125 mHz

In order to keep a margin of 125 mHz, the DFD should never be larger than 75 mHz

This leads to an acceptable DFD = 75 mHz

Second Target: Frequency Outside Interval

A second target could be related to the quality target which is given in SO GL:

Article 127 and Annex III of SO GL specify Frequency quality defining parameters in CE, establishing ± 50 mHz as the standard frequency range, which shall not be exceeded during more than 15,000 minutes per year.

SO GL requires that the frequency of Continental Europe stays within an interval of ± 50 mHz for the whole time, except for a maximum of 15,000 minutes per year.

This volume covers both the DFDs and the frequency deviations due to outages in the grid. Given that there are statistically less than 100 large outages per year and more than 2,500 DFDs per year, most of the 15,000 minutes will be used by DFDs.

This roughly translates to 40 minutes per day which can be used by DFD. Considering that there are daily approx. 7 large DFDs, this can be converted into a value of around 5 minutes per DFD.

So, a second target could be:
A DFD should not leave the interval of ± 50 mHz for more than 5 minutes

5.6 POSSIBLE MITIGATION MEASURES FOR DFD

PREVIOUS STUDIES

ENTSO-E has previously launched projects to study the DFDs phenomena and to propose measures for their mitigation ([3], [5]). One of the main conclusions from those studies is that the problem shall be tackled at its source and corrective measures shall be designed appropriately and systematically. Some measures have been proposed to mitigate the DFD without eliminating it, – e.g.: increasing aFRR volumes. aFRR is only activated after an imbalance occurs and is much slower than DFDs. FCR is fast enough, although increasing its volume could be difficult because it would be costly and it does not solve the problem at the source. Other potential options which can tackle the effects of DFDs are:

a) Feedforward activation of aFRR;

b) Design of specific mFRR products;

c) Introducing ramping products (e.g. 10 min) with support of batteries or other fast-acting units, which can recharge during the rest of the hour.

In the current state of work, the task force has established a list of possible solutions, which may or may not have been examined in the past:

a) Introduction of 15-minute market schedules and balancing;

b) Introduction of ramping on generation schedules;

c) Introduce ramping on market schedules;

d) Introduction of a limit of change in net position of a market area/bidding zone between two successive market periods;

e) Introduction of 15-minute period imbalance settlement in each balancing area;

f) Introduction of ramp-based imbalance settlement;

g) Translation of ramping on generators into the imbalance settlement;

h) Use changes between ISP for BRPs as marked based aFRR bids;

i) Additional Frequency Containment Reserves.

The task force is continuing its work and will complete a list of possible solutions and for each solution will list its Merits, its Challenges, the Implementation issues and a possible Timeline for introduction.

6. CAUSAL FACTORS

The following Causal Factors have been identified by the Task Force:

1. No efficient incentives in place for market participants or control tools/processes in place to avoid significant DFDs;
2. Frequency Containment Reserves are designed to stabilise the system frequency and are effective for other imbalance patterns than those causing DFDs. Hence, Frequency Containment Reserves are not dimensioned to prevent significant DFDs;
3. A single point of failure in processing nominal and backup values in a specific case of four interconnector lines;
4. The current monitoring tools and alarming systems are not applicable for this kind of error;
5. Current process and procedure for detecting long-lasting frequency deviations does not have criteria for deviations below 50 mHz.

7. RECOMMENDATIONS AND ACTIONS

1. **Analysis to be completed to determine how many additional reserves should be procured until Market or TSO based Solutions to DFDs are implemented. The analysis should determine:**

   If an increase in reserves is warranted (if so how much); especially if reserves should be increased in control blocks where the occurrence of DFDs is frequent and large ACEs are observed in those control blocks during those DFDs.

   Causal Factor: 1 & 2

2. **Consultation document to be developed by ENTSO-E to consider Market and/or TSO proposals to mitigate DFDs:**

   a) The task force recommends that a report is completed listing the possible solutions and for each solution to list its Merits, its Challenges, the Implementations issues and a possible Timeline for introduction;

   b) The task force recommends that all possible solutions are investigated both from a system security point of view and from a market impact point of view. It is further recommended that each solution be tested in reference to the EU network codes and guidelines to make sure no solution is proposed which is contradictory to EU law;

   c) The task force further recommends executing simulations in order to test the efficiency of possible solutions;

   d) Given that the Market situation may differ in different market areas and different member states on the Synchronous grid, the task force also recommends that the solution be open for possible hybrid solutions where one type of solution is implemented in one Country and another solution in another Country. The goal of the hybrid solution should be that the DFDs can be reduced to the established acceptable level.

   Causal Factor: 1 & 2

3. **Set Frequency Quality Targets which define acceptable levels of DFD:**

   a) Frequency deviations should never be larger than ±75 mHz due to DFDs to allow for the dimensioning outages in the system without reaching 49.8 Hz or 50.2 Hz;

   b) The frequency deviation due to DFDs should not be outside the interval of ±50 mHz for more than 5 minutes in order to respect the quality target set on the frequency of the CE region in SOGL.

   Causal Factor: 1 & 2

4. **Check the existing Definition and Implementation of fail-safe measurement and telecommunication standards, for all interconnectors values used by LFC across CE and identify follow-up actions as necessary. Define and implement control system functionality standards to detect "frozen" LFC values across CE.**

   Causal Factor: 3 & 4

5. **Centralised process and tools to facilitate the timely resolution of frequency deviation incidents to be reviewed and improved.**

   Causal Factors: 4 & 5

8. REFERENCES

[1] European Commission, “Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation”, (2017).

[2] Union for the Coordination of Transmission of Electricity (UCTE), “Final Report System Disturbance on November 4 2006”, (2007).

[3] Eurelectric & ENTSOE, “Deterministic Frequency Deviations – Root Causes and Proposals for Potential Solutions”, (2011).

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ABBREVIATIONS

ACE	Area Control Error
FRR	Automatic Frequency Restoration Reserves
AGC	Automatic Generation Control
BRP	Balance Responsible Party
CB	Control Block
CC	Coordination Centre
DFD	Deterministic Frequency Deviation
EAS	ENTSO-E Awareness System
FCR	Frequency Containment Reserves
FRM	Flow Reliability Margin
ICS	Incident Classification Scale
ISP	Imbalance Settlement Period
LFC	Load Frequency Controller
LFDD	Low-Frequency Demand Disconnection
RG CE	Region Continental Europe
SMM	Serbia, Macedonia and Montenegro
SO GL	System Operation Guideline
TRM	Transmission Reliability Margin

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