Long Lasting Frequency Deviations

Measures taken by Continental European TSOs to address Long Lasting Frequency Deviations

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About ENTSO-E

ENTSO-E, the European Network of Transmission System Operators for Electricity, is the pan-European association of 42 electricity transmission system operators (TSOs) in 35 countries. In 2009, ENTSO-E was registered in the EU legislation and has since then been given a series of legal mandates.

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1. Executive Summary

This report summarises the work performed by all Continental European Transmission System Operators (TSOs) to prevent, detect and resolve Long Lasting Frequency Deviations (LLFDs), which occur exceptionally in the Continental Europe (CE) power system and which can contribute to larger frequency deviations such as that observed in the system on 10 January 2019. In isolation, an LLFD is usually fairly small and does not create a security threat by itself. It is in combination with other events, such as a large outage of generation or load, or a significant deterministic frequency deviation (DFD), that the LLFD can contribute to the deterioration of grid security.

The measures detailed in this report, which have been implemented by Continental European TSOs, can be categorised as follows:

- Measures to prevent LLFDs from occurring;
- Measures to detect the occurrence of an LLFD;
- Measures to resolve an LLFD when it occurs.

Measures identified and implemented to prevent the occurrence of an LLFD include the development of best practice on telecommunication standards and best practice for detecting frozen measurements in the Load Frequency Control system.

Measures identified and implemented to detect the occurrence of an LLFD include data quality tests and data comparisons in the ENTSO-E Awareness System (EAS) and a new early detection system (the implementation of an alarm which is triggered based on a time deviation of at least 6 seconds in at most 4 hours). These measures will ensure that an LLFD cannot stay in the system for a long time without being detected.

Measures identified and implemented to resolve the occurrence of an LLFD include a new process and check-list procedures which are applied by all TSOs.

ENTSO-E is convinced that the implementation of these measures will reduce the LLFDs in both size and number of occurrences, therefore reducing the risk to grid security due to large frequency deviations where LLFDs are a contributing factor.

2. Introduction

This report presents the work performed by all Continental European TSOs to prevent, detect and resolve LLFDs, which occur exceptionally in the CE power system, and which can contribute to larger frequency deviations such as that observed in the system on 09 January 2019. In isolation, an LLFD is usually quite small and does not create a security threat by itself. It is in combination with other events, such as a large outage of generation or load or a significant DFD, that the LLFD can contribute to the deterioration of grid security.

2.1 LLFDs in January 2019

An LFD of 0 to maximum −60 mHz (average −30 mHz) began on Wednesday, 09 January 2019 at 13:25 and persisted until 11 January 2019 at 09:37. The synchronous time deviation increased from −14 seconds on 09 January to −84 seconds on 11 January, due to this low steady-state frequency deviation in CE. At 21:02 on 10 January, the LLFD coincided with a DFD, which quickly caused the frequency to decrease to a value of 49.808 Hz. Due to the frequency drop, RTE automatically reduced approximately 1.7 GW of load through the Industrial Interruptible Service, which caused 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.

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

The permanent long-lasting deviation of the Serbia, Macedonia and Montenegro (SMM) control block, which is now resolved, also affected the frequency between 09 and 11 January 2019, the average hourly FRCE of the SMM control block being −83 MW. However, the 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.

In its meeting of 06 February 2019, the ENTSO-E System Operations Committee approved the establishment of the Task Force Continental Europe Significant Frequency Deviations.

2.2 LLFDs explained

LLFDs can be caused intentionally or by errors in measurements or schedules in Automatic Generation Control (AGC). Deviations may also occur due to issues in activating Frequency Restoration Reserves.

FRCE is defined in Art 143 of the SO GL:

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

With:

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

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 (approximately 30,000 MW/Hz). Thus, an error of 600 MW will create an approximate 20 mHz LLFD.

Intentional deviations are not usual in the CE Synchronous Area, but when they occur it is usually the result of non-technical causes. Intentional deviations also lead to LLFDs following the same rule as above. The permanent activation of primary reserves to contain LLFDs can lead to the depletion and the resulting unavailability of FCR from limited energy sources. Given that the average usage of primary reserve is non-zero during an LLFD, the reserve of energy is systematically reduced until unavailable, unless it is replaced. This means that, in time, there are much fewer than 3,000 MW available for primary control in the CE system unless the sources are substituted.

The permanent use of, for instance, 500 MW of primary reserves leads to an unavailability of primary reserves which can be much larger than 500 MW. This weakens the system against additional events during the LLFD. The remaining reserve will be insufficient to cover the reference incident of CE (3,000 MW), unless substituted, and can therefore lead to a larger frequency drop than can be expected under normal operation.

LLFDs also lead to large compensation programmes which require accounting and administration. In addition, these deviations lead to time deviations on electronic clocks which are sensitive to system frequency.

2.3 Recommendations from the Task Force Continental Europe Significant Frequency Deviations

The ENTSO-E Task Force Continental Europe Significant Frequency Deviations recommended the following measures for implementation:

- Define and implement fail-safe measurement and telecommunication standards for all Interconnector values used by LFCs across CE.
- Define and implement Control System functionality standards to detect “frozen” LFC values across CE.
- Extend EAS Functionality.
- Develop a centralised process to facilitate a timely resolution of frequency deviation incidents.
- Develop an additional Operational Procedure to consider LLFDs.

In the following chapters, the measures are further detailed and split into the following categories:

- Measures to prevent LLFDs from occurring;
- Measures to detect the occurrence of an LLFD;
- Measures to resolve an LLFD when it occurs.

3. Preventing LLFDs

As an LLFD can occur at any time when there is an error in one of the LFC systems in the interconnected system of CE, it is important to reduce the risk of occurrence of such errors.

Most usual errors are:

- Measurement errors on an interconnection;
- Scheduling error on a border between bidding zones;
- Telecommunication failure on one or more tie-lines;
- Missing interconnectors in the LFC system.

These errors can be anticipated and reduced with the best practices described in this chapter.

3.1 Telecommunication standards

The Continental Europe System Frequency expert working group has developed a Standards and Measurements Technical Report in November 2019 which has become a best practice document for all CE TSOs.

This technical report considers existing best-practice and state-of-the-art technology and proposes further improvements of these practices considering recent changes in operational processes including real-time coordination. It compares different technical implementations and operational experiences and shares these technical functions or concepts amongst all CE TSOs. Examples of the best practices considered within the technical report are detailed below:

Measurement data and technologies for processing

To gain an overview of current real-time data processing standards, the System Frequency Expert Working Group performed a survey prior to setting a common standard for checking the cross-border real-time measurements used in an LFC. The standard considers data quality tags as well as the maximum times for the checking of updated or refreshed data within the SCADA system. Implementation of the standards and changes of individual TSOs' Scada systems is ongoing.

Plausibility check of measurement data

To immediately improve robustness and reduce risks of errors in calculating FRCE, TSOs checked measurement data from other sources (e.g. telemetry sources or duplicate SCADA data points (measured or estimated) to ensure the redundancy and reliability of FRCE calculations in the LFC.

3.2 Best Practice to avoid frozen measurements

The Continental European Coordinated System Operation expert working group has developed a best practice technical report detailing methods in how to avoid frozen measurements in TSOs' LFCs. This best practice report helps to detect and avoid an incorrect input to the LFC. Examples of the best practices considered within the technical report are detailed below:

Communication paths

Measurement values (for at least the first and second values) in the LFCs are guaranteed to always have different sources and communication paths.

Alarms for unchanged LFC measurements

For any cross-border LFC measurement, if the value measured does not change, with at least a given threshold value during the period of for instance one minute, an alarm will be generated to indicate a possible frozen measurement.

Comparison of different LFC measurements

In the event of a deviation between two LFC input sources, higher than a predefined value, the LFC will display an error sign and create a SCADA alarm.

The LFC measurements are checked for incorrect or implausible values by an automatic detection system within the LFC. The system checks the average deviation between measurements and the system shows the difference and gives visual and acoustic alarms if the average deviation is above a certain threshold. The incorrect or implausible measurement can then be checked and, if necessary, replaced or deactivated by the operator.

Comparison of measured values with estimated values

A continuous process of comparing each SCADA measurement value with each estimated value (by the state estimator functionality in the Energy Management System) is executed to detect a possible error. Based on this possible error, a SCADA alarm is generated and the measured value can be set as suspicious and then excluded from the LFC processing.

Quality codes on measurements

The quality of the measurements is checked by the SCADA capability to associate "quality" codes to the real time measurements. Such codes are generated by the telecommunication protocol and/or the SCADA itself as a certification of the acquired telemetry measurement, and the quality codes are continuously monitored by the operators. A bad quality code warns the operator about the risk of anomalous telemetry measurement, following which the operator can compare the telemetry measurement with the value computed by the on-line state estimator or with the telemetry measurement coming from the neighbouring TSO in order to check its reliability.

Automated checks between LFC measurements and virtual metering values

A virtual metering value (consisting of, e.g. a 15-minute average value) of the cross-border measurements is created and used in the LFC. This enables a comparison between the virtual metering value on each cross-border line with the actual real-time metered value of the cross-border line. If the difference is higher than a set threshold, a SCADA alarm is generated and the potential error is checked by the operator.

Check the validity of measured values based on the total net sum of the substation

The first Kirchhoff law is applied to the substations where the cross-border lines connect. The sum of the measurements of all of the lines connecting to a substation must add up to zero. If this is not the case, it could indicate a measurement error which then requires checking by the operator.

Total balance check of the LFC area border

The sum of first values per border can be compared with the sum of the second values per border and, in the event that a difference is greater than a specific threshold, an alarm is triggered in the SCADA system and the values are checked by the operator.

Routine checks

Daily Routine: Manual measurement checks of all cross-border lines are carried out daily to determine the plausibility of values and status of deactivated values, and that the correct LFC input channel is selected. If an error is detected then it is reported to the relevant IT support team.

Check of scheduled cross-border exchanges

The LFC uses an algorithm to determine if the LFC is using the correct scheduled exchange values. The algorithm compares the scheduled exchange values from the local scheduling system with the values imported into the LFC. In the event of a difference an alarm is generated in the SCADA and the operator can check and correct the error.

4. Detecting LLFDs

Several early detection mechanisms have been developed by TSOs to avoid the situation whereby any LLFD, even if undetected by the TSO which is the source of the LLFD, remains in the power system for an extended period.

4.1 Using the EAS to detect LLFDs

Quality of EAS data

To improve the overall quality and availability of data in EAS, an automatic regular check of the measurement data is implemented. Data owners are automatically informed about potential data quality degradation and counter measures are taken to ensure that the general availability and quality of measurement data remains high.

EAS Data sanity checks

Data sanity checks are implemented in the EAS to improve robustness and reduce the risks of errors in calculating the FRCE. Automatic checks and alarms have been developed (to be deployed mid-2021) for the actual and scheduled border values between control blocks. In priority order:

1. calculations, visualisations and alarming of border value discrepancies for all borders between control blocks in the EAS based on two measurements with a common threshold.

2. a feasibility concept has been developed to implement data from other sources in EAS which enables consistency checks between different platforms.

3. implementation of additional real-time balance calculations for comparison and cross-checking based on exchanged data

4.2 Time trigger for detecting LLFDs

To improve the alarming and subsequent resolution processes for LLFDs, the TSOs of CE agreed to implement a grid-time-deviation-based frequency monitoring and alarming system. This is in addition to the already existing frequency procedure (> | 50 mHz |). The main objective of this additional monitoring procedure is to detect minor LLFDs, enabling an earlier investigation into the source of the LLFD. In addition, frequency traffic lights for the Coordination Centres (CCs) North (Amprion) and South (Swissgrid) were implemented in the EAS to highlight the possible existence of an LLFD.

The electrical time is a time calculated value based on the standard power system frequency of 50 Hz in the CE power system. Fifty oscillations of alternating current equate to one second of electrical time. Frequency fluctuations lead to deviations in electrical time and, if the frequency is lower than 50 Hz, then fifty oscillations takes slightly longer. If, however, the frequency is higher than 50 Hz, the time interval for fifty oscillations is shorter. As one second of electrical time always constitutes precisely fifty oscillations, the electrical time in seconds can last slightly longer or shorter than a second of coordinated universal time (UTC) depending on the frequency. The electrical time deviation is calculated by comparing electrical time with UTC time, which is determined using highly precise atomic clocks operated by Swissgrid.

This electrical time deviation is constantly balanced by TSOs. For instance, when the electrical time deviation exceeds a value of twenty seconds, TSOs take measures to correct the electrical time. To balance the electrical time deviation, the frequency set point is changed to 49.990 Hz if the electrical time is running ahead of UTC time and to 50.010 Hz if the electrical time is lagging behind UTC time.

Thus, the electrical time deviation represents the frequency deviation for a certain period of time and can be used to detect and alarm minor LLFDs, as illustrated by the example below.

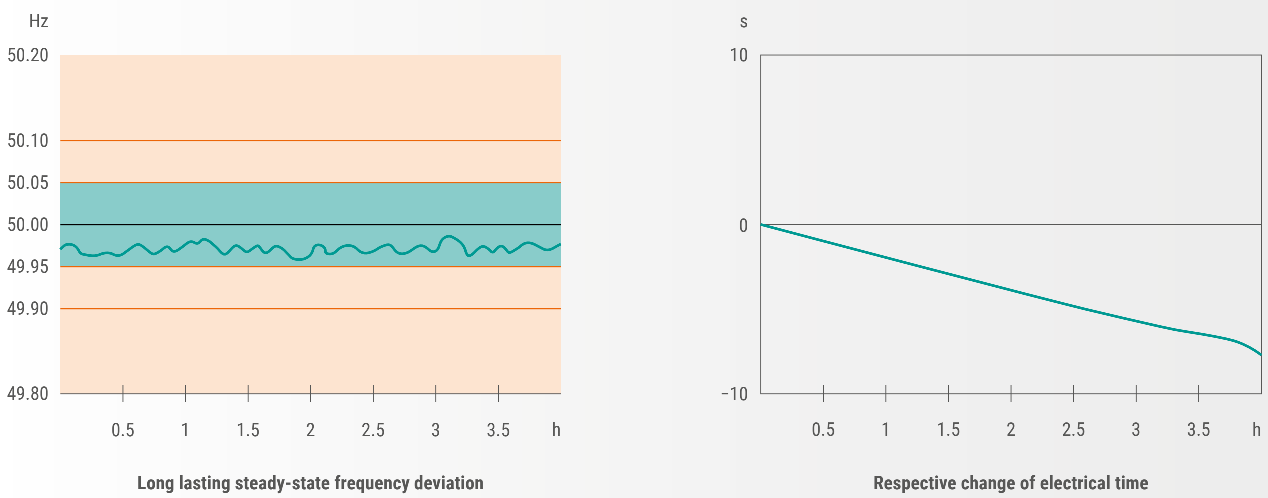

Figure 1: Relationship between frequency deviation and electrical time

This example shows an LLFD of approximately −30 mHz during 4 hours. The electrical time lags UTC time by approximately 8.6 s.

Electrical Time Deviation Alarms

The relationship between frequency deviation and electrical time, as described above, is used to implement this additional monitoring and alarming procedure. The existing procedures are extended by the continuous monitoring of the absolute and relative electrical time.

Monitoring and Alarming of the Relative Electrical Time Deviation

The monitoring of the relative electrical time deviation is implemented according to the following criterion.

$| \Delta th - \Delta th\text{-}4 | > 6$ s

The above-mentioned criterion is defined as the delta of the electrical time deviation during the last four hours. If the delta of the electrical time deviation exceeds 6 seconds during the last 4 hours, an alarm is triggered. The delta of 6 seconds for 4 hours is equivalent to an average frequency deviation of more than 20 mHz. The criterion is checked permanently by both CCs.

Both CCs monitor this criterion with independent methodologies to guarantee redundancy. Whereas Swissgrid compares the two relevant snapshots of the grid time, Amprion calculates the integral of the frequency deviation during the last 4 hours.

If the criterion is fulfilled, an alarm is generated in the local SCADA system of the CCs. After the occurrence of such an alarm, Amprion and Swissgrid liaise to verify the existence of a real frequency deviation and coordinate further actions. In the event of a real frequency deviation, the CCs set the respective alarm in the EAS (frequency traffic light) and begin the subsequent investigation processes, as detailed in Chapter 5.

Monitoring and Alarming of the Absolute Grid Time Deviation

The monitoring of the absolute electrical time deviation is implemented according to the following criterion.

$| \Delta t | > 60$ s

The above-mentioned criterion is fulfilled when the absolute value of the electrical time deviation exceeds the value of 60 seconds. The criterion is permanently checked by both CCs

If the criterion is fulfilled, an alarm is generated in the local SCADA system of the CCs. After the occurrence of such an alarm, Amprion and Swissgrid liaise to verify the existence of a real frequency deviation and to coordinate further actions. In the event of a real frequency deviation, the CCs set the respective alarm in the EAS (frequency traffic light) and begin the subsequent investigation processes, as detailed in Chapter 5.

EAS Frequency Traffic Light

All frequency related alarms are centralised in the frequency traffic lights in the North Sea and the Mediterranean as shown below on the EAS System State page.

Figure 2: EAS frequency traffic lights with status "green"

For redundancy reasons, there are two frequency traffic lights, each controlled by the CC North and South independently. The frequency traffic lights are controlled by the CCs simultaneously when one or more of the following conditions are fulfilled:

No.	Condition	Traffic Light	Activation
1	Frequency deviation $\| \Delta f \| > 50$ mHz for $t > 15$ min	Yellow	automatically
2	Frequency deviation $\| \Delta f \| > 100$ mHz for $t > 5$ min	Yellow	automatically
3	Grid time deviation $\| \Delta t_h - \Delta t_{h-4} \| > 6$ s	Yellow	manually
4	Grid time deviation $\| \Delta t \| > 60$ s	Yellow	manually
5	Frequency deviation $\| \Delta f \| > 200$ mHz for $t > 30$ sec	Red	automatically

Table 1: Activation conditions of the EAS frequency traffic lights

The conditions listed in Table 1 are monitored by the two CCs as described in chapter 4. Once one of the trigger criteria in Table 1 are fulfilled, an automatic alarm is generated in the local SCADA systems of each CC. Although the alarms for large steady-state frequency deviations are transmitted automatically to the EAS, the alarms for LLFDs (equivalent to grid time deviation) are set manually in the EAS after coordination between the two CCs.

5. Resolving LLFDs

5.1 Procedure to resolve an LLFD

A new alarm and investigation process and checklists for resolving LLFDs have been implemented by CE TSOs. The process for an LLFD is structured as follows:

Figure 3: LLFD alarm and investigation process

After the occurrence of an LLFD alarm, both CCs begin a bilateral call to assess the situation and coordinate further actions.

EAS Alarm

If the CCs confirm the presence of an LLFD, the EAS frequency traffic light is set to status "yellow" (Alert).

Figure 4 : EAS frequency traffic lights with status "yellow"

CC Investigation (Use of the CC-Checklist)

The CCs execute the steps of the *CC-Checklist for long lasting steady-state frequency deviations* to investigate the cause of the frequency deviation and identify the source. If the source can be identified, the CCs coordinate measures with the relevant TSO to solve the frequency deviation. The CC investigation does not necessarily have to be triggered by an LLFD alarm.

TSO Investigation and CSO Escalation (Use of TSO-Checklist)

If the CCs are unable to identify the source based on the information in the EAS and the LFC, then they contact all CE TSOs via phone and email and ask them to execute the checks of the *TSO-Checklist for Long Lasting Steady-State Frequency Deviations*. Amprion is responsible for contacting the control rooms of all CE North TSOs, and Swissgrid is responsible for contacting the control rooms of all CE South TSOs. In addition, an email is sent to the control rooms of all CE TSOs.

6. Conclusion

The measures detailed in this report which have been implemented by CE TSOs can be categorised as follows:

- Measures to prevent LLFDs from occurring;
- Measures to detect the occurrence of an LLFD;
- Measures to resolve an LLFD when it occurs.

Measures identified and implemented to prevent the occurrence of an LLFD include the development of best practice on telecommunication standards and best practice on detecting frozen measurements in the LFC system.

Measures identified and implemented to detect the occurrence of an LLFD include data quality tests and data comparisons in the EAS system and the implementation of a new early detection system (an alarm which is triggered based on a time deviation of at least 6 seconds in at most 4 hours). These measures will ensure that an LLFD cannot stay in the system for a long time without being detected.

Measures identified and implemented to resolve the occurrence of an LLFD include a new early detection system and process as well as check-list procedures applied by all TSOs.

ENTSO-E is convinced that the implementation of these measures will reduce the LLFDs in both size and number of occurrences, therefore reducing the risk to grid security due to large frequency deviations where LLFDs are a contributing factor.

Glossary

AGC	Automatic Generation Control
CC	Coordination Centre (North & South)
CE	Continental Europe
CSO	Coordinated System Operation Working Group
DFD	Deterministic Frequency Deviation
EAS	ENTSO-E Awareness System
EMS	Energy Management System, calculation tool
FRCE	Frequency Restoration Control Error
LFC	Load Frequency Controller
LLFD	Long Lasting Frequency Deviation
mHz	milliHertz, measure for frequency
Pact	Active Power measured
Psch	Scheduled Power
s	second(s)
SCADA	Supervisory Control and Data Acquisition, observation and control system
SFD	Significant Frequency Deviation
SMM	Serbia, Macedonia and Montenegro
UTC	Coordinated Universal Time

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