Frequency quality analysis

2025

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Chapter 1. Introduction

This report presents the results of the frequency quality study of the Nordic synchronous system for the year 2025. The results have been obtained by analyzing data from Fingrid's PMU (Phasor Measurement Unit) measurements. All times are given in Finnish time (CET/CEST+1).

Chapter 2 presents information about the measurement data used in this report. Chapter 3 of the report includes a frequency quality reporting framework proposed by the FQ2 (Frequency Quality, Phase 2) Project Report. This chapter also presents the frequency quality evaluation criteria defined in the System Operation Guideline (SO GL) as well as the results from Fingrid's previous years' frequency quality analysis. The fourth chapter presents in detail the frequency disturbances where the deviation exceeds 300 mHz. The last chapter is a summary of the results.

The term standard frequency range is used to refer to frequencies between 49.9 Hz and 50.1 Hz. The current Nordic target level for the number of minutes outside this range is not more than 10 000 minutes per year. 60-second oscillation, which is analyzed in Chapter 3.8, refers to a low-frequency oscillation observed in the Nordic power system with a time period of roughly 60 seconds.

Chapter 2. Measurement data

Frequency data for the analysis outlined in this report was gathered from the PMUs at different locations. For every hour, measurements from the PMU with the largest amount of available data was used. It is assumed that these measurement values represent the frequency of the whole Nordic synchronous system. The frequency data used has a sample rate of 10 Hz meaning that the interval between two samples is 0.1 s. The data used in this study can be accessed at Fingrid's website [1].

The amount of valid measurement data in percentages per month in 2025 is presented in Table 2.1. The yearly availability of data for years 2020 to 2025 can be seen in Table 2.2 [2,3,4,5,6]. In 2025, there was valid measurement data for 99.61 % of the time. Some of the data is missing due to telecommunication errors. From Table 2.1, we can see that the availability has been the worst in May at 98.05 %, followed by August at 98.80 %. In all other months, the data availability exceeded 99.5 %. Overall, the availability in 2025 has been high throughout the year. Compared to the years 2020-2025, the yearly availability in 2025 is the third highest.

Table 2.1. The amount of valid measurement data available per month in 2025

Month	Available data
January	99.97 %
February	99.95 %
March	99.96 %
April	99.97 %
May	98.05 %
June	99.76 %
July	99.78 %
August	98.80 %
September	99.56 %
October	99.64 %
November	99.97 %
December	99.97 %

Table 2.2. The amount of valid measurement data available for years 2020-2025

Year	Available data
2020	97.82 %
2021	99.92 %
2022	99.56 %
2023	99.58 %
2024	99.95 %
2025	99.61 %

Chapter 3. Frequency Quality Indices

This chapter includes the frequency quality indices defined and proposed by the Frequency Quality, phase 2 project report, for monitoring frequency quality at all times [7]. Frequency evaluation criteria for the instantaneous frequency data defined in SO GL (System Operation Guideline) Article 131(1)(a) are also presented in this chapter. Article 131 is shown on the following page.

All the input frequency data used to calculate the frequency indices has either a resolution of 0.1 seconds or the average of the 0.1 second data. For example, a resolution of 1 second means that the average of ten 0.1 second values has been used. Most of the proposed indices are presented as averages for every month of the year, day of the week, hour of the day, and minute of the hour. In some instances, yearly variation is also included.

System Operation Guideline, Article 131:

"1. The frequency quality evaluation criteria shall comprise:

(a) for the synchronous area during operation in normal state or alert state as determined by Article 18(1) and (2), on a monthly basis, for the instantaneous frequency data:

(i) the mean value;

(ii) the standard deviation;

(iii) the 1- ,5- ,10- , 90- ,95- and 99-percentile;

(iv) the total time in which the absolute value of the instantaneous frequency deviation was larger than the standard frequency deviation, distinguishing between negative and positive instantaneous frequency deviations;

(v) the total time in which the absolute value of the instantaneous frequency deviation was larger than the maximum instantaneous frequency deviation, distinguishing between negative and positive instantaneous frequency deviations;

(vi) the number of events in which the absolute value of the instantaneous frequency deviation of the synchronous area exceeded 200 % of the standard frequency deviation and the instantaneous frequency deviation was not returned to 50 % of the standard frequency deviation for the CE synchronous area and to the frequency restoration range for the GB, IE/NI and Nordic synchronous areas, within the time to restore frequency. The data shall distinguish between negative and positive frequency deviations;

(b) for each LFC block of the CE or Nordic synchronous areas during operation in normal state or alert state in accordance with Article 18(1) and (2), on a monthly basis:

(i) for a data-set containing the average values of the FRCE of the LFC block for time intervals equal to the time to restore frequency:
- the mean value;
- the standard deviation;
- the 1- ,5- ,10- , 90- ,95- and 99-percentile;
- the number of time intervals in which the average value of the FRCE was outside the Level 1 FRCE range, distinguishing between negative and positive FRCE; and
- the number of time intervals in which the average value of the FRCE was outside the Level 2 FRCE range, distinguishing between negative and positive FRCE."

3.1 Average frequency and standard deviation

This section includes the results for average frequency and standard deviation. Chapter 3.1.3 has the combined results for mean value and standard deviation according to SO GL Article 131(1)(a) (i-ii).

3.1.1 Average frequency

The following figures show the average frequency for the year 2025. The resolution of the frequency data that has been used is 1 second. The average frequency is calculated with the following formula, where f_i is the value of the frequency and n is the number of samples.

$$\bar{f} = \frac{\sum_i^n f_i}{n}$$

Figure 3.1 represents the average frequency for every month. The average frequency remained close to 50 Hz throughout the year. The largest deviation of the monthly average, 1.6 mHz, occurred in December. Overall, the average frequency in 2025 was slightly better than in the previous year, as the number of deviations exceeding 0.25 mHz was lower. However, the largest deviation of the monthly average frequency was clearly higher than in previous years and differed noticeably from earlier observations. Overall, the average frequency remained above 50 Hz for most of the year, similar to 2024, 2023, and 2022. Earlier years showed a more even distribution of monthly averages around 50 Hz.

Figure 3.1. Average frequency for each month in 2025

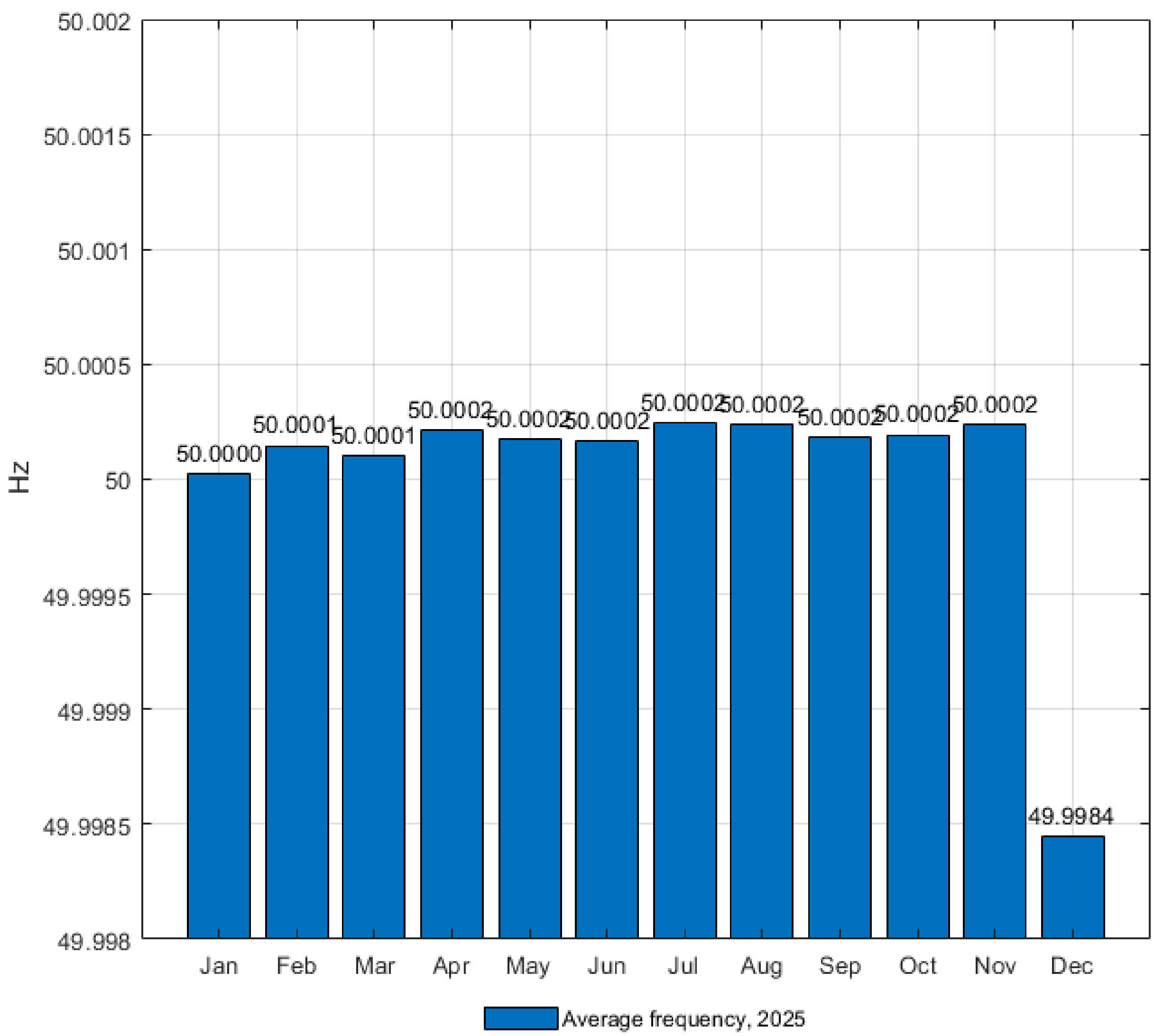


Figure 3.2 shows the average frequencies for each day of the week. The highest average frequency occurred on Friday and the lowest on Sunday.

***Figure 3.2**. Average frequency for each day of the week in 2025*

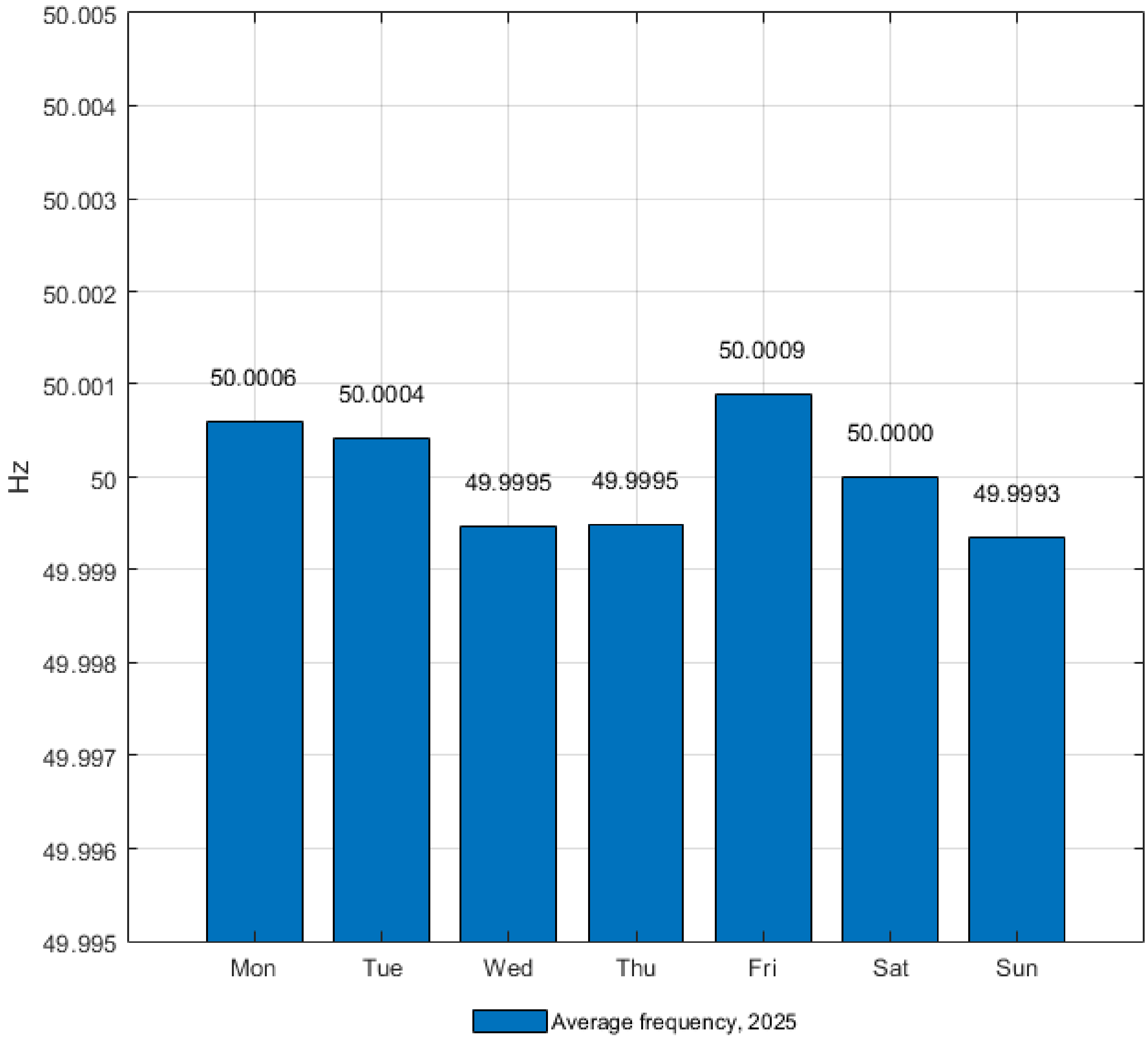


Figure 3.3 shows the average frequencies during each hour of the day. The frequency has been lowest at 2 am, 5 am, and 4 pm. The frequency has been higher during the morning hours between 8 am and noon, as well as in the evening, except at 10 pm, and around midnight. The trend is very similar to the year 2024, although the deviations of the average frequency from 50 Hz have been smaller.

Figure 3.3. Average frequency for each hour of the day in 2025

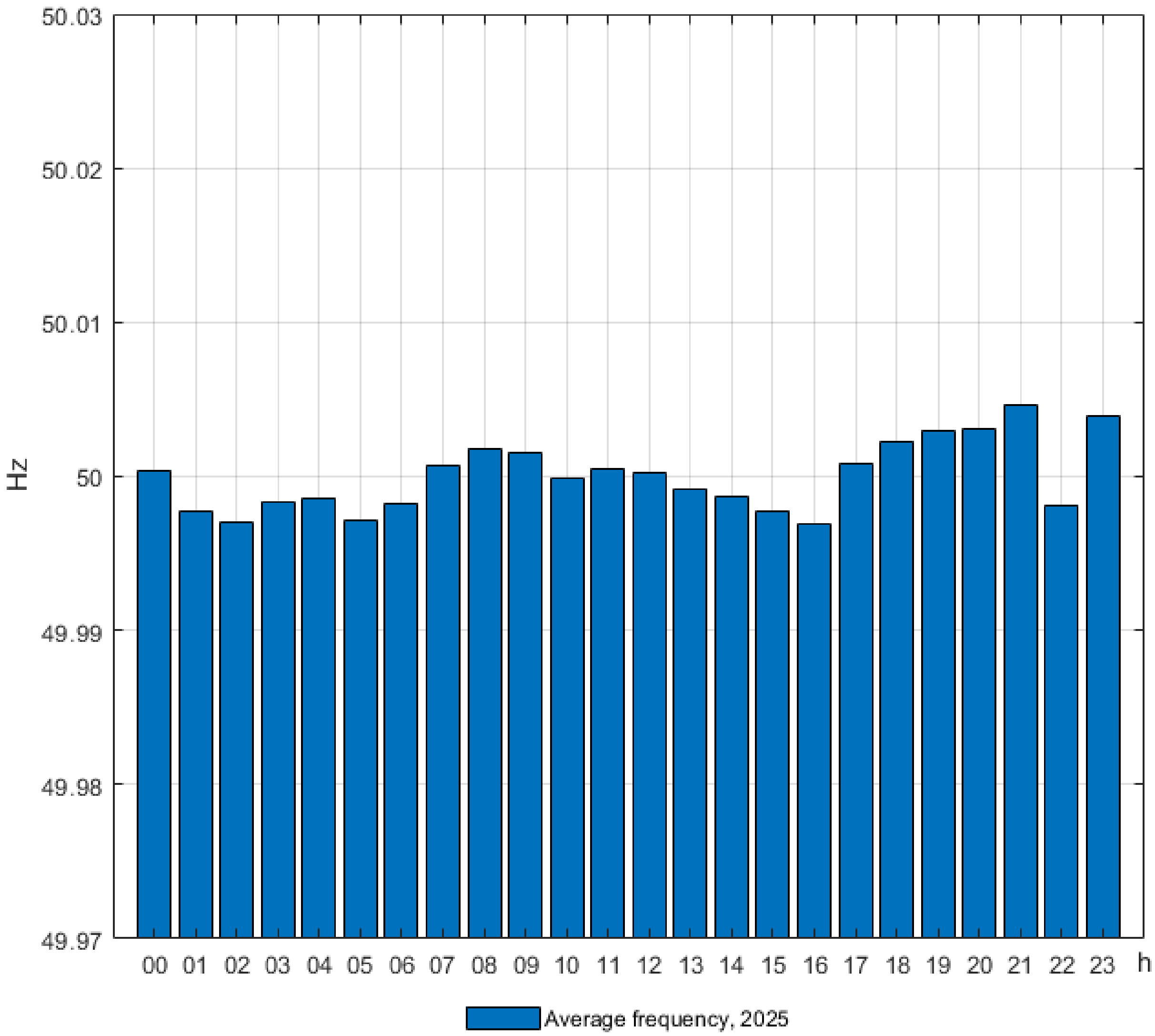
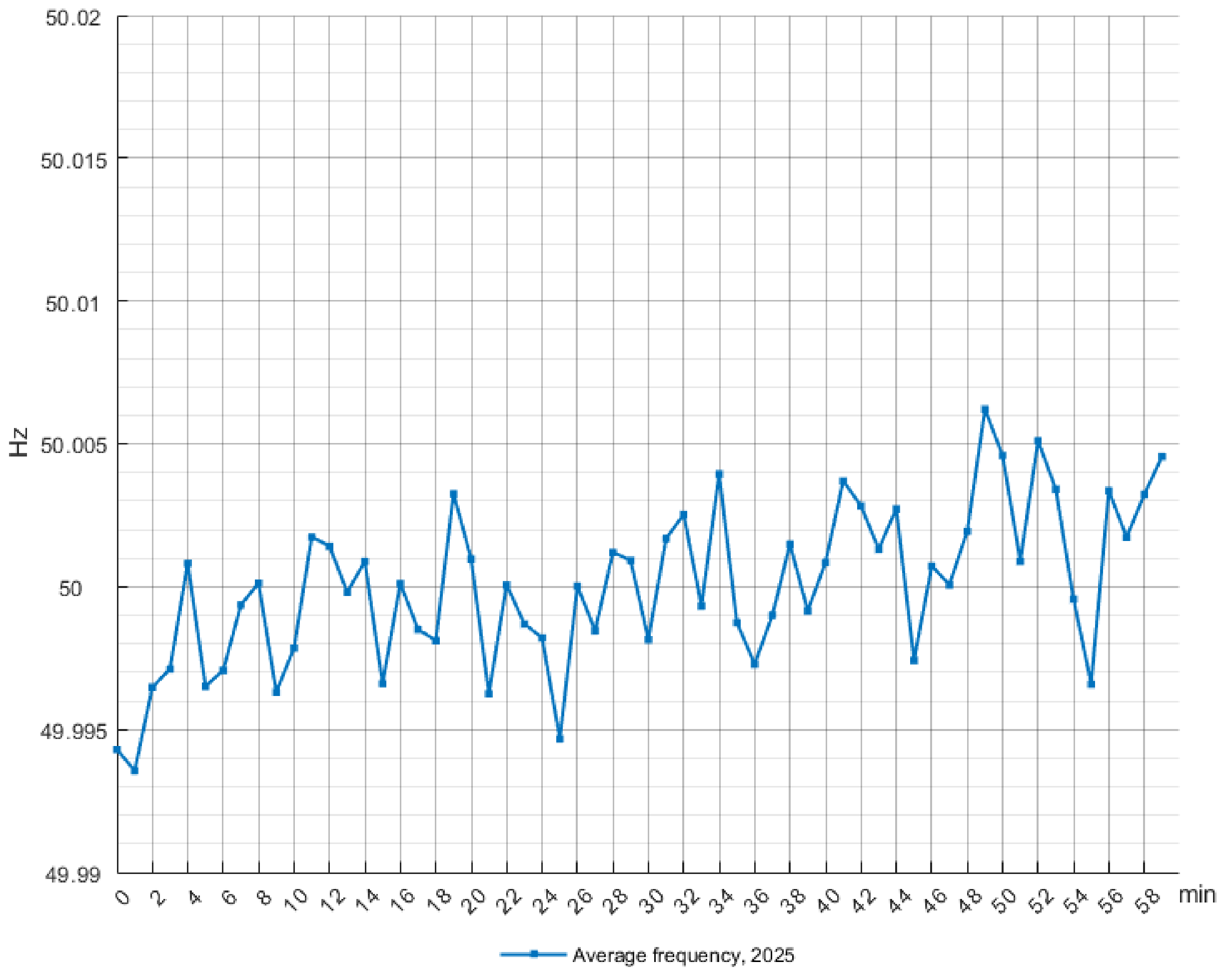


Figure 3.4 shows the average frequency within the hour. In general, the frequency has been higher in the latter part of the hour. The difference between consecutive minutes varies between 0.2 and 6.9 mHz. The largest difference has decreased slightly compared to the year 2024, where the largest difference was 7.5 mHz.

***Figure 3.4**. Average frequency for each minute of the hour in 2025*



3.1.2 Standard deviation

This section includes the figures representing the standard deviation of frequency during the year 2025. The resolution of the frequency data is 1 second. Below is the formula that was used to calculate the standard deviation.

$$\sigma = \sqrt{\frac{1}{n}\sum_{i}^{n}(f_i - \bar{f})^2}$$

Figure 3.5 shows the standard deviation for each month in 2025. The low values of the standard deviations indicate that the 1-second frequency values have been closer to the mean value and vice versa. The highest deviation was obtained in May, while the lowest was obtained in December. Overall, the standard deviation values have been lower than in 2024, while a broadly similar month-by-month trend can be observed.

***Figure 3.5**. Standard deviation of the frequency for every month in 2025*

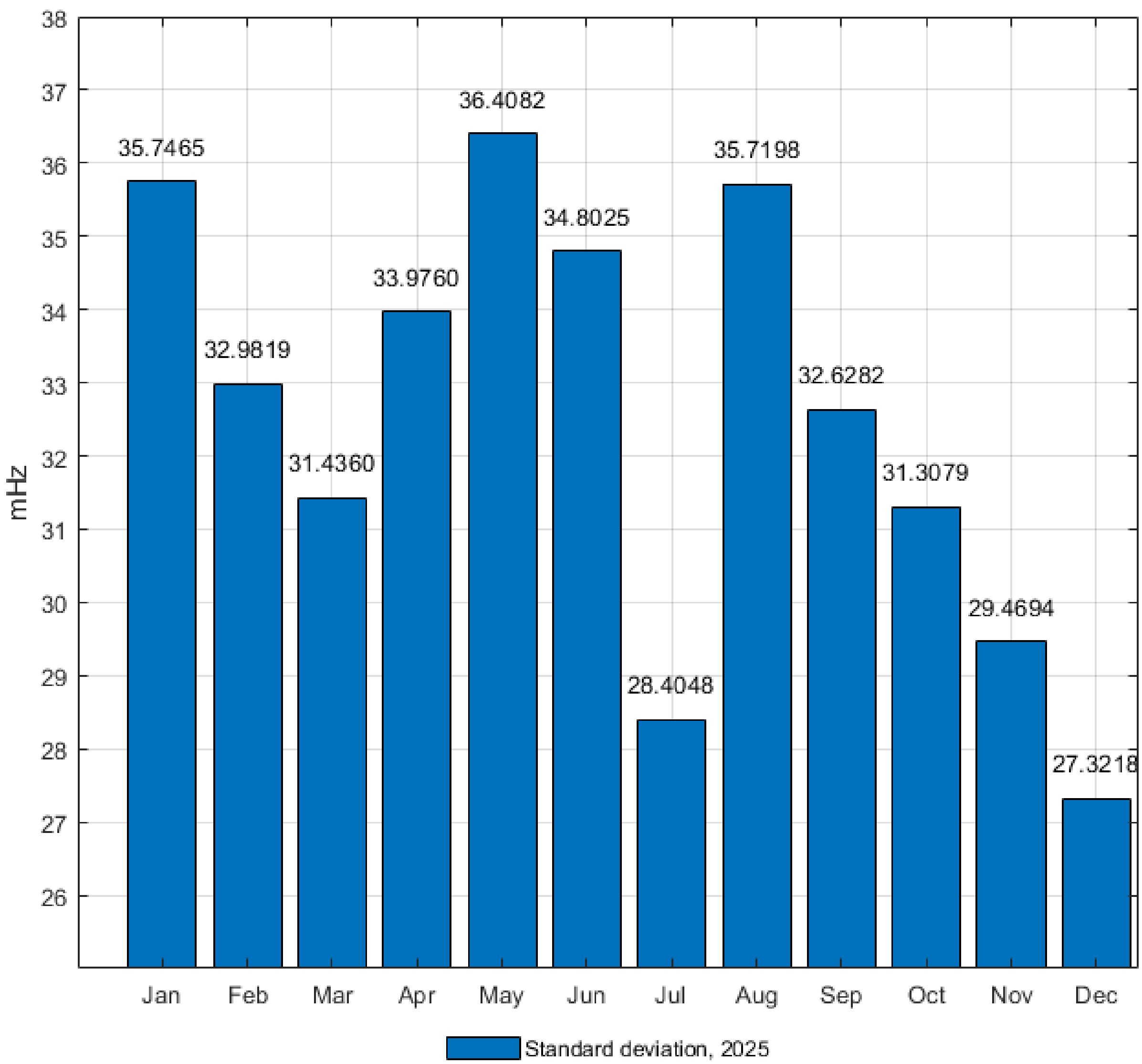


Figure 3.6 represents the standard deviation for each day of the week. Overall, the frequency quality has been fairly stable during the early part of the week. The highest deviation was observed on Thursday, while the lowest was observed on Sunday. From Thursday onwards, the standard deviation decreases towards the weekend. Compared to 2024, there is more variation in the standard deviation during the latter part of the week.

***Figure 3.6**. Standard deviation of the frequency for every day of the week in 2025*

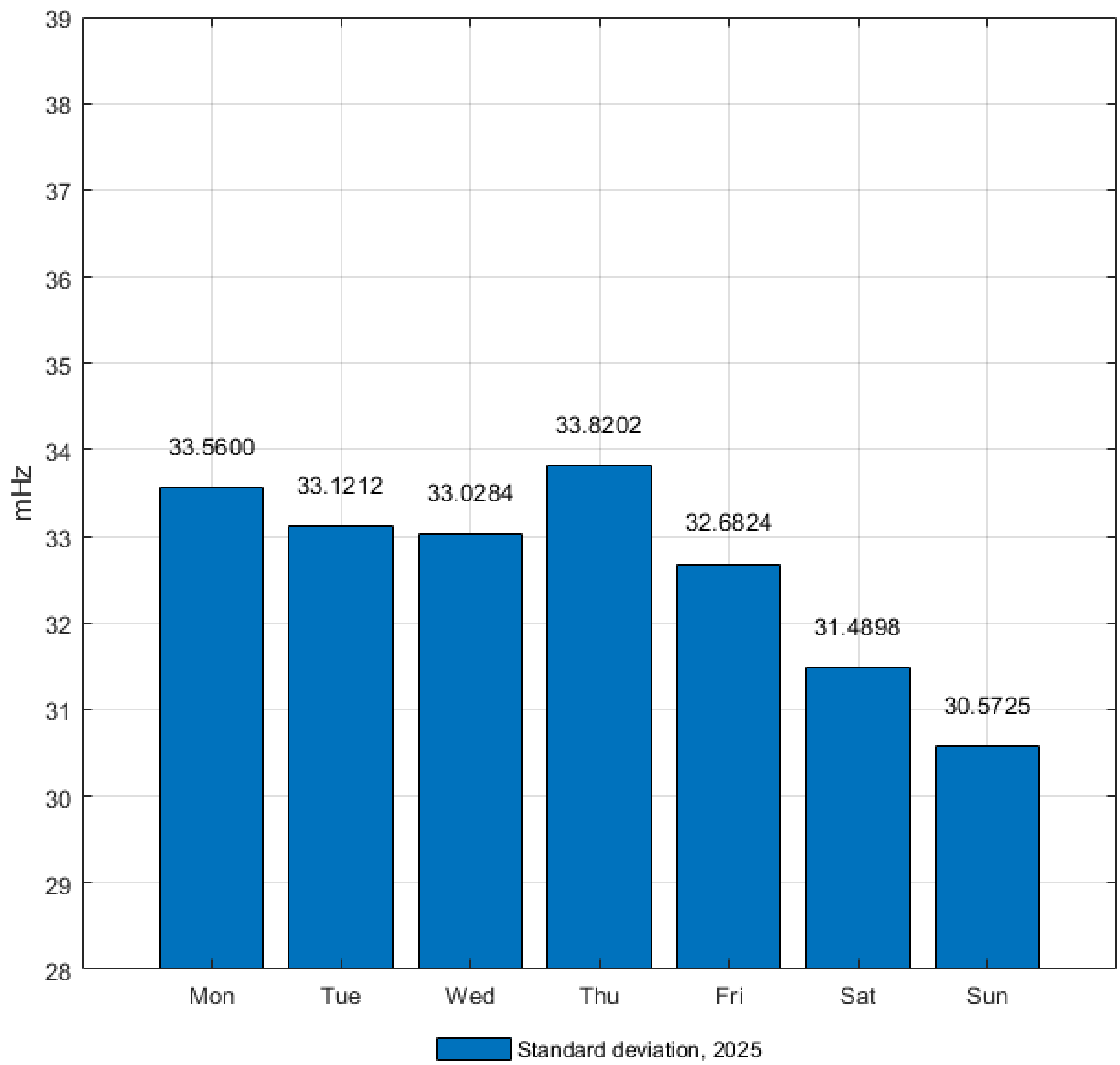


Figure 3.7 shows the standard deviation during each hour of an average day. The standard deviation values have been highest at 1 am, 7 am, and 6 pm, while the lowest values were observed between 2 am and 5 am. Overall, the standard deviation values have been lower than in 2024, with larger differences between consecutive hours. A broadly similar hourly trend is still visible.

***Figure 3.7**. Standard deviation of the frequency for every hour of the day in 2025*

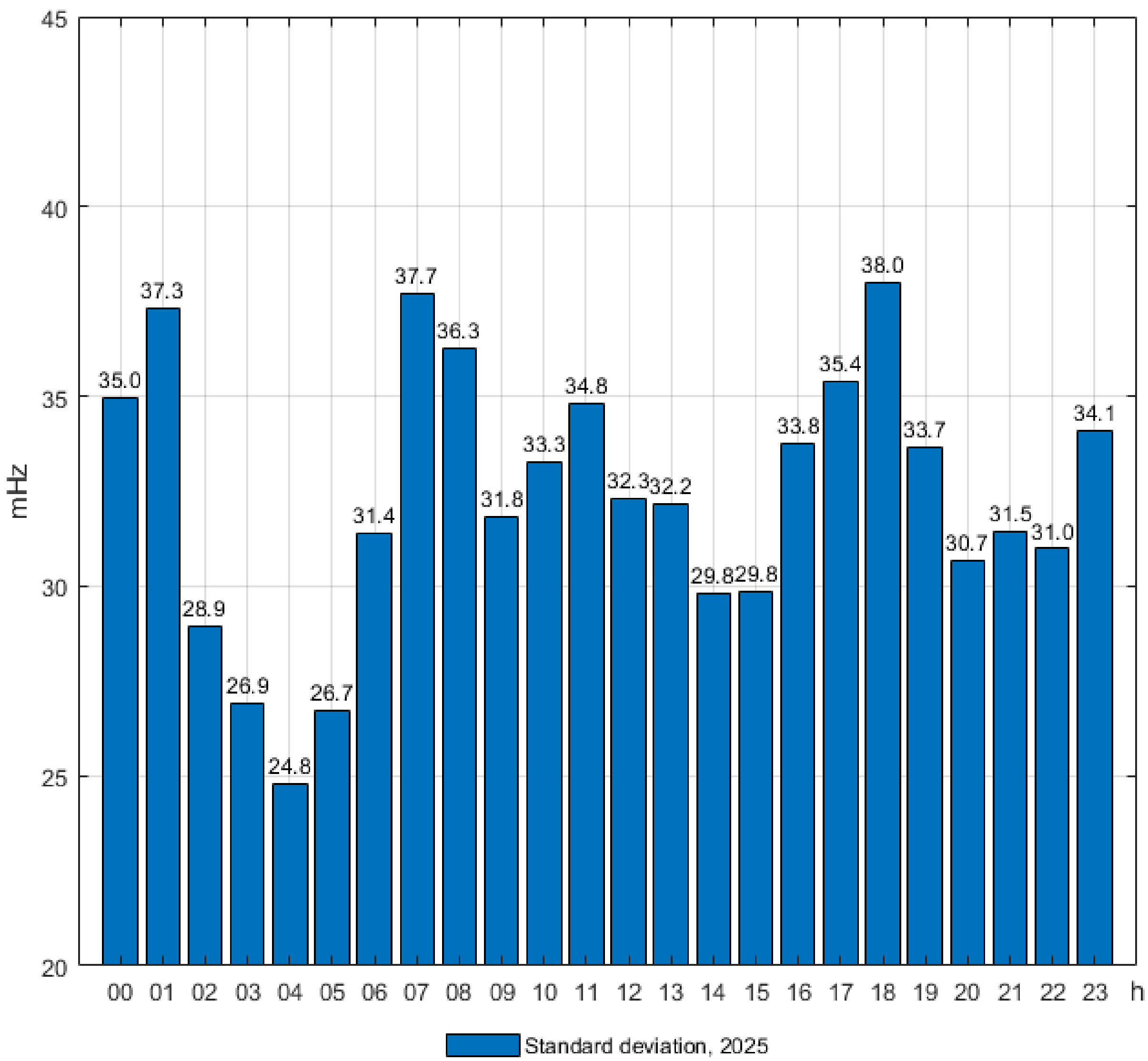
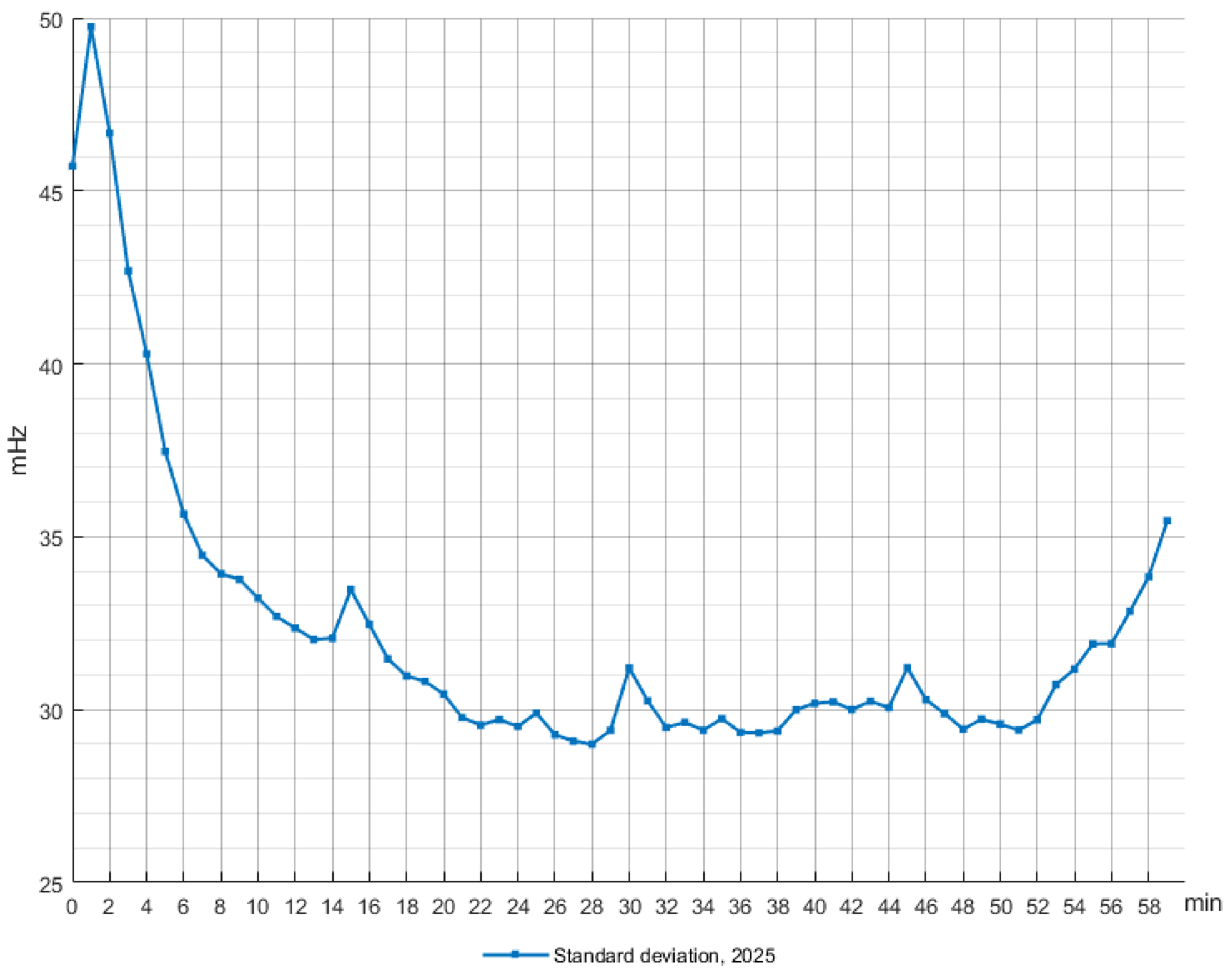


Figure 3.8 represents the standard deviation within an hour. The standard deviation has the highest values at the beginning of the hour, which indicates a weaker quality of frequency during that time. The standard deviation decreases until approximately the half-hour mark, from where it increases again towards the end of the hour. Overall, the standard deviation values have been lower than in previous years.

Figure 3.8**. **Standard deviation of the frequency for every minute of the hour in 2025



3.1.3 Mean value and standard deviation

Mean values and standard deviations of the frequency, according to SO GL Article 131(a) i and (ii), month by month for years 2020 to 2025, can be found in Tables 3.1 and 3.2. The same results are also presented in Figure 3.9. The resolution of the used data is one second.

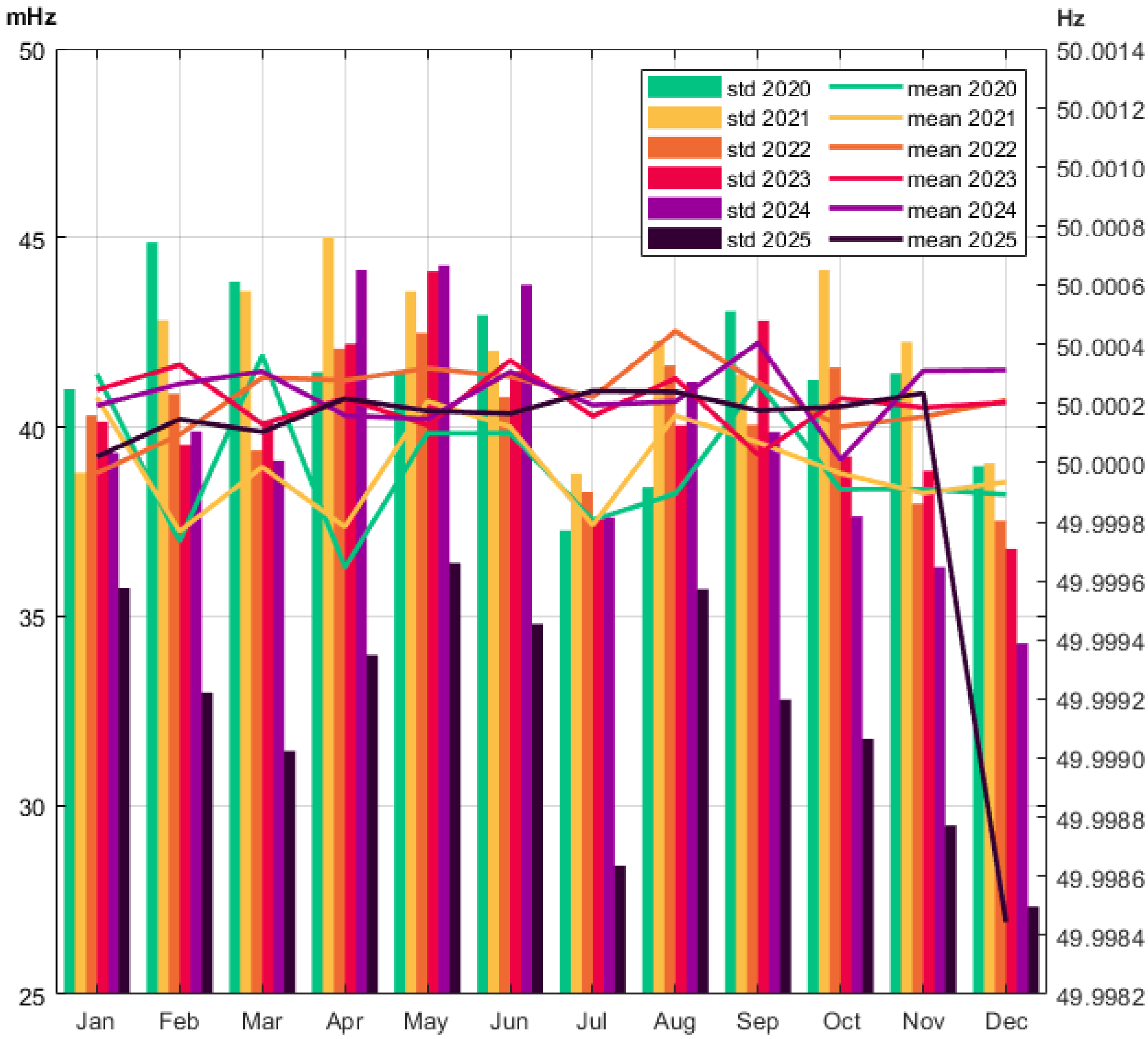
***Table 3.1**. Mean values and standard deviations for years 2020-2022*

	2020		**2021**		**2022**	
Month	**Mean value (Hz)**	**Standard deviation (mHz)**	**Mean value (Hz)**	**Standard deviation (mHz)**	**Mean value (Hz)**	**Standard deviation (mHz)**
January	50.0003	41.0	50.0002	38.8	50.0000	40.3
February	49.9997	44.9	49.9998	42.8	50.0001	40.9
March	50.0004	43.8	50.0000	43.6	50.0003	39.4
April	49.9996	41.5	49.9998	45.0	50.0003	42.1
May	50.0001	41.5	50.0002	43.6	50.0003	42.5
June	50.0001	43.0	50.0001	42.0	50.0003	40.8
July	49.9998	37.3	49.9998	38.8	50.0002	38.3
August	49.9999	38.4	50.0002	42.3	50.0004	41.6
September	50.0003	43.1	50.0001	41.4	50.0003	40.1
October	49.9999	41.2	50.0000	44.2	50.0001	41.6
November	49.9999	41.4	49.9999	42.3	50.0002	38.0
December	49.9999	39.0	49.9999	39.1	50.0002	37.5
Entire year	**50.0000**	**41.4**	**50.0000**	**42.0**	**50.0002**	**40.3**

Table 3.2. Mean values and standard deviations for years 2023-2025

	2023		**2024**		**2025**	
Month	**Mean value (Hz)**	**Standard deviation (mHz)**	**Mean value (Hz)**	**Standard deviation (mHz)**	**Mean value (Hz)**	**Standard deviation (mHz)**
January	50.0002	40.1	50.0002	39.3	50.0000	35.7
February	50.0003	39.5	50.0003	39.9	50.0001	33.0
March	50.0001	40.2	50.0003	39.1	50.0001	31.4
April	50.0002	42.2	50.0002	44.2	50.0002	34.0
May	50.0001	44.1	50.0001	44.3	50.0002	36.4
June	50.0003	41.5	50.0003	43.8	50.0002	34.8
July	50.0002	37.6	50.0002	37.6	50.0002	28.4
August	50.0003	40.0	50.0002	41.2	50.0002	35.7
September	50.0000	42.8	50.0004	39.9	50.0002	32.6
October	50.0002	39.2	50.0000	37.6	50.0002	31.3
November	50.0002	38.8	50.0003	36.3	50.0002	29.5
December	50.0002	36.8	50.0003	34.3	49.9984	27.3
Entire year	**50.0002**	**40.3**	**50.0002**	**39.9**	**50.0000**	**32.6**

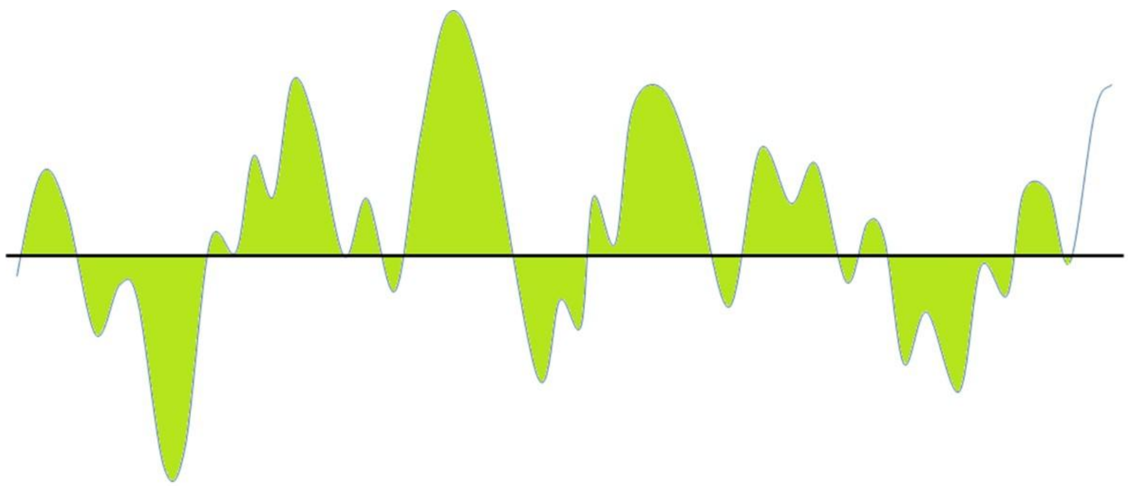
Figure 3.9. Mean values and standard deviations for years 2020-2025



3.2 Frequency area

The frequency area is an indicator of how much the frequency differs from 50.0 Hz. The approach can be seen in Figure 3.10. The value is presented as a share of half of the normal frequency area (49.9-50.1 Hz). For example, when an hourly value is calculated and the frequency has been equal to 49.9 Hz for the whole hour, the value of this index is 100%. The resolution of the input frequency data is 0.1 s. The formula for determining the frequency area is presented below in Figure 3.10.

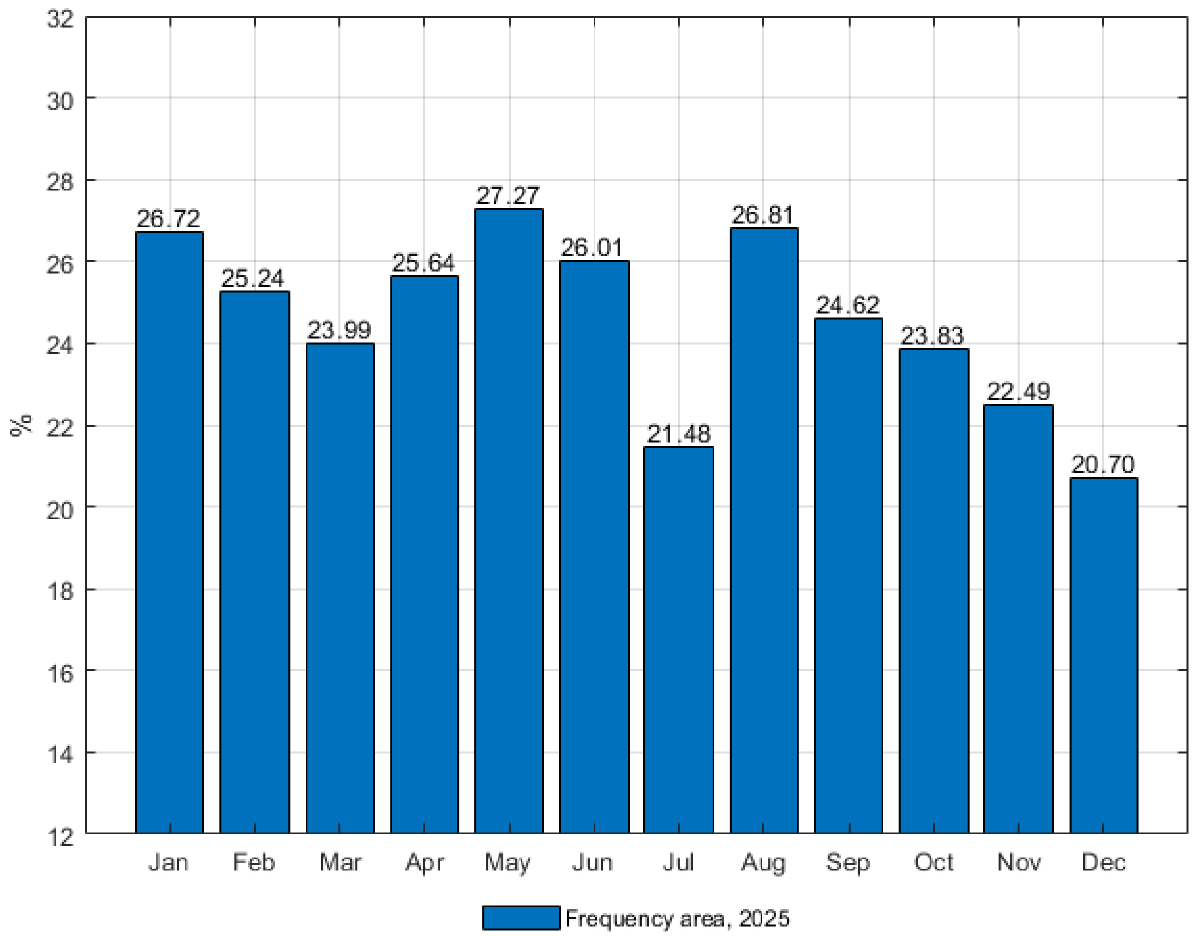
Figure 3.10*. *Frequency quality index: Frequency area [7]



$$Frequency\ area = \frac{1}{n * 0.1Hz} \sum_{i}^{n} |f(i) - 50.0Hz|$$

Figure 3.11 represents the average frequency area for every month in 2025. The frequency area has been the largest in January, May, and August, and the smallest in July and December.

***Figure 3.11**. The average frequency area for every month in 2025*



The average frequency area during each day of the week can be seen in Figure 3.12. The frequency area has been highest on Thursday and lowest on Sunday. The values decrease towards the end of the week. Compared to previous years, the frequency area values have been lower.

***Figure 3.12**. The average frequency area for every day of the week in 2025*

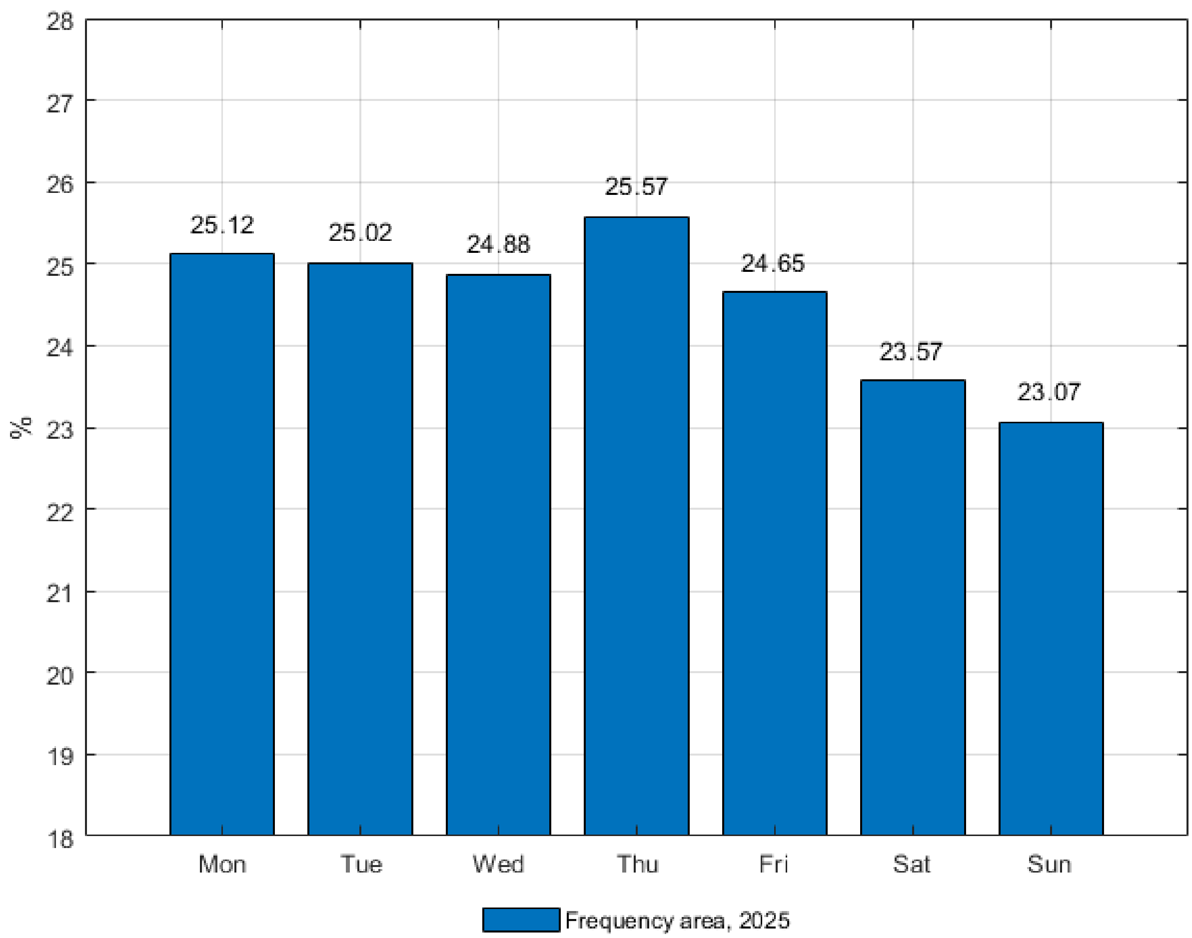


Figure 3.13 represents the frequency area for every hour of the day. The figure shows that the frequency area has been larger around midnight, during the morning, and in the early evening. This trend is similar to the previous year, although the early morning hours show clearer differences.

Figure 3.13. The average frequency area for every hour inside the day in 2025

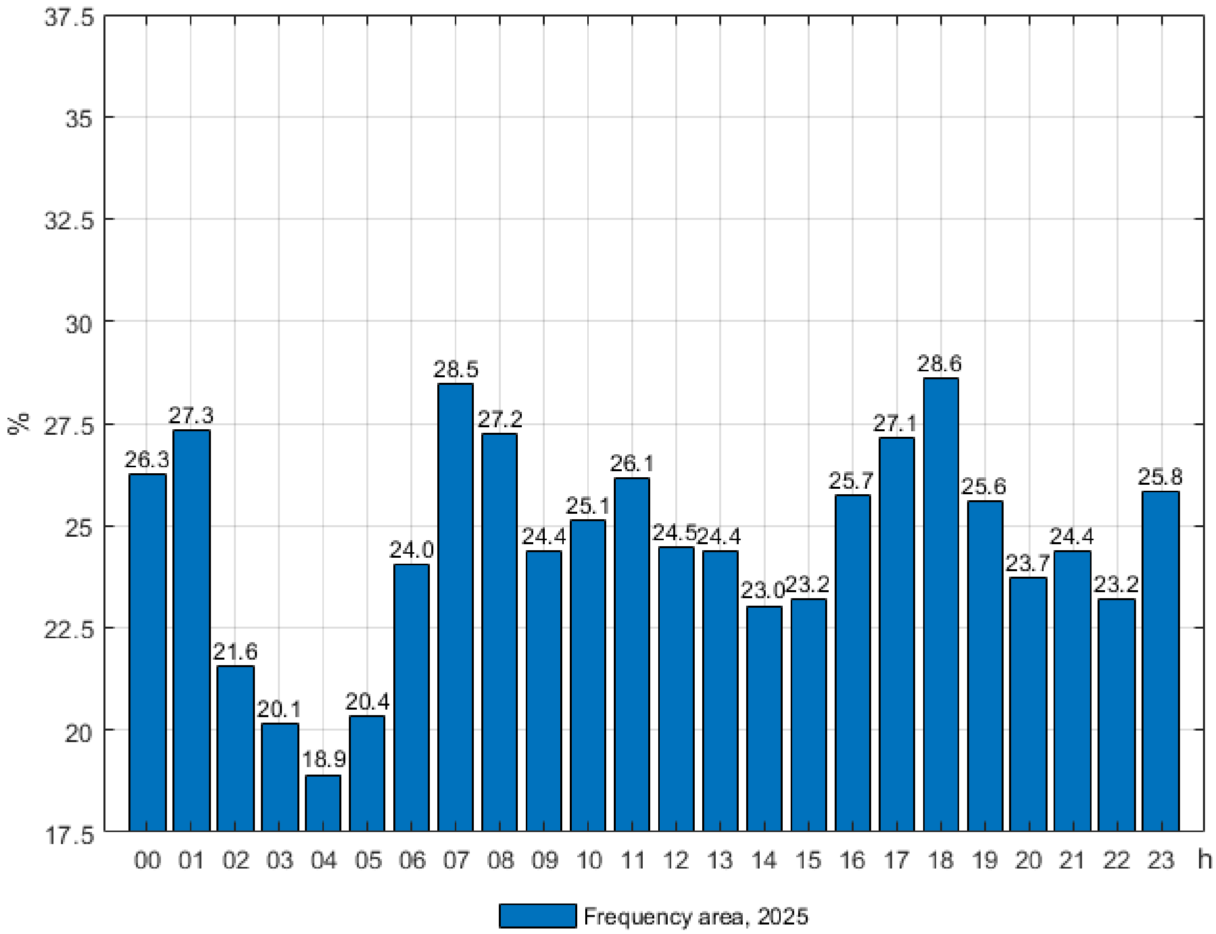
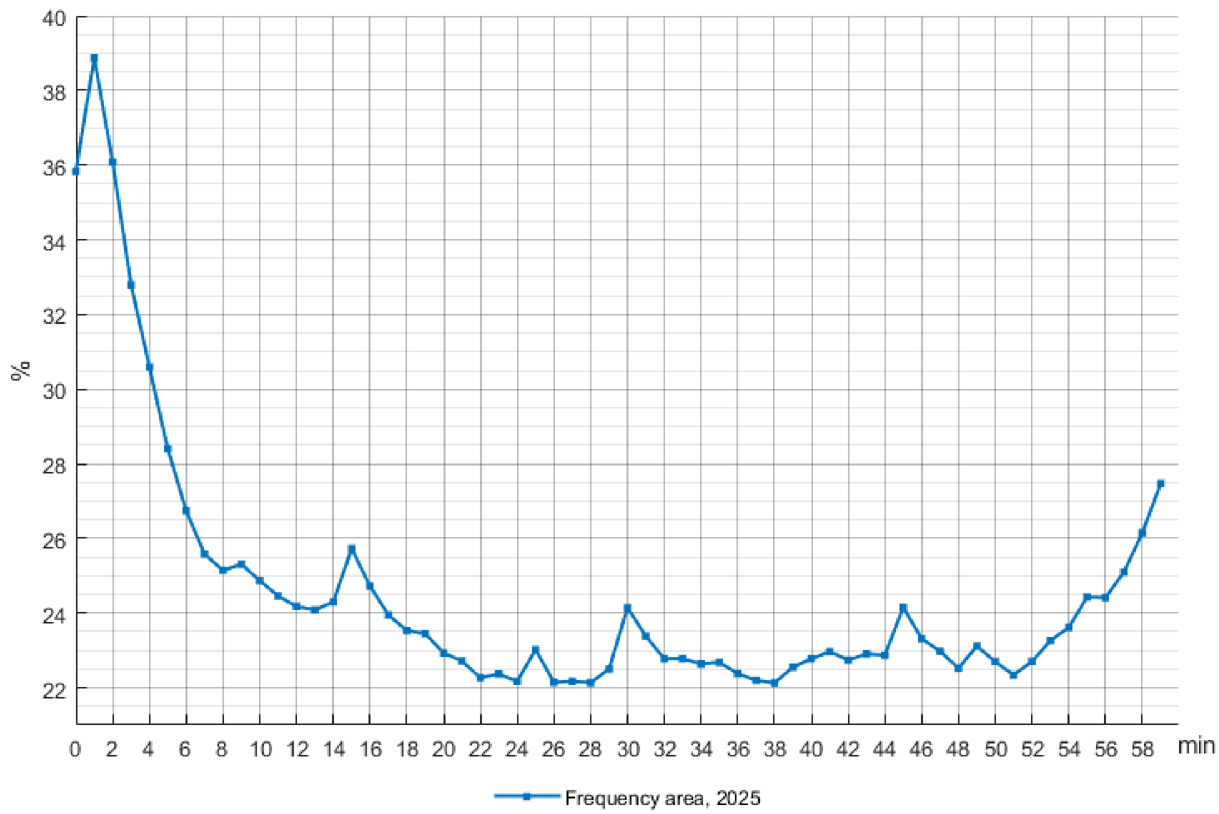


Figure 3.14 represents the frequency area within the hour. The frequency area has been smaller in the middle of the hour, while more deviation has occurred closer to the hour shift and especially in the first minutes of the hour. The impact of the 15-minute market resolution is also visible in the data, with peaks occurring around the quarter-hour intervals.

***Figure 3.14**. The average frequency area for every minute within the hour in 2025*



3.3 1-, 5-, 10-, 90-, 95-, 99-percentile of frequency

A certain percentile of frequency indicates the frequency below which a given percentage of the samples in the observation period fall. For example, the 1st percentile is the frequency below which 1% of the samples are found. The same criteria are also defined in SO GL Article 131(1)(a) (iii). The resolution frequency of the data is 1 second.

The 1st, 5th, 10th, 90th, 95th, and 99th percentiles were calculated for every month and for the entire year. Tables 3.3-3.8 contain the results from 2020 to 2025. All results are summed up in Figure 3.15.

***Table 3.3**. The 1st, 5th, 10th, 90th, 95th, and 99th percentiles for the year 2020*

	2020					
Month	**1st (Hz)**	**5th (Hz)**	**10th (Hz)**	**90th (Hz)**	**95th (Hz)**	**99th (Hz)**
Jan	49.903	49.932	49.948	50.052	50.067	50.098
Feb	49.896	49.927	49.943	50.057	50.075	50.108
Mar	49.898	49.930	49.946	50.057	50.073	50.106
Apr	49.901	49.932	49.948	50.052	50.068	50.099
May	49.902	49.932	49.948	50.053	50.068	50.099
Jun	49.900	49.930	49.946	50.054	50.071	50.105
Jul	49.913	49.939	49.953	50.047	50.061	50.090
Aug	49.912	49.938	49.952	50.049	50.064	50.094
Sep	49.901	49.932	49.947	50.055	50.072	50.108
Oct	49.904	49.933	49.948	50.052	50.069	50.099
Nov	49.903	49.933	49.948	50.053	50.069	50.099
Dec	49.905	49.936	49.951	50.049	50.063	50.094
Entire year	**49.903**	**49.933**	**49.948**	**50.052**	**50.069**	**50.100**

Table 3.4. The 1st, 5th, 10th, 90th, 95th, and 99th percentiles for the year 2021

	2021					
Month	**1st (Hz)**	**5th (Hz)**	**10th (Hz)**	**90th (Hz)**	**95th (Hz)**	**99th (Hz)**
Jan	49.911	49.937	49.951	50.050	50.066	50.094
Feb	49.901	49.932	49.948	50.055	50.072	50.106
Mar	49.902	49.931	49.946	50.056	50.074	50.109
Apr	49.892	49.927	49.944	50.057	50.075	50.110
May	49.899	49.930	49.946	50.056	50.073	50.106
Jun	49.901	49.931	49.947	50.053	50.069	50.100
Jul	49.909	49.937	49.951	50.049	50.064	50.095
Aug	49.902	49.932	49.947	50.053	50.070	50.106
Sep	49.906	49.934	49.949	50.053	50.069	50.102
Oct	49.897	49.929	49.945	50.056	50.074	50.111
Nov	49.900	49.931	49.947	50.053	50.070	50.105
Dec	49.908	49.937	49.951	50.050	50.066	50.096
Entire year	**49.902**	**49.932**	**49.948**	**50.053**	**50.070**	**50.103**

Table 3.5. The 1st, 5th, 10th, 90th, 95th, and 99th percentiles for the year 2022

	2022					
Month	**1st (Hz)**	**5th (Hz)**	**10th (Hz)**	**90th (Hz)**	**95th (Hz)**	**99th (Hz)**
Jan	49.904	49.935	49.950	50.050	50.066	50.100
Feb	49.902	49.934	49.950	50.051	50.068	50.103
Mar	49.905	49.936	49.951	50.050	50.065	50.096
Apr	49.901	49.932	49.948	50.053	50.070	50.104
May	49.899	49.931	49.947	50.054	50.071	50.105
Jun	49.900	49.933	49.949	50.052	50.067	50.097
Jul	49.909	49.939	49.953	50.048	50.064	50.096
Aug	49.900	49.933	49.949	50.052	50.069	50.104
Sep	49.908	49.936	49.951	50.051	50.067	50.102
Oct	49.903	49.934	49.949	50.053	50.070	50.105
Nov	49.906	49.938	49.953	50.047	50.062	50.091
Dec	49.911	49.941	49.955	50.046	50.062	50.099
Entire year	**49.904**	**49.935**	**49.950**	**50.051**	**50.067**	**50.100**

Table 3.6. The 1st, 5th, 10th, 90th, 95th, and 99th percentiles for year 2023

	2023					
Month	**1st (Hz)**	**5th (Hz)**	**10th (Hz)**	**90th (Hz)**	**95th (Hz)**	**99th (Hz)**
Jan	49.904	49.936	49.951	50.051	50.068	50.101
Feb	49.904	49.937	49.952	50.050	50.066	50.097
Mar	49.901	49.934	49.950	50.050	50.067	50.099
Apr	49.901	49.933	49.948	50.053	50.071	50.106
May	49.893	49.928	49.945	50.056	50.073	50.106
Jun	49.900	49.933	49.949	50.052	50.069	50.101
Jul	49.912	49.940	49.954	50.047	50.062	50.094
Aug	49.902	49.935	49.951	50.050	50.066	50.097
Sep	49.901	49.932	49.947	50.054	50.071	50.108
Oct	49.905	49.937	49.952	50.049	50.065	50.097
Nov	49.905	49.939	49.953	50.047	50.064	50.102
Dec	49.910	49.942	49.956	50.045	50.061	50.095
Entire year	**49.903**	**49.935**	**49.951**	**50.051**	**50.067**	**50.101**

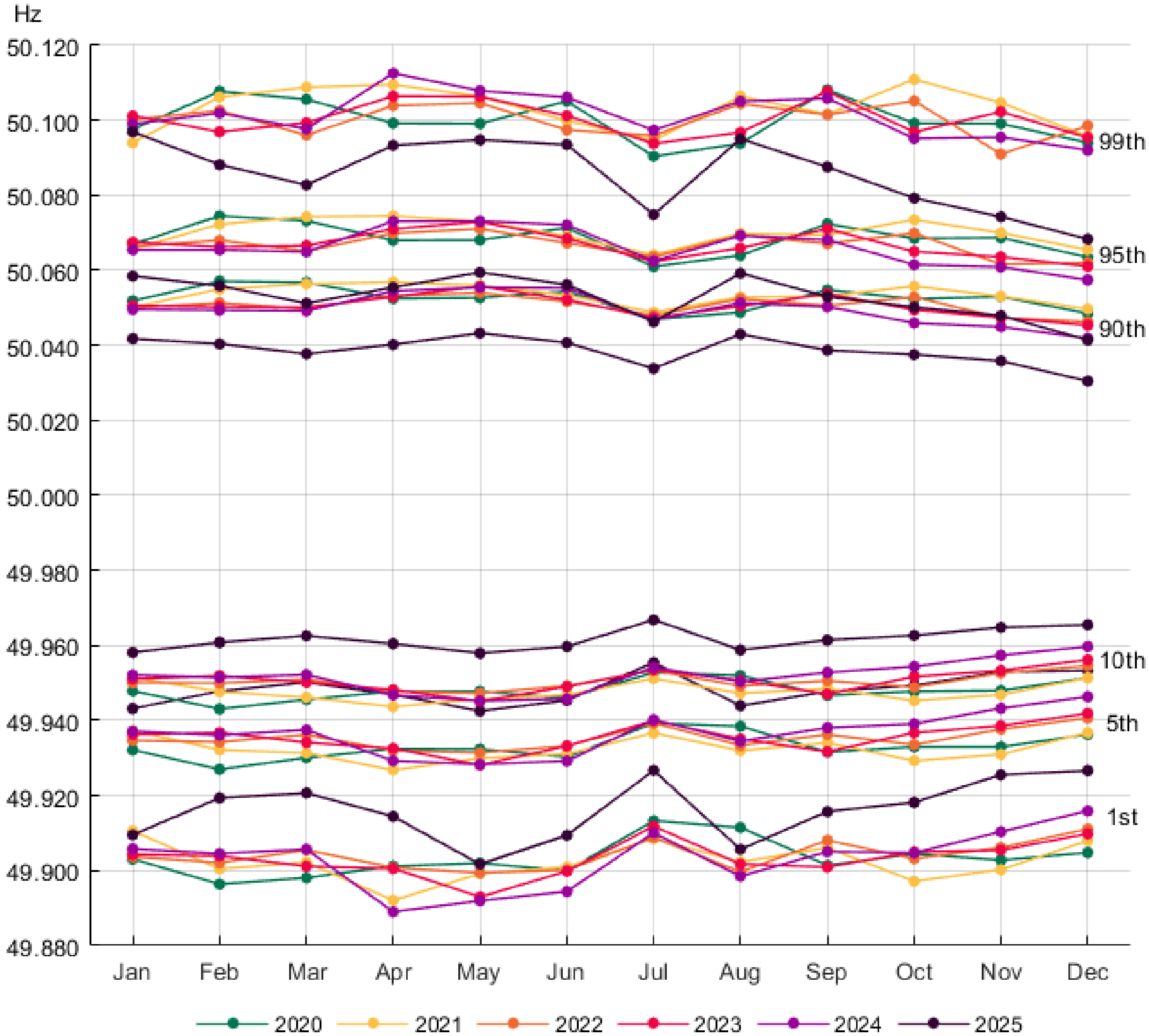
Table 3.7. The 1st, 5th, 10th, 90th, 95th, and 99th percentiles for the year 2024

	2024					
Month	**1st (Hz)**	**5th (Hz)**	**10th (Hz)**	**90th (Hz)**	**95th (Hz)**	**99th (Hz)**
Jan	49.906	49.937	49.952	50.050	50.065	50.099
Feb	49.905	49.936	49.952	50.049	50.065	50.102
Mar	49.906	49.938	49.952	50.049	50.065	50.098
Apr	49.889	49.929	49.947	50.054	50.073	50.113
May	49.892	49.928	49.945	50.055	50.073	50.108
Jun	49.894	49.929	49.946	50.055	50.072	50.106
Jul	49.910	49.940	49.954	50.047	50.062	50.097
Aug	49.899	49.935	49.950	50.051	50.069	50.105
Sep	49.905	49.938	49.953	50.050	50.068	50.106
Oct	49.905	49.939	49.954	50.046	50.062	50.095
Nov	49.910	49.943	49.957	50.045	50.061	50.095
Dec	49.916	49.946	49.960	50.042	50.057	50.092
Entire year	**49.902**	**49.936**	**49.952**	**50.050**	**50.066**	**50.102**

Table 3.8. The 1st, 5th, 10th, 90th, 95th, and 99th percentiles for the year 2025

	2025					
Month	**1st (Hz)**	**5th (Hz)**	**10th (Hz)**	**90th (Hz)**	**95th (Hz)**	**99th (Hz)**
Jan	49.910	49.943	49.958	50.042	50.058	50.097
Feb	49.919	49.948	49.961	50.040	50.056	50.088
Mar	49.921	49.950	49.963	50.038	50.051	50.083
Apr	49.914	49.947	49.960	50.040	50.055	50.093
May	49.902	49.943	49.958	50.043	50.059	50.095
Jun	49.909	49.945	49.960	50.041	50.056	50.094
Jul	49.927	49.955	49.967	50.034	50.046	50.075
Aug	49.906	49.944	49.959	50.043	50.059	50.095
Sep	49.916	49.948	49.961	50.039	50.053	50.088
Oct	49.918	49.949	49.963	50.038	50.050	50.079
Nov	49.926	49.953	49.965	50.036	50.048	50.074
Dec	49.927	49.953	49.966	50.030	50.041	50.068
Entire year	**49.916**	**49.948**	**49.962**	**50.038**	**50.053**	**50.087**

Figure 3.15. The 1st, 5th, 10th, 90th, 95th, and 99th percentiles for the years 2020-2025



More detailed results for the percentiles of 2025 are shown in the next figures. Figure 3.16 is a visual representation of the given percentiles for each month in 2025. The percentiles in January, April through June, and August are the furthest away from 50 Hz, which indicates that the frequency values are spread around 50 Hz with a wide distribution. In March, July, and December, the percentiles were closest to 50 Hz, which suggests that the frequency deviations have remained within a more limited range. The percentiles are comparable to those of the previous years, although the results are generally closer to the 50 Hz mark.

***Figure 3.16**. The 1st, 5th, 10th, 90th, 95th, and 99th percentile of the frequency for every month in 2025*

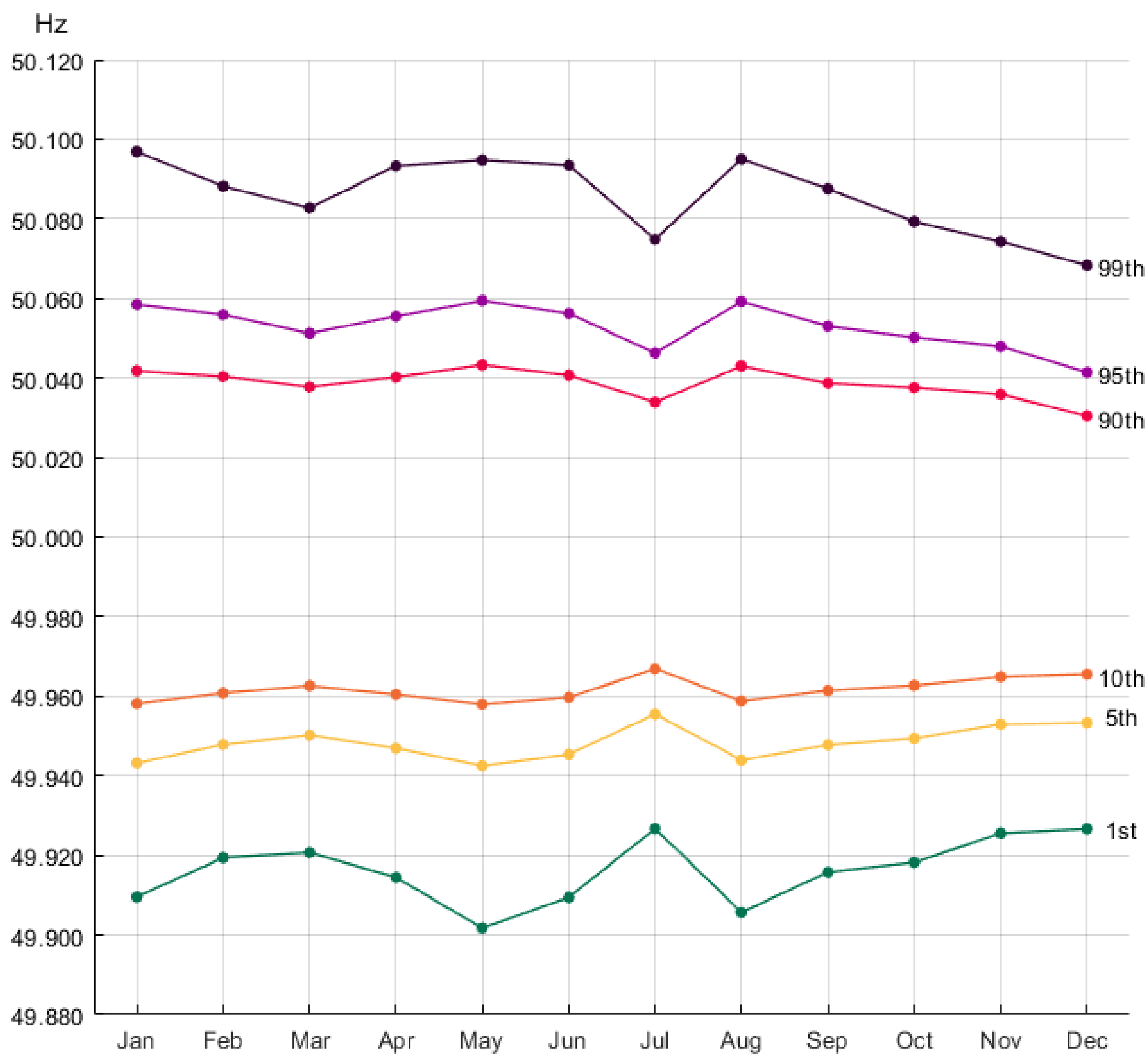


Figure 3.17 shows the percentiles for each day during the week. Overall, the percentiles remain relatively stable throughout the week. Towards the end of the week, the percentiles gradually move closer to 50 Hz. The most notable change is seen in the 99th percentile, which shows the largest decrease from Monday to Sunday.

***Figure 3.17**. The 1st, 5th, 10th, 90th, 95th, and 99th percentile of the frequency for every day of the week in 2025*

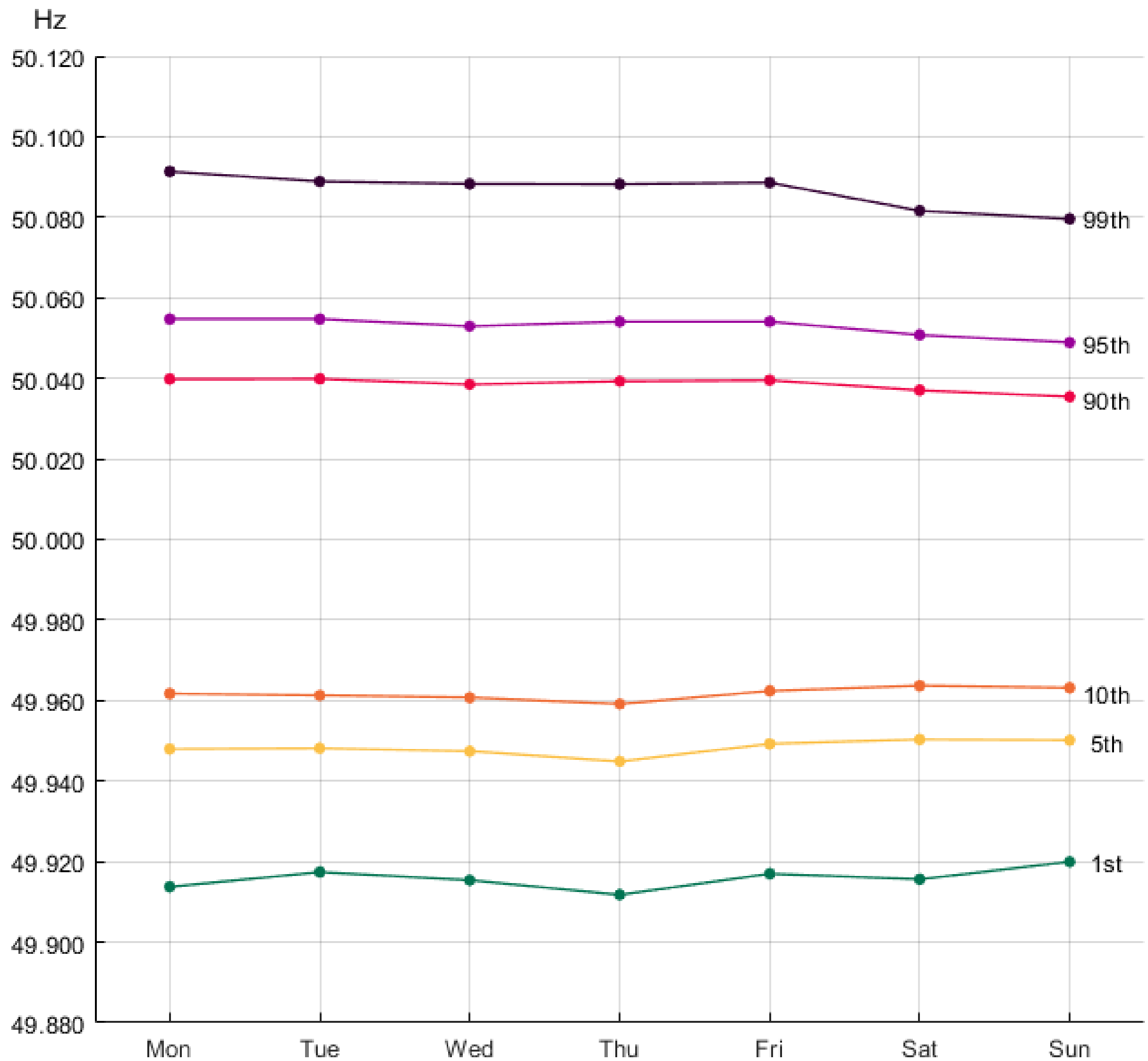


Figure 3.18 represents the frequency percentiles within a day. The higher percentiles are highest around 7–9 am and 5–7 pm, indicating a greater occurrence of high frequency values during these periods. The lower percentiles show a different pattern. Their lowest values occur around 1 am, while their highest values occur around 4 am. In addition, relatively low lower-percentile values occur around 7 am, 11 am, and 4–6 pm.

***Figure 3.18**. The 1st, 5th, 10th, 90th, 95th, and 99th percentile of the frequency for every hour of the day in 2025*

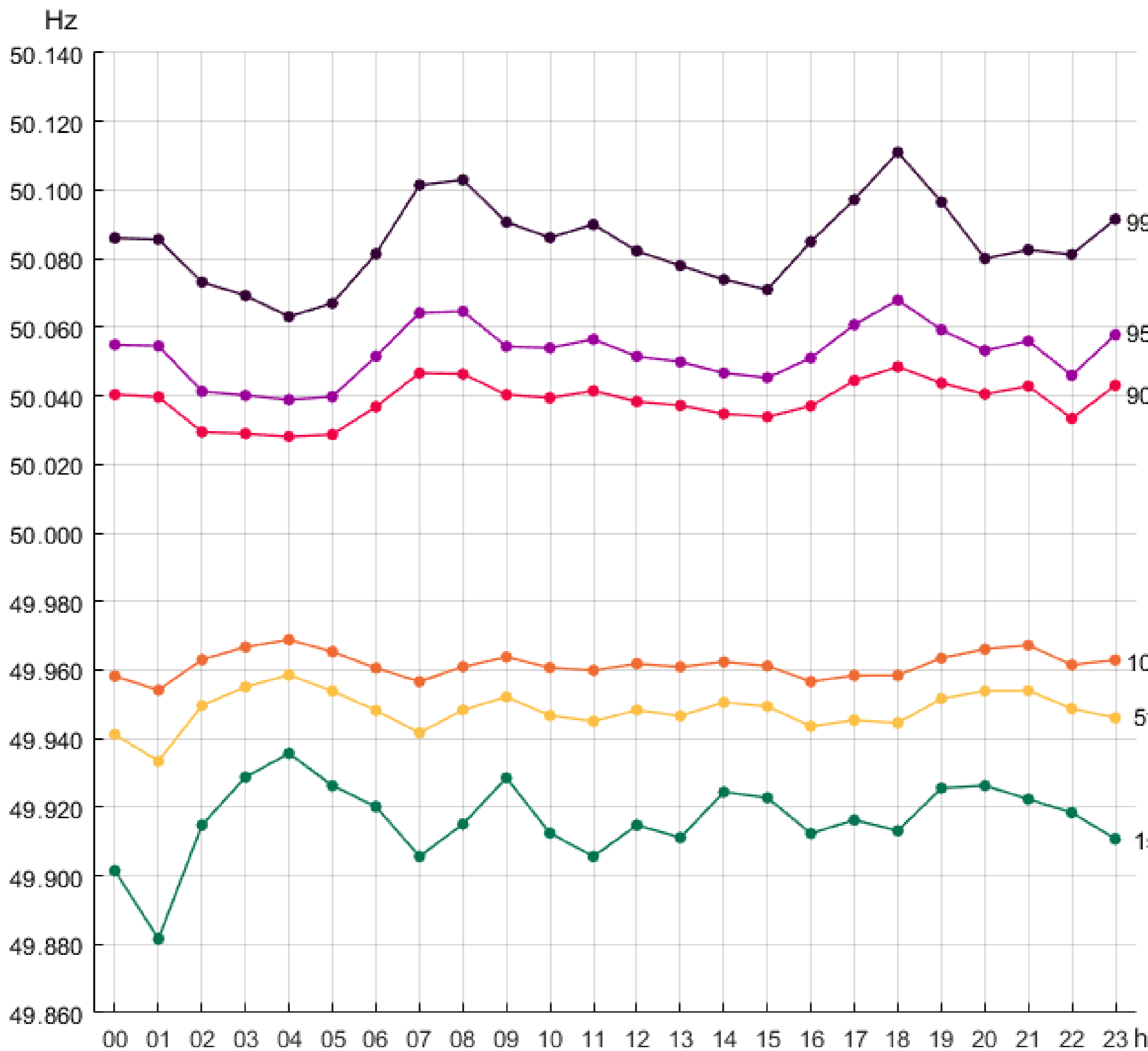
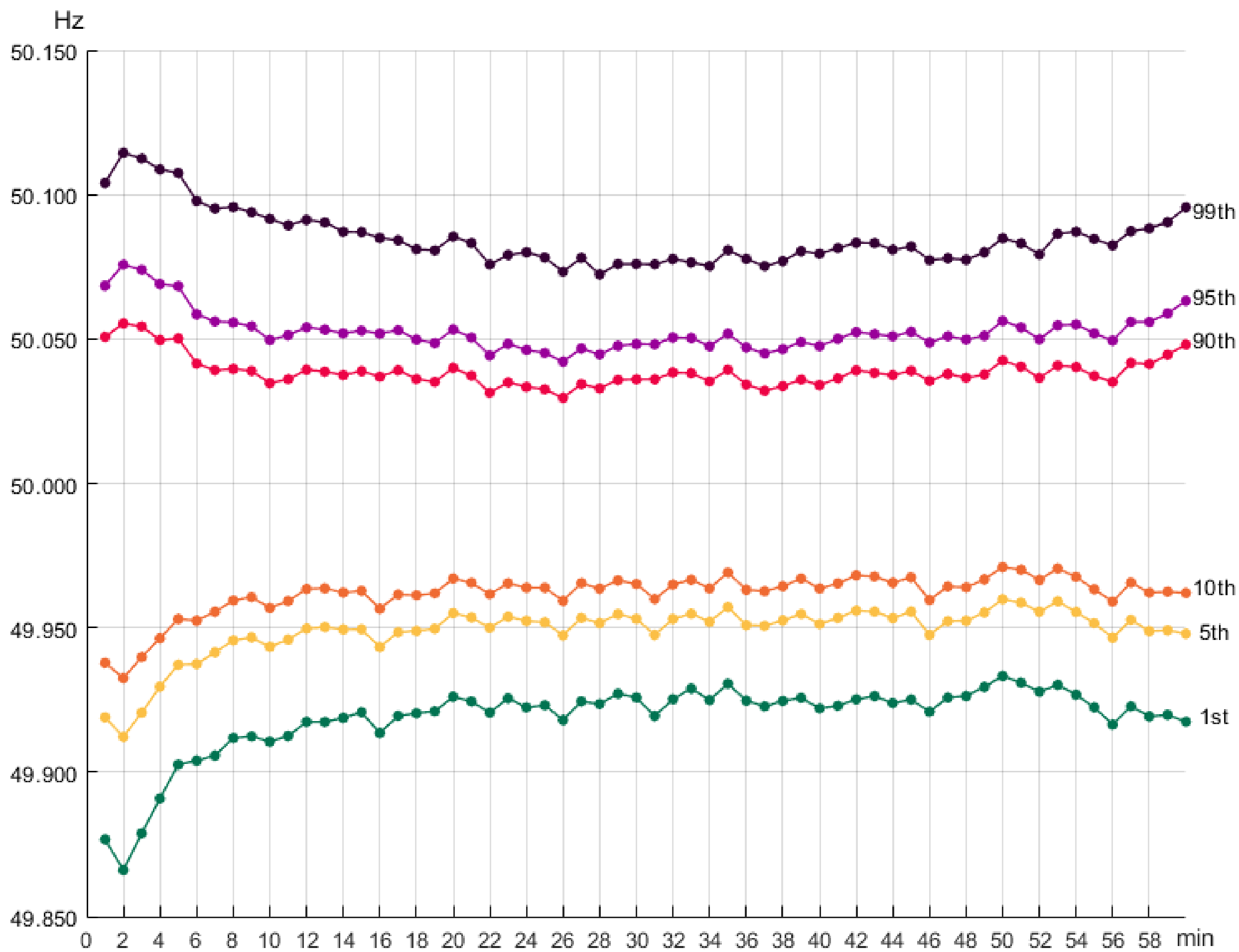


Figure 3.19 shows the percentiles within an hour. Overall, more frequency deviation has occurred close to the hour shift. The 90th, 95th, and 99th percentiles gain the highest values during the first few minutes of the hour. The 10th, 5th, and 1st percentiles gain the lowest values during the first minutes of the hour.

***Figure 3.19**. The 1st, 5th, 10th, 90th, 95th, and 99th percentile of the frequency for every minute inside the hour in 2025*



3.4 Time outside different ranges

Time outside a specific range is calculated by multiplying the number of samples that are outside the given frequency range by the time duration of the sample. This calculation uses data where the interval between consecutive samples is 1 second.

3.4.1 Time outside 49.9-50.1 Hz

Figure 3.20 shows cumulative minutes outside the standard frequency range in 2025. The cumulative minutes outside the standard frequency range reached only slightly over half of the Nordic target level of 10 000 minutes. The cumulative growth of minutes outside the standard frequency range is more steady compared to 2024. Periods of faster growth occur in particular in May, June, and August. Overall, the cumulative minutes have decreased to approximately half compared to the previous years.

Figure 3.20. Cumulative minutes outside the standard frequency range in 2025

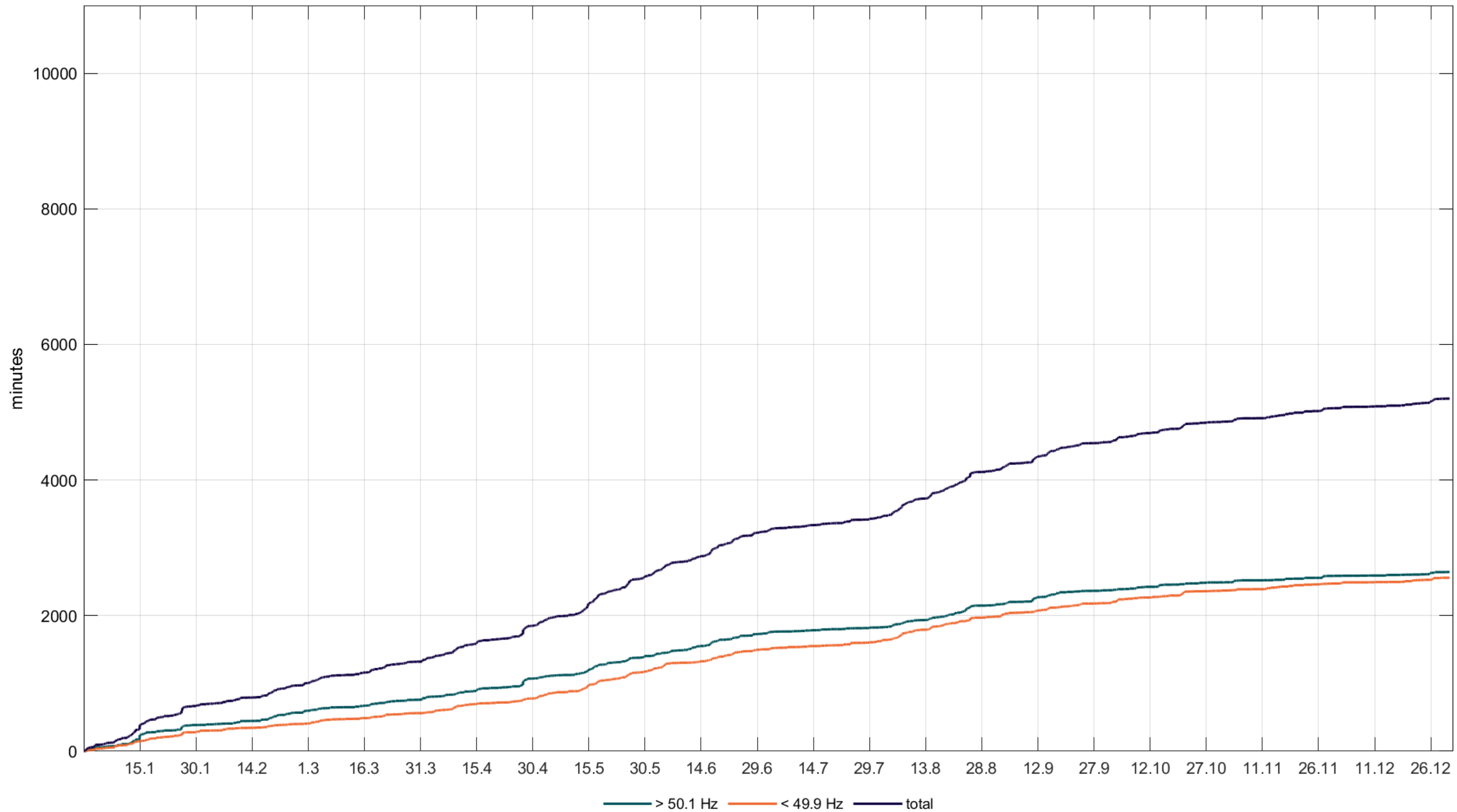
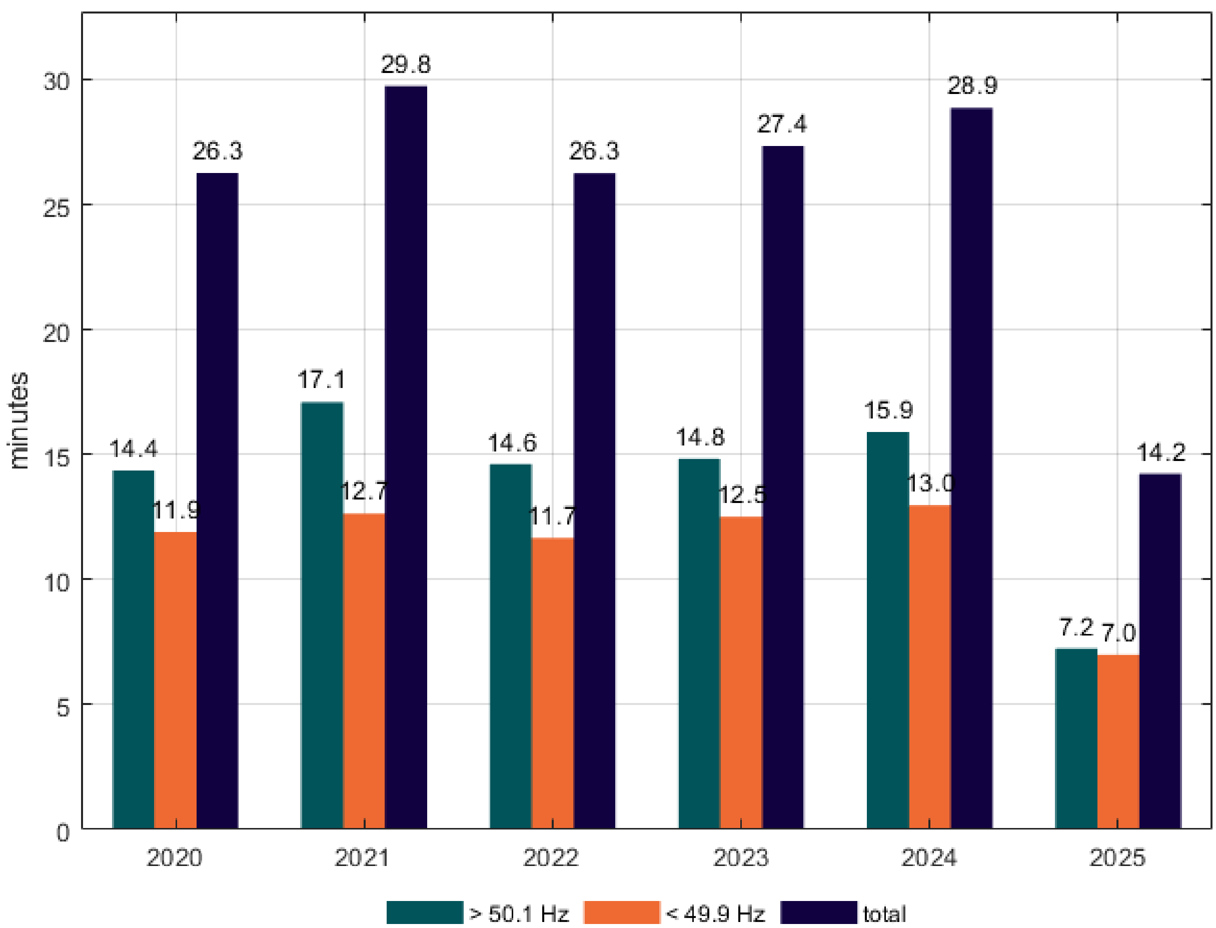


Figure 3.21 represents the daily average number of minutes per year outside the standard frequency range in 2020-2025. The number of minutes outside the standard frequency range has decreased to approximately half compared to 2024. Every year, there have been more over-frequencies than under-frequencies.

Figure 3.21. Daily average number of minutes per year that the frequency was outside the standard frequency range in 2020-2025



The same results can be seen in Table 3.9 as a percentage of time in and outside the standard frequency range. The availability of the data has been taken into account so that 100% corresponds to the total time for which the data was available.

***Table 3.9**. Percentage of time over, below, and inside the standard frequency range*

Year	> 50.1 Hz	< 49.9 Hz	49.9 Hz - 50.1 Hz
2020	1.02 %	0.85 %	98.13 %
2021	1.19 %	0.88 %	97.93 %
2022	1.02 %	0.81 %	98.17 %
2023	1.03 %	0.87 %	98.09 %
2024	1.10 %	0.90 %	97.99 %
2025	0.50 %	0.49 %	99.01 %

Table 3.10 presents the total duration in minutes per year for which the frequency has been over or below the standard frequency range and the total number of minutes outside the standard frequency range. Values have been scaled with the availability of data to estimate true minutes outside the standard frequency range per year.

***Table 3.10**. Minutes over and below the standard frequency range*

Year	> 50.1 Hz (min)	< 49.9 Hz (min)	Total (min)
2020	5375	4456	9831
2021	6247	4621	10868
2022	5357	4273	9630
2023	5438	4586	10025
2024	5822	4749	10571
2025	2653	2565	5218

Tables 3.11 and 3.12 contain the total time (in minutes) for which the frequency was outside the standard frequency range (49.9-50.1 Hz) month by month for the years 2020-2025. These results are based on the evaluation criteria defined in SO GL Article 131(1)(a) (iv). The results from the previous tables are not entirely comparable due to differences in the availability of measurement data. The same information is presented visually in Figure 3.22.

***Table 3.11**. Total time for which the frequency was outside the 49.9-50.1 Hz band in years 2020-2022*

	2020		**2021**		**2022**	
Month	**> 50.1 Hz (min)**	**< 49.9 Hz (min)**	**> 50.1 Hz (min)**	**< 49.9 Hz (min)**	**> 50.1 Hz (min)**	**< 49.9 Hz (min)**
January	385	375	299	199	449	363
February	619	506	547	393	454	361
March	598	489	687	390	339	315
April	411	405	682	620	524	413
May	422	399	618	466	568	460
June	563	430	428	407	373	428
July	251	179	322	262	357	285
August	259	179	589	386	555	453
September	614	390	471	295	464	267
October	420	333	717	516	574	374
November	397	359	537	425	255	306
December	320	352	346	275	420	233
Entire year	**5258**	**4396**	**6242**	**4631**	**5334**	**4260**

Table 3.12. Total time for which the frequency was outside the 49.9-50.1 Hz band in years 2023-2025

	2023		**2024**		**2025**	
Month	**> 50.1 Hz (min)**	**< 49.9 Hz (min)**	**> 50.1 Hz (min)**	**< 49.9 Hz (min)**	**> 50.1 Hz (min)**	**< 49.9 Hz (min)**
January	474	356	424	335	388	290
February	332	334	461	327	205	117
March	428	420	394	337	166	155
April	600	420	749	669	313	216
May	629	621	673	638	332	412
June	459	436	603	572	327	309
July	305	211	389	259	94	122
August	365	407	583	478	329	361
September	617	408	569	337	220	201
October	370	342	342	355	117	182
November	478	334	339	273	96	107
December	359	278	293	191	56	84
Entire year	**5416**	**4568**	**5819**	**4770**	**2643**	**2558**

***Figure 3.22**. Total time for which the frequency was outside the 49.9-50.1 band in years 2020-2025*

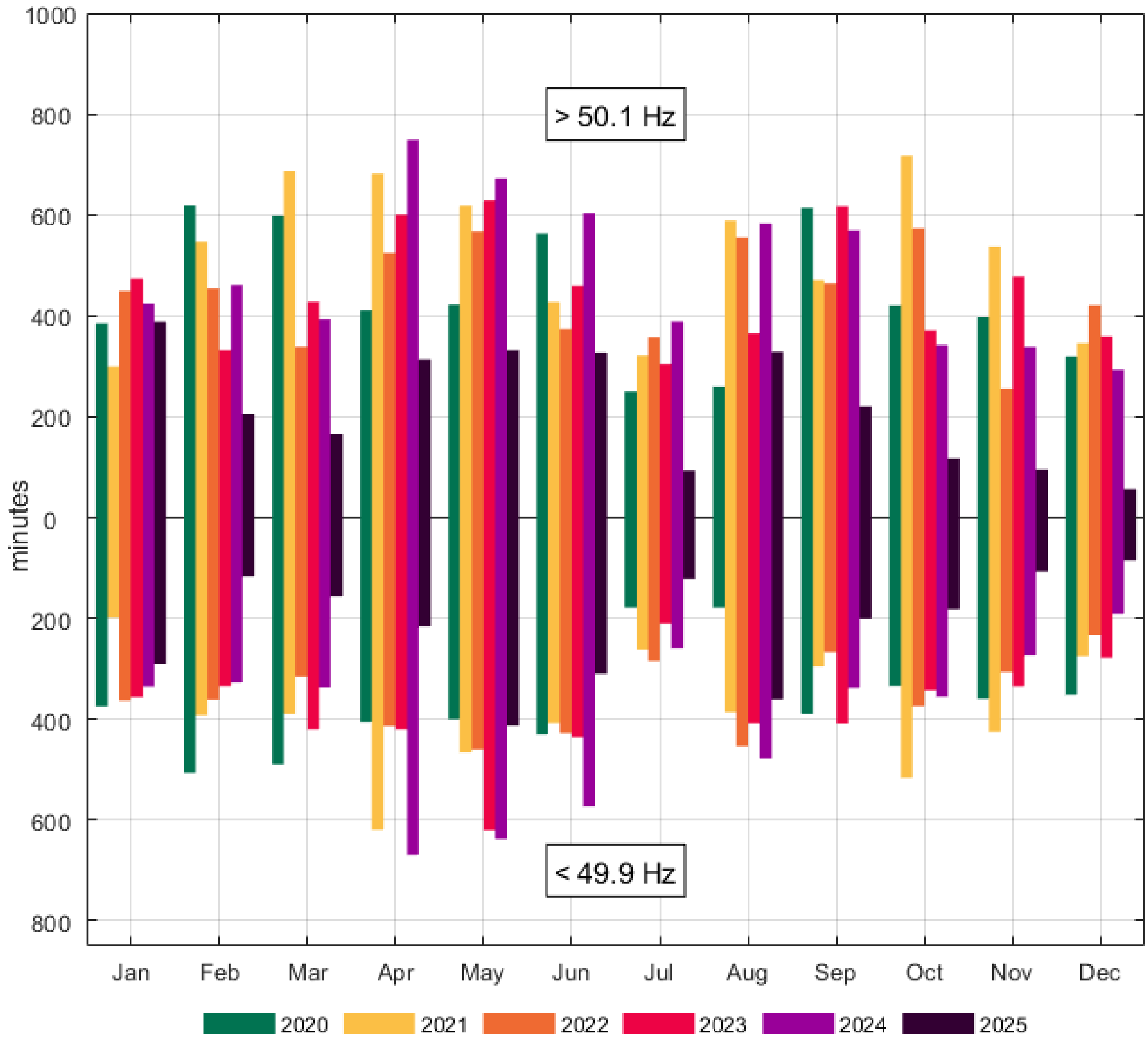


Figure 3.23 shows the daily average in minutes, month by month, for which the frequency has been outside the standard frequency range in the years 2020-2025. In 2025, May had the longest time outside the standard frequency range, while December had the best frequency in this comparison.

***Figure 3.23**. Daily average time for which the frequency was outside the standard frequency range month by month for years 2020-2025*

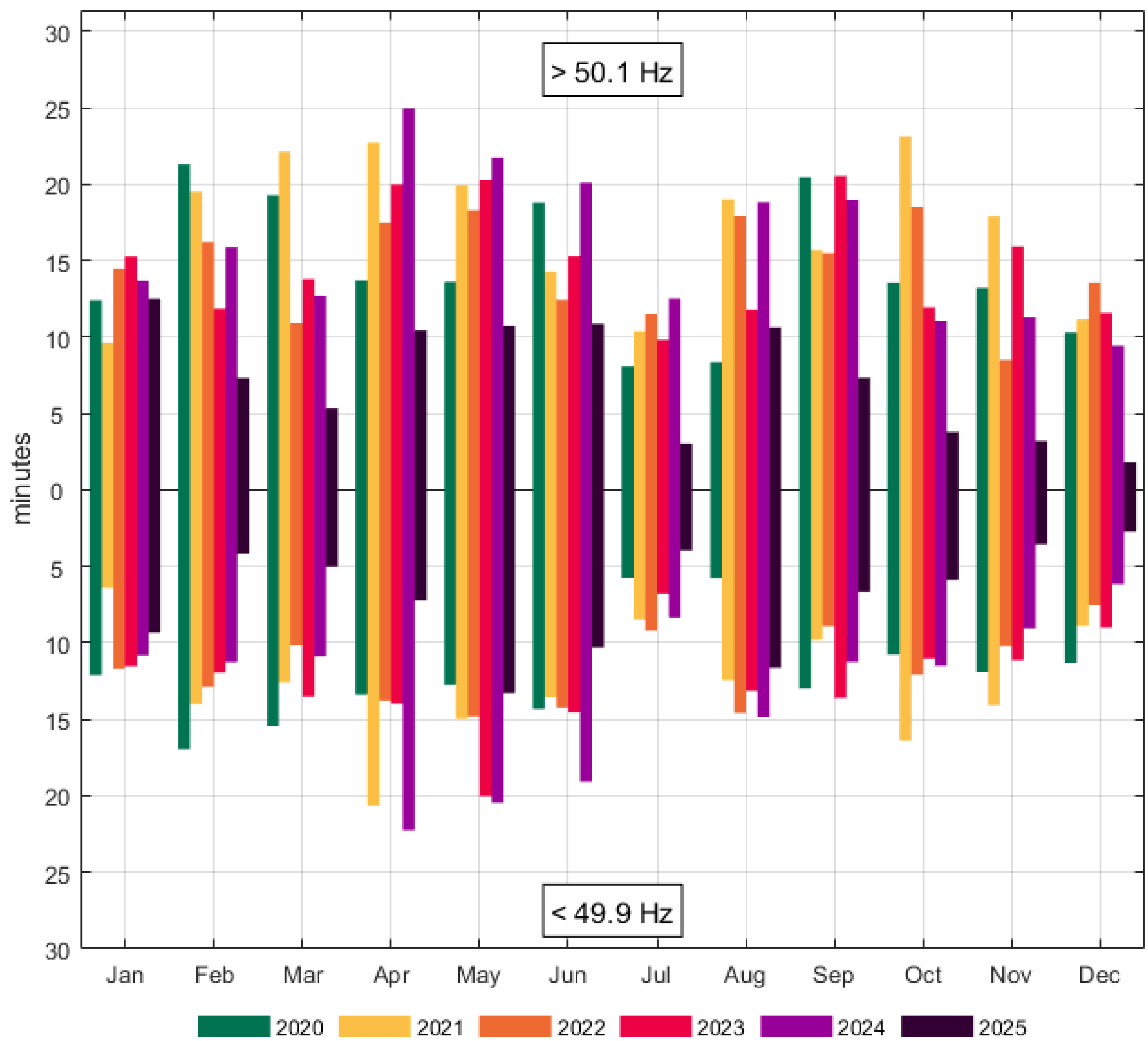


Figure 3.24 represents the daily average time for which the frequency has been outside the standard frequency range during each day of the week. In 2025, the frequency has been outside the standard frequency range the most on Monday and least on Sunday.

***Figure 3.24**. Daily average time that the frequency was outside the standard frequency range during each day of the week for years 2020-2025*

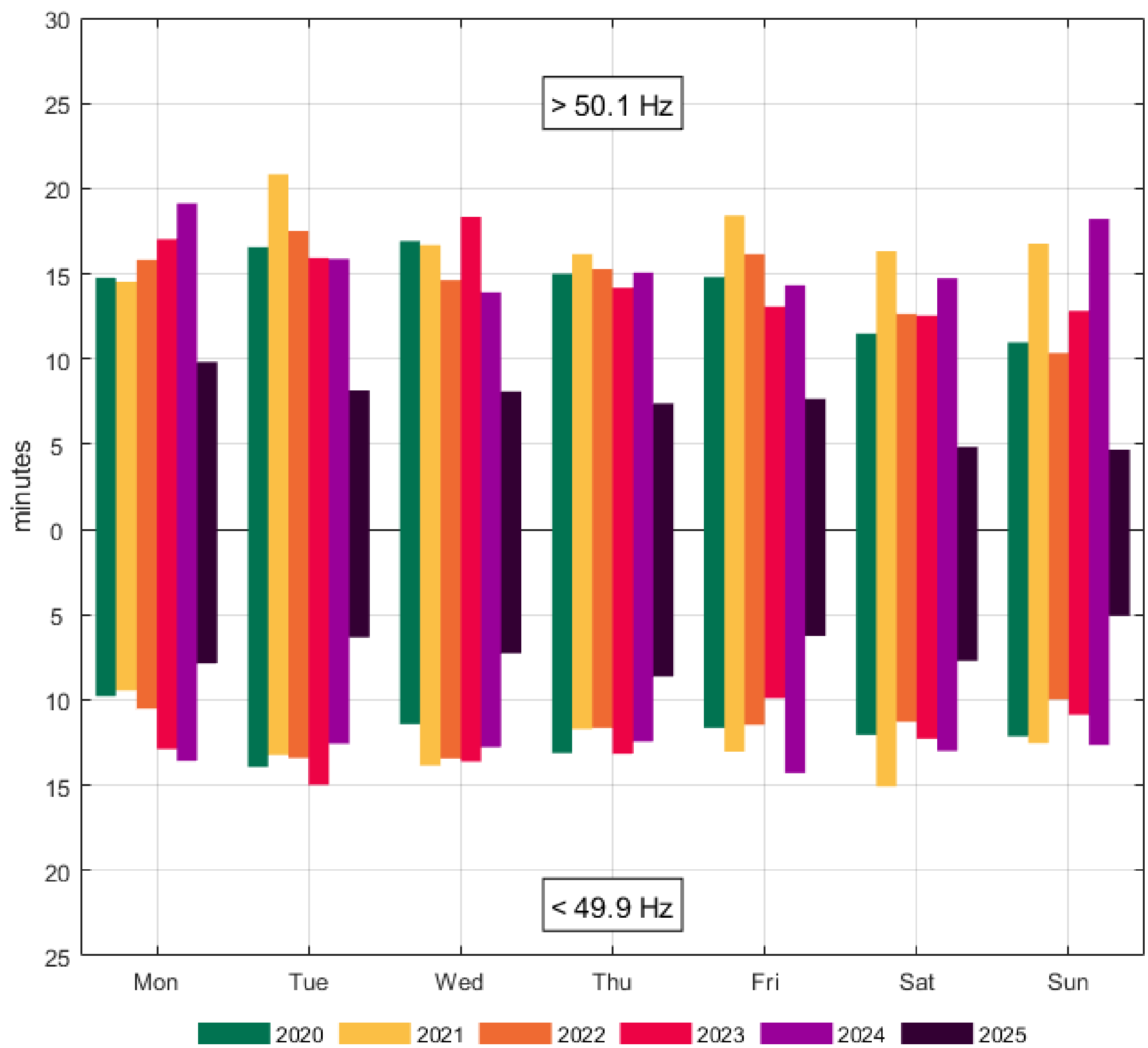


Figure 3.25 represents the daily average time that the frequency was outside the standard frequency range for each hour within a day. In 2025, the frequency exceeded 50.1 Hz most frequently around 7–8 am and 6 pm. Frequencies under 49.9 Hz were most common at 1 am. The frequency was most consistently within the standard frequency range around 3-6 am and 2-3 pm.

***Figure 3.25**. Daily average time for which the frequency was outside the standard frequency range during each hour of the day for years 2020-2025*

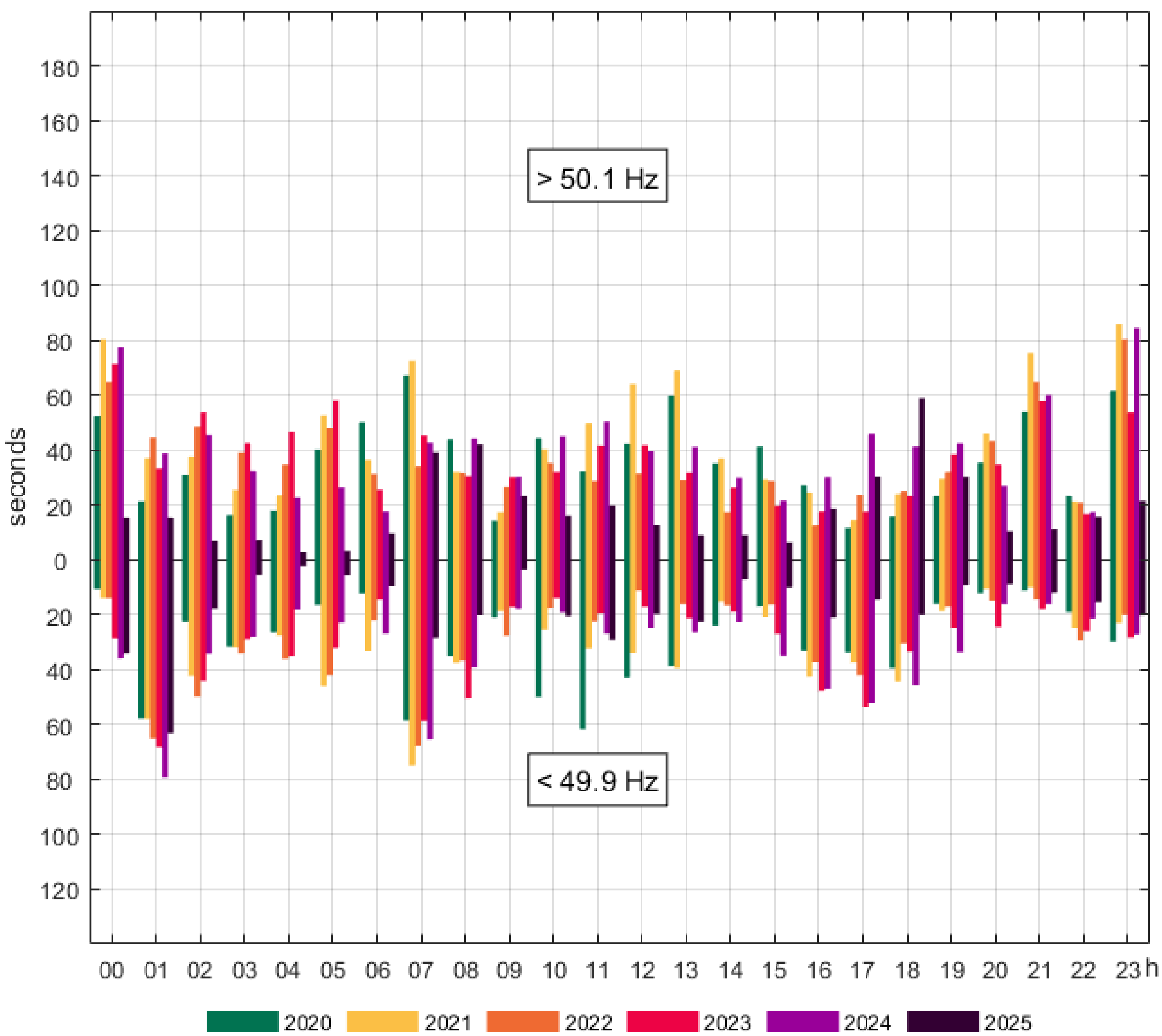


Figure 3.26 shows the daily average time outside the standard frequency range per hour and the absolute value of Nordic consumption and production differences. Also, the transmission difference of HVDC links connecting the Nordic power system to the rest of Europe is presented.

The differences were calculated by subtracting the average power of the previous hour from the corresponding value of the current hour. The differences are presented as absolute values. Consumption and production data were retrieved from the Nordpool website, and the transmission powers of the HVDC links are direct measurement data. The hours are given in Finnish time (UTC+2 / UTC+3).

In the morning, the peak for the production difference is around 1500 MWh, while the peak for the consumption difference is around 2000 MWh. At midnight, the peaks for both the production and consumption differences are approximately 1300 MWh. The peaks of the production difference have increased significantly compared to 2024, whereas the peaks of the consumption difference have remained approximately at the same level as in 2024. The trends in HVDC transmission differences are comparable to those in 2024, with slightly higher peaks, reaching approximately 800 MWh at 11 am and approximately 900 MWh at 6 pm.

***Figure 3.26**. Seconds per hour outside the standard frequency range and the absolute values of Nordic consumption, production and HVDC transmission differences in 2025*

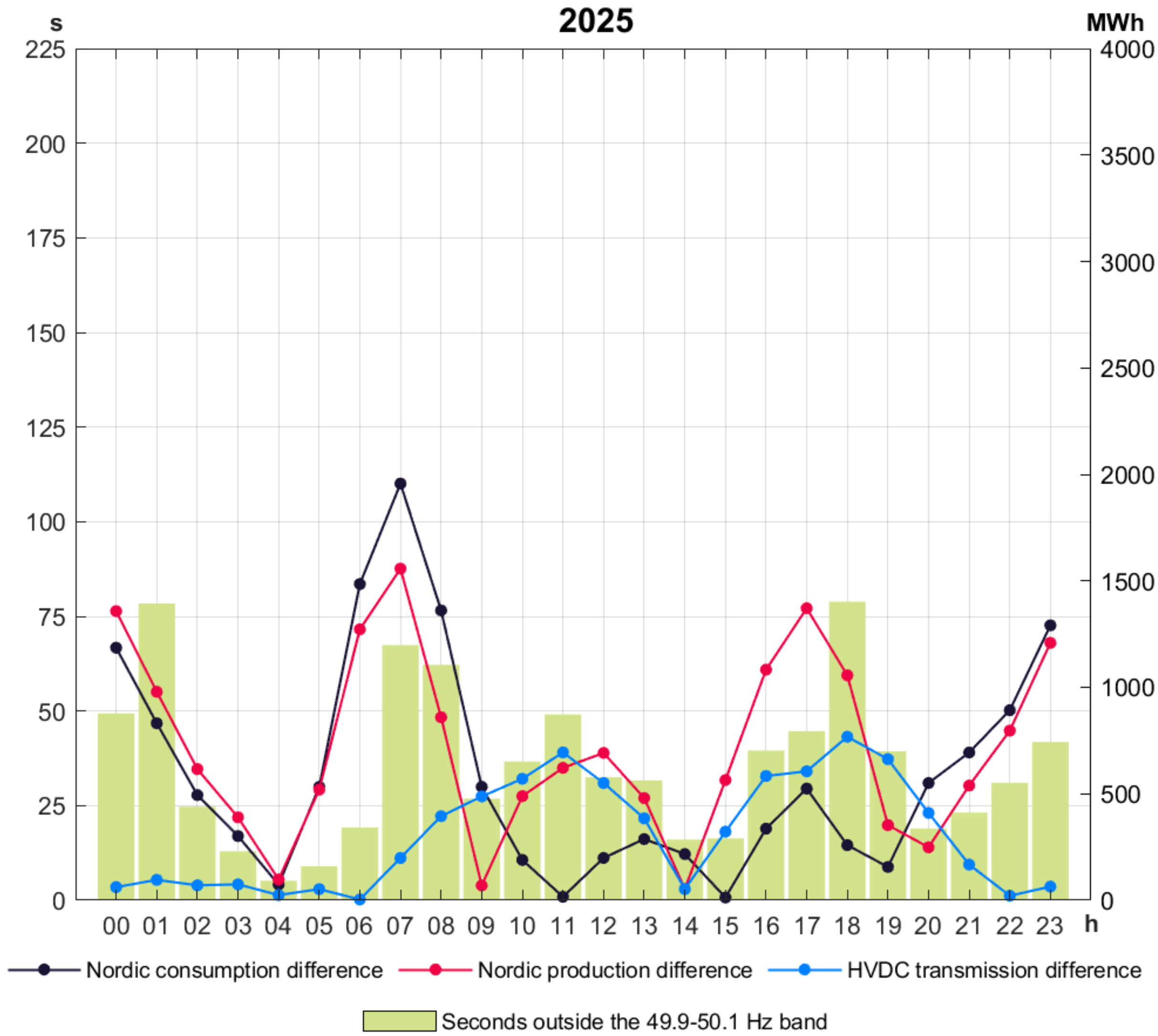


Figure 3.27 illustrates an average hour divided into 60 minutes. For each minute of the average hour, a value in seconds per hour indicates how long the frequency has been above or below the standard frequency range. During the years 2020-2025, the frequency has most often been outside the standard frequency range at the beginning of the hour. The frequency has remained most consistently within the standard frequency range in the middle of the hour. Towards the end of the hour, the time above the standard frequency range increases again. In 2025, fewer seconds were spent outside the standard frequency range throughout the hour compared to previous years. The variation between different parts of the hour also appears slightly less distinct than in previous years.

Figure 3.27. Number of seconds per hour outside the standard frequency range in 2020-2025 for each minute of an average hour

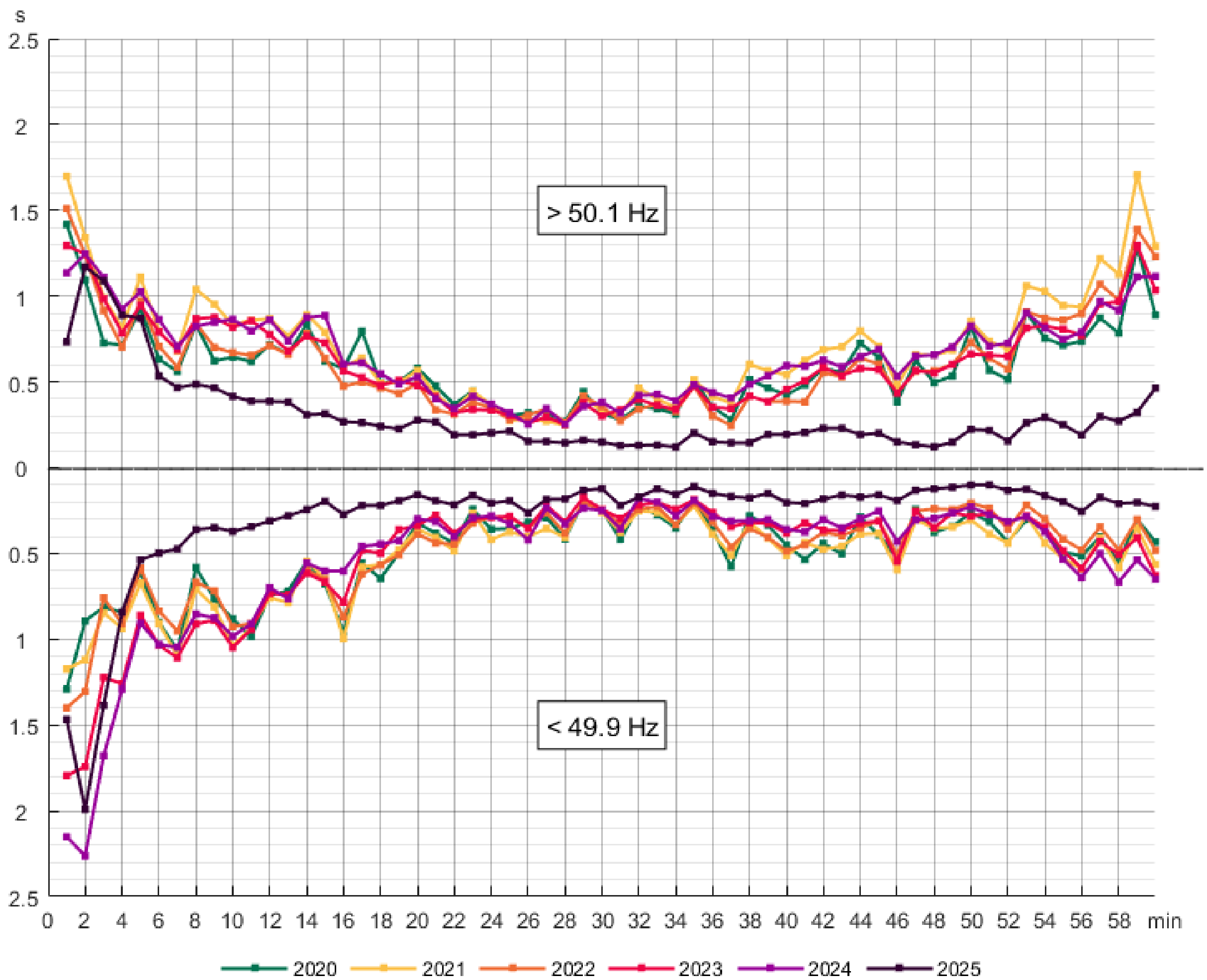
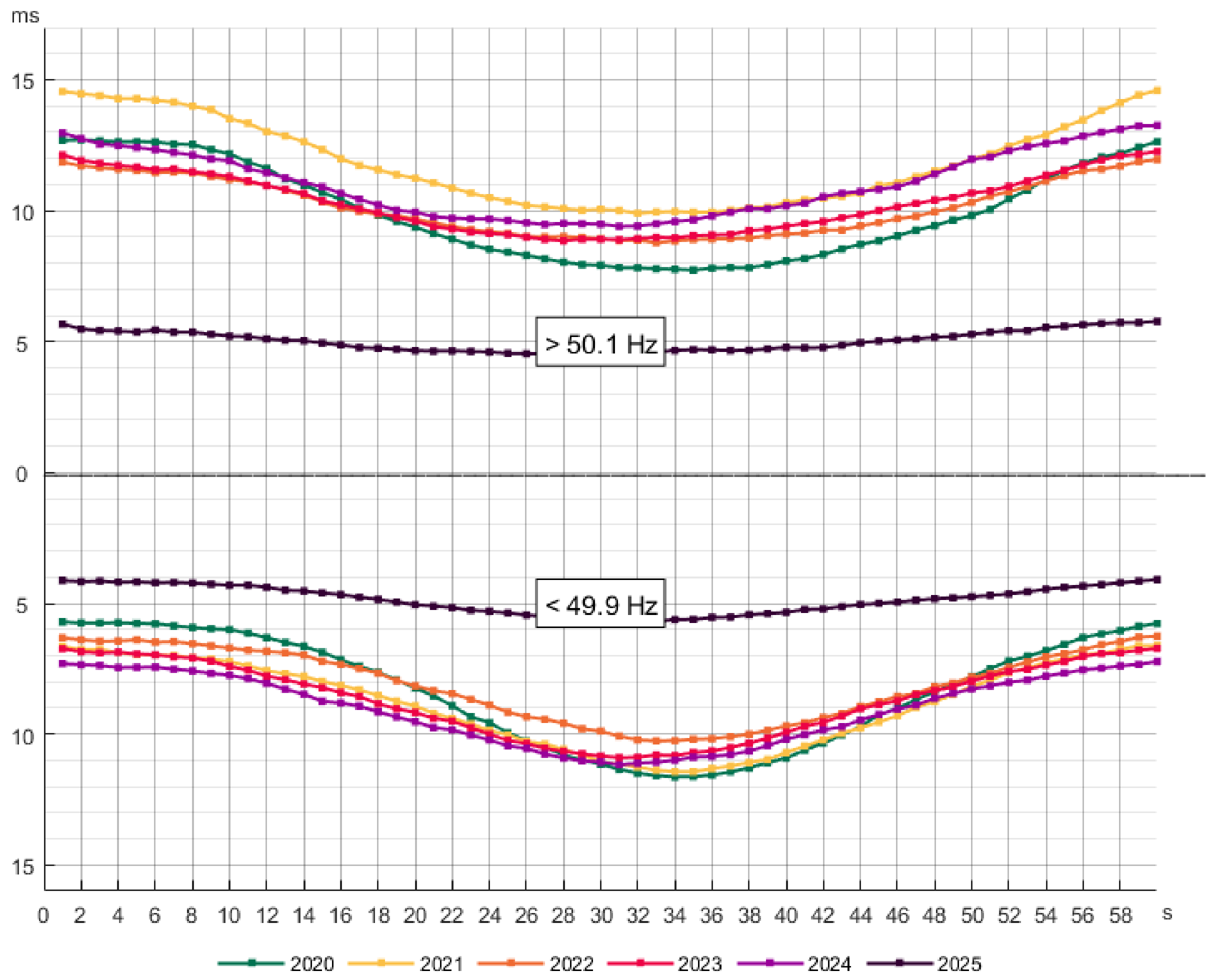


Figure 3.28 illustrates an average minute divided into 60 seconds. For each second of the average minute, there is a value in milliseconds per minute indicating the time that the frequency has been above or below the standard frequency range. Over-frequencies occur more often at the beginning and at the end of the average minute. Under-frequencies occur more frequently in the middle of the minute. Both under- and over-frequencies have been less common throughout the minute in 2025 compared to 2024.

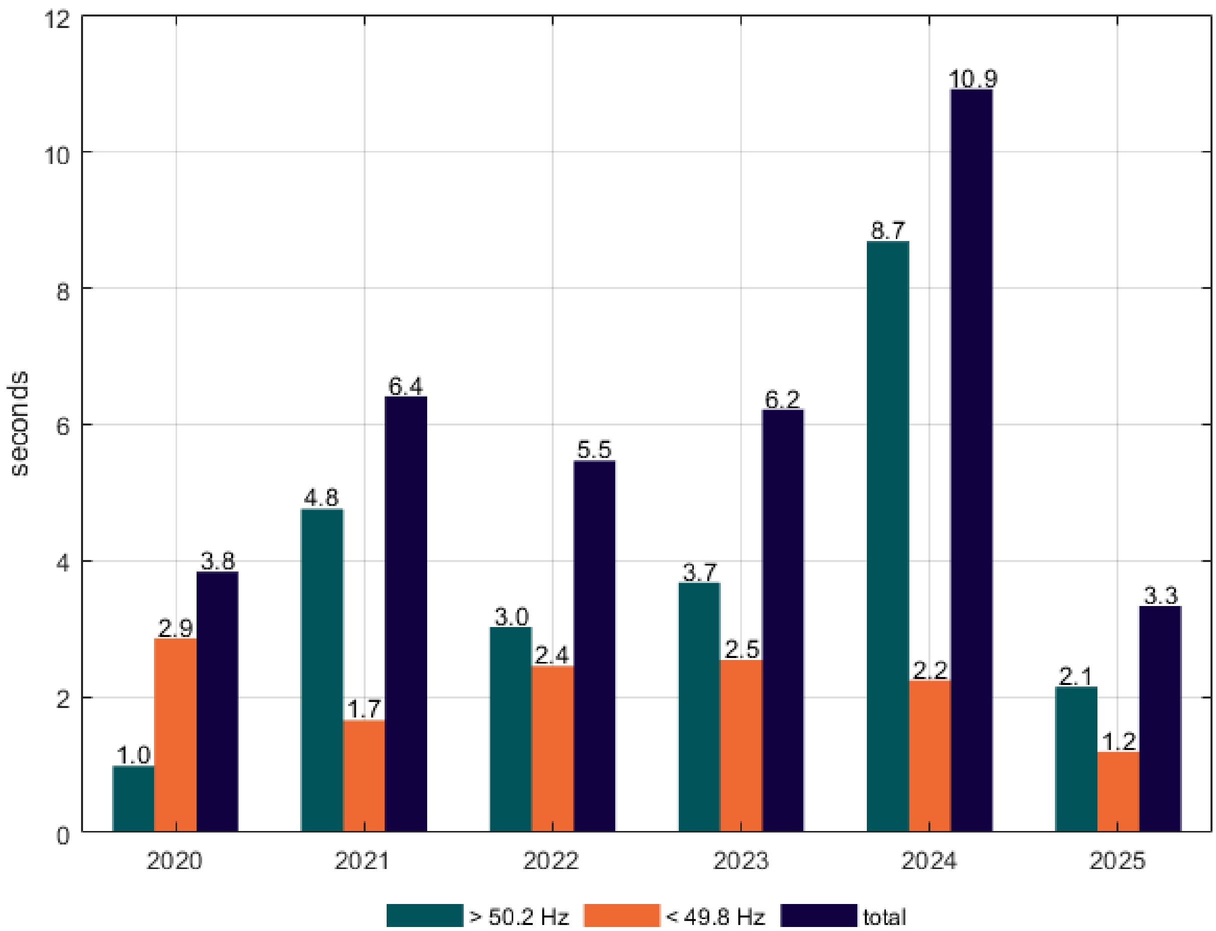
***Figure 3.28*. Number of milliseconds per minute outside the standard frequency range in 2020-2025 for each second of an average minute**



3.4.2 Time outside 49.8-50.2 Hz

Figure 3.29 shows the frequency deviations exceeding ±200 mHz as an average number of seconds per day. The total time outside the range 49.8–50.2 Hz was clearly lower in 2025 than in 2024. In 2025, over-frequencies exceeding 200 mHz were more common than under-frequencies, which is in line with the trend observed in previous years, excluding 2020. When examining the years 2020–2025, 2025 has the lowest total time outside the range 49.8–50.2 Hz. Larger frequency disturbances were also less frequent in 2025 compared to previous years.

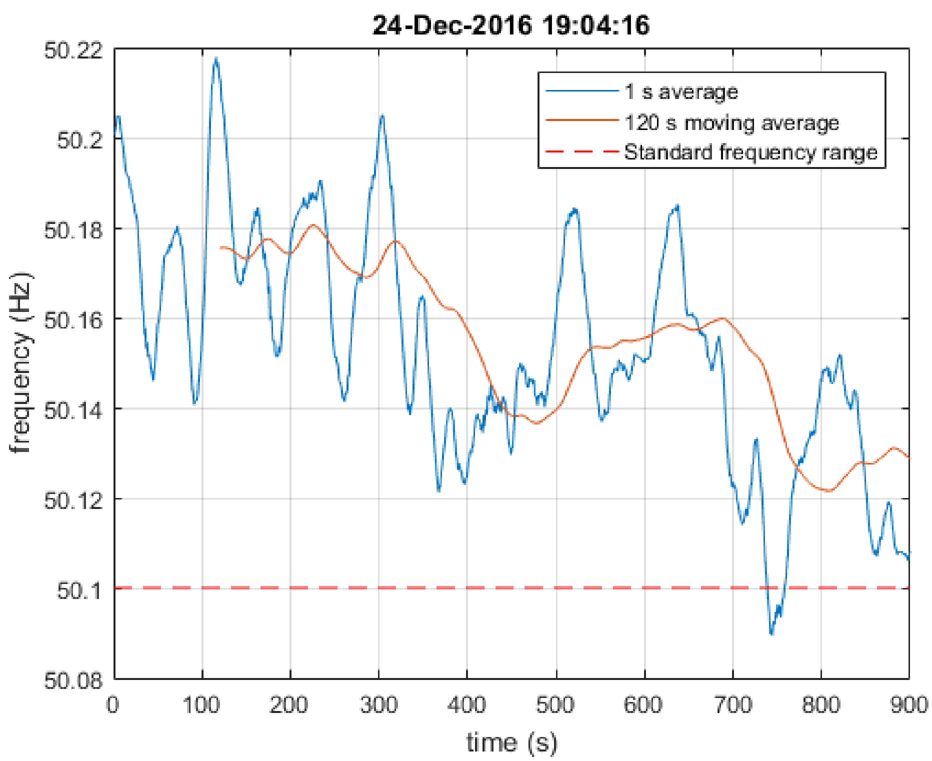
***Figure 3.29**. Average number of seconds per day that the frequency was outside the 49.8-50.2 Hz band for years 2020-2025*



The number of events for which the frequency deviation exceeded ± 200 mHz and did not return to the standard frequency range within the next 15 minutes has been calculated using two different methods. The number of events is also specified in Article 131(1)(a)(vi) of SOGL.
Method 1: the number of events for which the frequency deviation exceeded ± 200 mHz and none of the frequency samples were inside the standard frequency range within the next 15 min.
Method 2: the number of events for which the frequency deviation exceeded ± 200 mHz and the 120-second moving average did not return to the standard frequency range within the next 15 min. The 120-second period was chosen because it is not significantly affected by the natural 60-second oscillation of the frequency, and thus it is considered suitable for determining if the frequency restoration was permanent.

An example of the calculating method is presented in Figure 3.30, which shows a frequency deviation from December 2016. The deviation starts at 0 s as the frequency exceeds 50.2 Hz, and the figure shows the following 15 minutes. This deviation is not counted as an event when using method 1, because the frequency goes momentarily inside the standard frequency range around 750 seconds from the start. By using method 2, this deviation is counted as an event. The 120-second moving average does not go inside the standard frequency range at any point during the 15-minute period. The resolution of the frequency data used was 1 second.

***Figure 3.30**. Comparison of methods for calculating the number of events where df > 200 mHz and the frequency is not restored within 15 min*



The number of events in 2020-2025 in which the frequency exceeded 49.8-50.2 Hz and did not even momentarily return to the standard frequency range within 15 minutes is presented in Table 3.13. These results were calculated using method 1.

Table 3.13. Number of events for which the frequency deviation exceeded ± 200 mHz and the frequency did not return to the 49.9-50.1 Hz band within 15 minutes. Calculated with method 1.

	2020		**2021**		**2022**		**2023**		**2024**		**2025**	
Month	**> 50.2 Hz**	**< 49.8 Hz**	**> 50.2 Hz**	**< 49.8 Hz**	**> 50.2 Hz**	**< 49.8 Hz**	**> 50.2 Hz**	**< 49.8 Hz**	**> 50.2 Hz**	**< 49.8 Hz**	**> 50.2 Hz**	**< 49.8 Hz**
January	0	0	0	0	0	0	0	0	0	0	0	0
February	0	0	1	0	0	0	0	0	1	0	0	0
March	0	0	1	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0
September	1	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0	0
Entire year	1	0	2	0	0	0	0	0	1	0	**0**	**0**

Table 3.14 shows the number of events in 2020-2025 in which the frequency exceeded the 49.8-50.2 Hz and the 120-second moving average did not return to the standard frequency range within the next 15 minutes. These results were calculated using method 2.

***Table 3.14**. Number of events for which the frequency deviation exceeded ± 200 mHz and the frequency did not return to the 49.9-50.1 Hz band within 15 minutes. Calculated with method 2.*

	2020		**2021**		**2022**		**2023**		**2024**		**2025**	
Month	**> 50.2 Hz**	**< 49.8 Hz**	**> 50.2 Hz**	**< 49.8 Hz**	**> 50.2 Hz**	**< 49.8 Hz**	**> 50.2 Hz**	**< 49.8 Hz**	**> 50.2 Hz**	**< 49.8 Hz**	**> 50.2 Hz**	**< 49.8 Hz**
January	0	0	0	0	0	0	0	0	1	0	2	0
February	0	0	2	0	0	0	0	0	1	0	0	0
March	0	0	1	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	1	0	0
May	0	0	1	0	0	0	0	0	0	1	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	1	0	0	0	0
September	1	0	1	0	0	0	2	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	1	0	0	0	1	0	0	0	0	0
December	0	0	0	0	1	0	0	0	0	0	0	0
Entire year	1	0	6	0	1	0	3	1	2	2	**2**	**0**
Sum	**1**		**6**		**1**		**4**		**4**		**2**	

3.4.3 Time outside 49.0-51.0 Hz

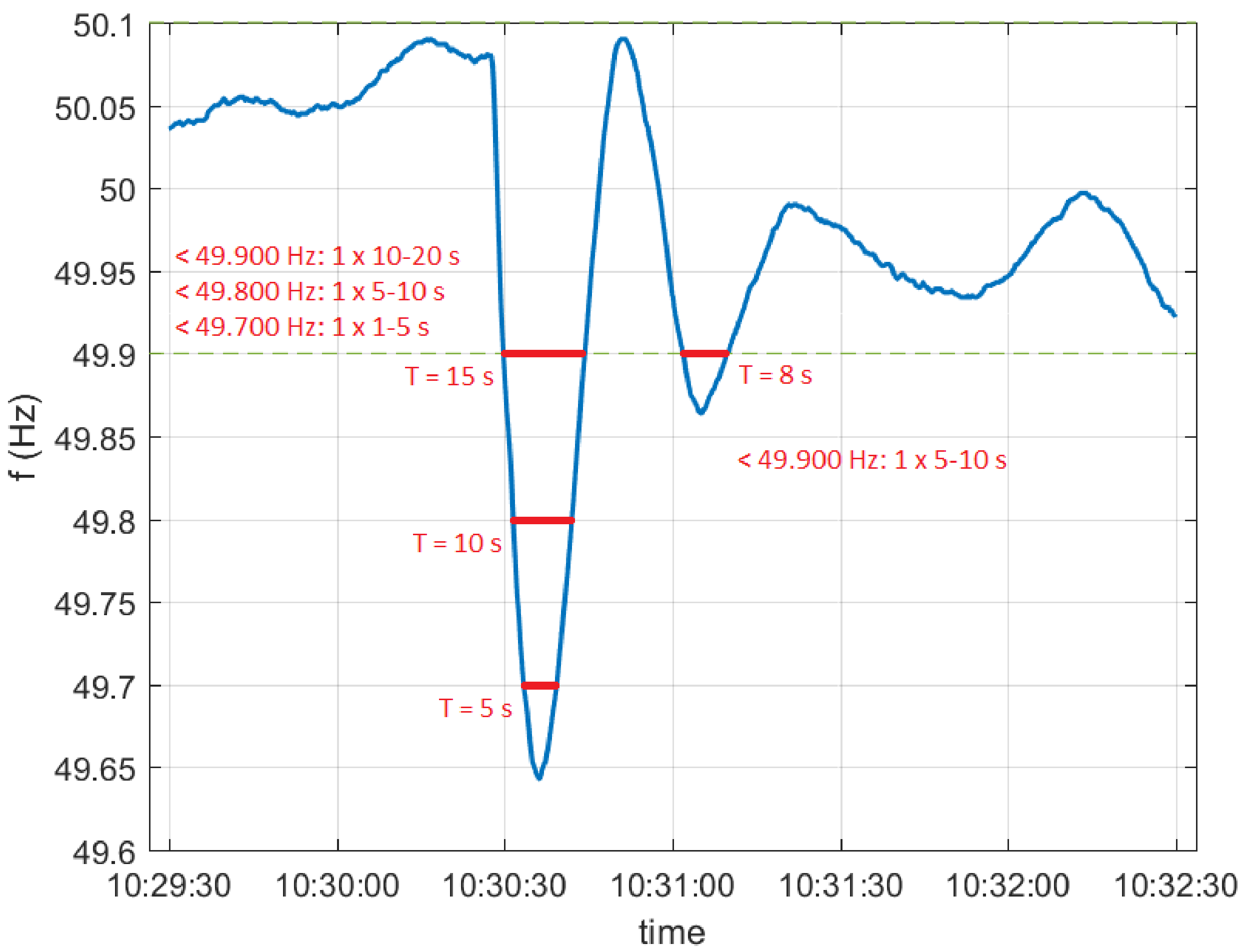
Time outside 49.0 Hz and 51.0 Hz is calculated by counting the number of samples that are below 49.0 Hz or above 51.0 Hz and multiplying the number by the time duration of the sample. The criteria are also defined in SO GL Article 131(1)(a) (v). The resolution of the data used was 1 second.

There were no instances in 2020-2025 where the frequency crossed 49.0 Hz or 51.0 Hz.

3.5 Number of frequency deviations with different durations

In this section, the deviations outside the standard frequency range have been sorted according to the amplitude and duration of the deviation, as well as whether the deviation was above or below the standard frequency range. Figure 3.31 gives an example of how the frequency deviations have been calculated. The example situation has two frequency deviations with different durations going below 49.900 Hz. This time period increases the number of frequency deviations < 49.900 Hz by two (2): one addition to the 10-20 s column and one addition to the 5-10 s column. The first frequency deviation also goes below 49.800 Hz and 49.700 Hz. These will also be counted as one frequency deviation < 49.800 Hz with a time of 5-10 s and one deviation < 49.700 Hz with a time of 1-5 s. Altogether, the example period contains four (4) frequency deviations. The time window of 5-10 s, for example, stands for frequency deviations lasting over five (5) seconds and under or exactly 10 seconds.

***Figure 3.31**. Example of how the number of frequency deviations is calculated [4]*



3.5.1 Deviations with a duration of 0-1 s, 1-5 s, 5-10 s, 10-20 s, 20-40 s, 40-60 s, and 1-3 min

The resolution of the frequency data used is 0.1 seconds.

Tables 3.15-3.20 provide more detailed information about frequency deviations from 2020 to 2025. These tables include the durations and amplitudes of the deviations, as well as the total amount, maximum duration, and average duration of the deviations.

Table 3.15. Total number of frequency deviation in 2020

f (Hz)	0-1s	1-5s	5-10s	10-20s	20-40s	40-60s	1-3 min	> 3min	Total amount	Max duration (s)	Average duration (s)
> 50.1	13424	4297	3245	5139	3274	626	531	84	30620	1288.50	10.06
> 50.2	31	10	20	11	1	0	0	0	73	22.70	5.13
> 50.3	0	1	1	1	0	0	0	0	3	10.70	6.67
< 49.9	11223	4102	2917	4572	2825	515	354	60	26568	922.30	9.60
< 49.8	38	39	14	11	7	2	0	1	112	390.70	9.48
< 49.7	1	1	2	2	0	0	0	0	6	17.90	7.80
< 49.6	0	1	0	0	0	0	0	0	1	2.70	2.70
< 49.5	0	0	0	0	0	0	0	0	0	0.00	0.00

Table 3.16. Total number of frequency deviation in 2021

f (Hz)	0-1s	1-5s	5-10s	10-20s	20-40s	40-60s	1-3 min	> 3min	Total amount	Max duration (s)	Average duration (s)
> 50.1	19397	5475	3582	5807	3800	811	635	101	39608	1620.00	9.25
> 50.2	99	41	20	27	17	6	5	0	215	83.80	8.26
> 50.3	2	0	0	0	0	0	0	0	2	1.00	0.55
< 49.9	15255	5009	3409	5004	3117	522	361	42	32719	747.40	8.24
< 49.8	33	24	12	12	2	2	1	0	86	107.80	7.14
< 49.7	2	2	4	3	0	0	0	0	11	14.10	6.31
< 49.6	1	2	2	0	0	0	0	0	5	7.80	4.42
< 49.5	0	1	0	0	0	0	0	0	1	3.50	3.50

Table 3.17. Total number of frequency deviation in 2022

f (Hz)	0-1s	1-5s	5-10s	10-20s	20-40s	40-60s	1-3 min	> 3min	Total amount	Max duration (s)	Average duration (s)
> 50.1	33186	4690	3589	5274	3353	667	508	81	51348	800.80	6.21
> 50.2	113	33	24	33	6	1	1	0	211	140.10	5.28
> 50.3	1	3	2	1	0	0	0	0	7	10.10	5.34
< 49.9	29351	4385	3304	4688	2753	501	371	45	45398	756.60	5.60
< 49.8	59	24	22	13	9	3	1	0	131	83.90	6.92
< 49.7	3	2	5	2	0	0	0	0	12	11.80	5.45
< 49.6	0	1	2	0	0	0	0	0	3	8.70	6.37
< 49.5	1	1	0	0	0	0	0	0	2	4.30	2.30

Table 3.18. Total number of frequency deviation in 2023

f (Hz)	0-1s	1-5s	5-10s	10-20s	20-40s	40-60s	1-3 min	> 3min	Total amount	Max duration (s)	Average duration (s)
> 50.1	34976	5374	4141	5367	2935	607	516	121	54037	857.50	6.01
> 50.2	121	22	25	21	10	2	4	0	205	158.50	6.60
> 50.3	9	3	1	2	0	0	0	0	15	11.20	2.47
< 49.9	28930	4592	3472	4782	2641	526	478	66	45487	601.20	6.01
< 49.8	121	48	22	13	5	1	2	0	212	123.70	4.42
< 49.7	2	1	3	3	0	0	0	0	9	15.60	7.88
< 49.6	2	0	0	2	0	0	0	0	4	11.30	5.70
< 49.5	0	0	2	0	0	0	0	0	2	7.80	7.05

Table 3.19. Total number of frequency deviation in 2024

f (Hz)	0-1s	1-5s	5-10s	10-20s	20-40s	40-60s	1-3 min	> 3min	Total amount	Max duration (s)	Average duration (s)
> 50.1	45243	5615	4118	5266	2734	638	610	153	64377	1489.80	5.43
> 50.2	366	49	43	39	10	6	6	3	522	434.40	6.11
> 50.3	6	4	2	0	0	0	0	0	12	8.30	2.33
< 49.9	36164	4772	3397	4352	2437	535	531	111	52299	902.30	5.44
< 49.8	159	41	11	15	6	0	2	0	234	122.80	3.54
< 49.7	2	0	4	0	0	0	0	0	6	8.70	5.65
< 49.6	2	2	0	0	0	0	0	0	4	1.80	1.03
< 49.5	1	0	0	0	0	0	0	0	1	0.10	0.10

Table 3.20. Total number of frequency deviation in 2025

f (Hz)	0-1s	1-5s	5-10s	10-20s	20-40s	40-60s	1-3 min	> 3min	Total amount	Max duration (s)	Average duration (s)
> 50.1	26586	3176	1867	1788	931	307	312	91	35058	1010.20	4.53
> 50.2	113	12	3	11	3	1	3	0	146	159.50	5.38
> 50.3	6	2	1	0	0	0	0	0	9	7.10	1.46
< 49.9	19308	2177	1111	1499	1092	301	366	99	25953	1006.20	5.90
< 49.8	105	23	10	4	2	0	2	0	146	84.20	2.95
< 49.7	1	0	0	0	0	0	0	0	1	0.10	0.10
< 49.6	0	0	0	0	0	0	0	0	0	0.00	0.00
< 49.5	0	0	0	0	0	0	0	0	0	0.00	0.00

Figure 3.32 is a visual representation of the data in Tables 3.15–3.20. The number of deviations is given as a daily average instead of a total number per year. In 2025, the number of frequency deviations has been the lowest in the observation period, except for deviations lasting 0–1 seconds, for which 2020 and 2021 show lower values.

***Figure 3.32**. Daily average number of frequency deviations per duration*

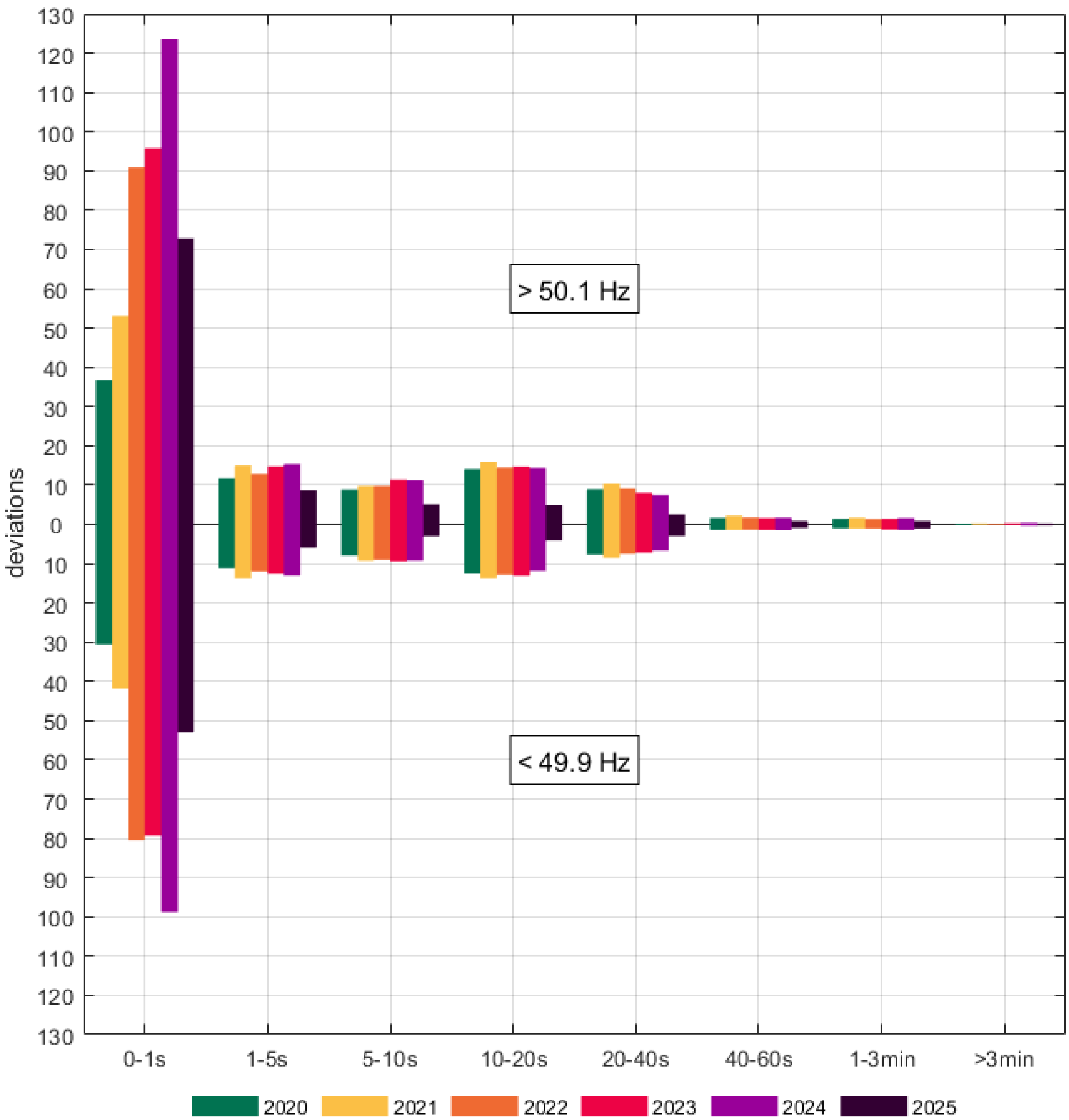
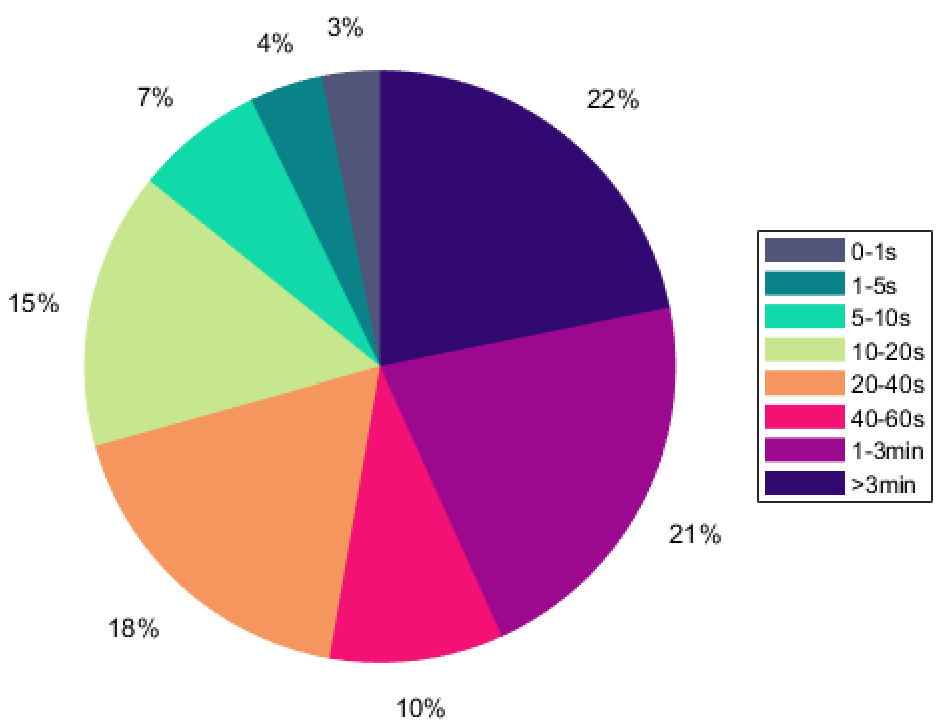


Table 3.21 shows how deviations of different durations affected the total time outside the standard frequency range in 2025. The times are given in minutes. Figure 3.33 illustrates, in percentages, how the total time outside the standard frequency range was distributed among deviations of different durations. Deviations lasting 1-3 min and more than 3 min accounted for 43 % of the total time outside the standard frequency range. The share of deviations lasting more than 3 minutes increased by eight percentage points compared to the previous year.

***Table 3.21**. Total minutes in 2025 that the frequency was outside the standard frequency range per duration of deviations*

	0-1 s	1-5 s	5-10 s	10-20 s	20-40 s	40-60 s	1-3 min	> 3 min	total
> 50.1 Hz	96	125	229	425	428	250	505	589	2646
< 49.9 Hz	69	84	138	360	506	244	608	545	2554
total	164	209	366	785	934	495	1113	1135	5200

***Figure 3.33**. Percentage of total time outside the standard frequency range caused by deviations of different durations*



The following figures provide more detailed information on the deviations in 2025. Figure 3.34 represents the total number of deviations per duration for each month in 2025. Most of the deviations lasted less than one second. Deviations occurred most frequently in May, June, August, and September, while November and December had the smallest number of deviations.

***Figure 3.34**. Total number of frequency deviations per duration for each month in 2025*

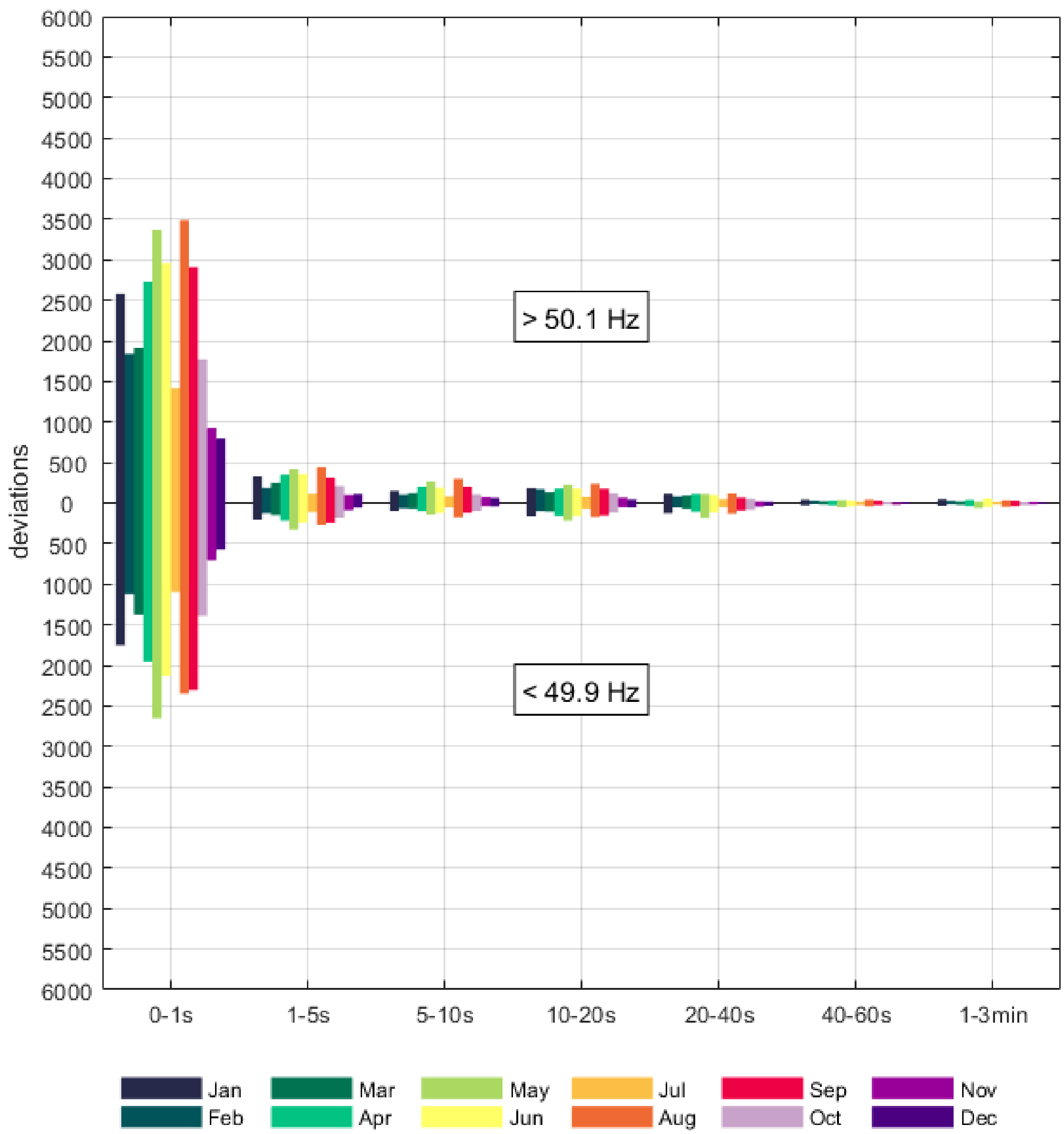
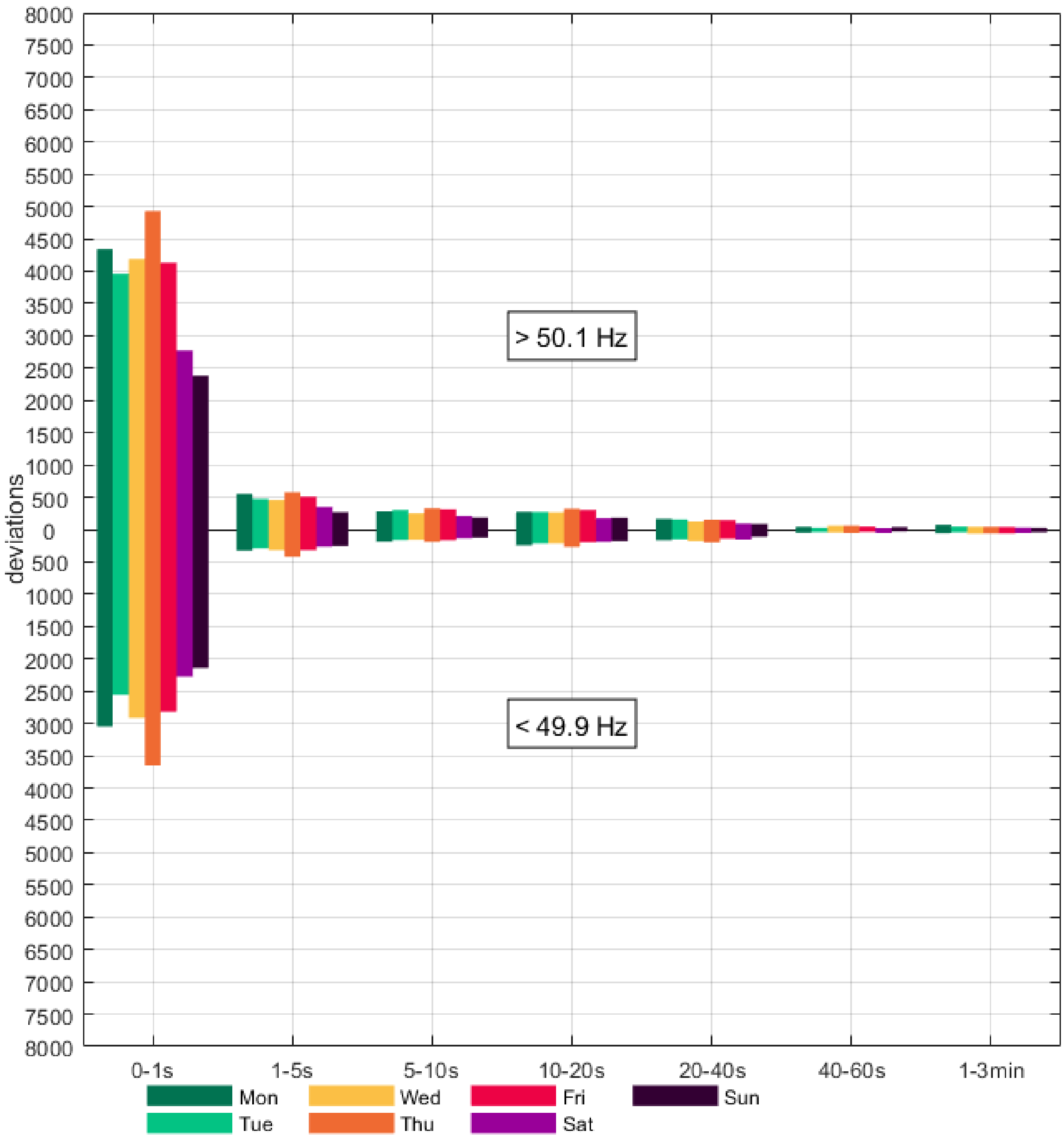


Figure 3.35 shows the number of frequency deviations by duration for each day of the week. The highest number of deviations occurred on Thursdays, while Sundays had the fewest deviations. Compared to 2024, the deviations decrease more clearly towards the end of the week, whereas in 2024 they were more evenly distributed across the week.

***Figure 3.35**. Total number of frequency deviations per duration for each day of the week in 2025*



Figures 3.36 and 3.37 illustrate the number of deviations per duration within the day. Figure 3.36 includes hours 0–11, while Figure 3.37 includes hours 12–23. Frequency values above the normal frequency range occurred most frequently during the morning hours around 7–8 am and at 6 pm. Frequency values below the normal frequency range were most common around midnight, at 1 am, 7 am, 11 am, 1 pm, and 11 pm.

***Figure 3.36*. Total number of frequency deviations per duration for hours 0-11 in 2025**

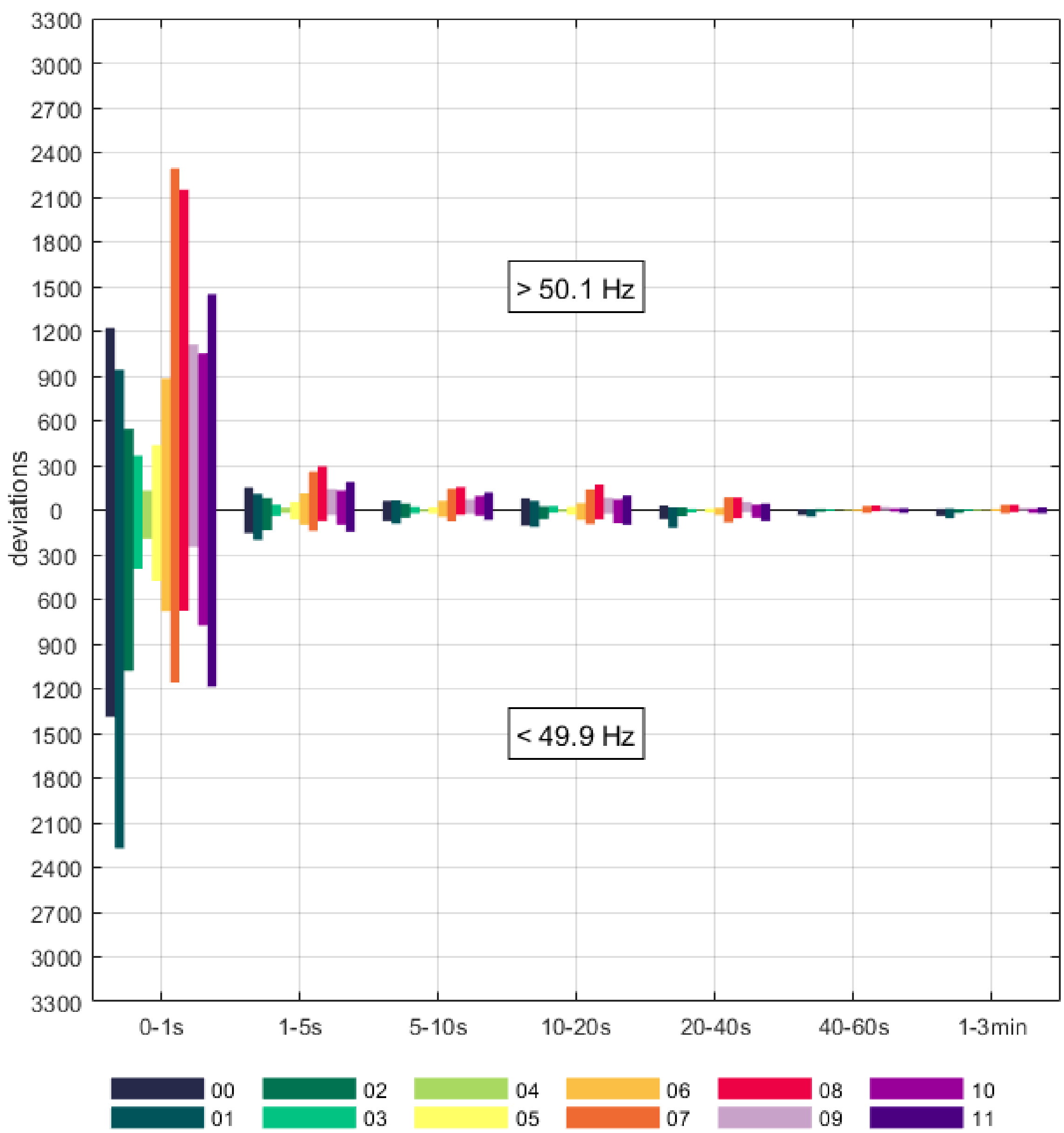


Figure 3.37. Total number of frequency deviations per duration for hours 12-23 in 2025

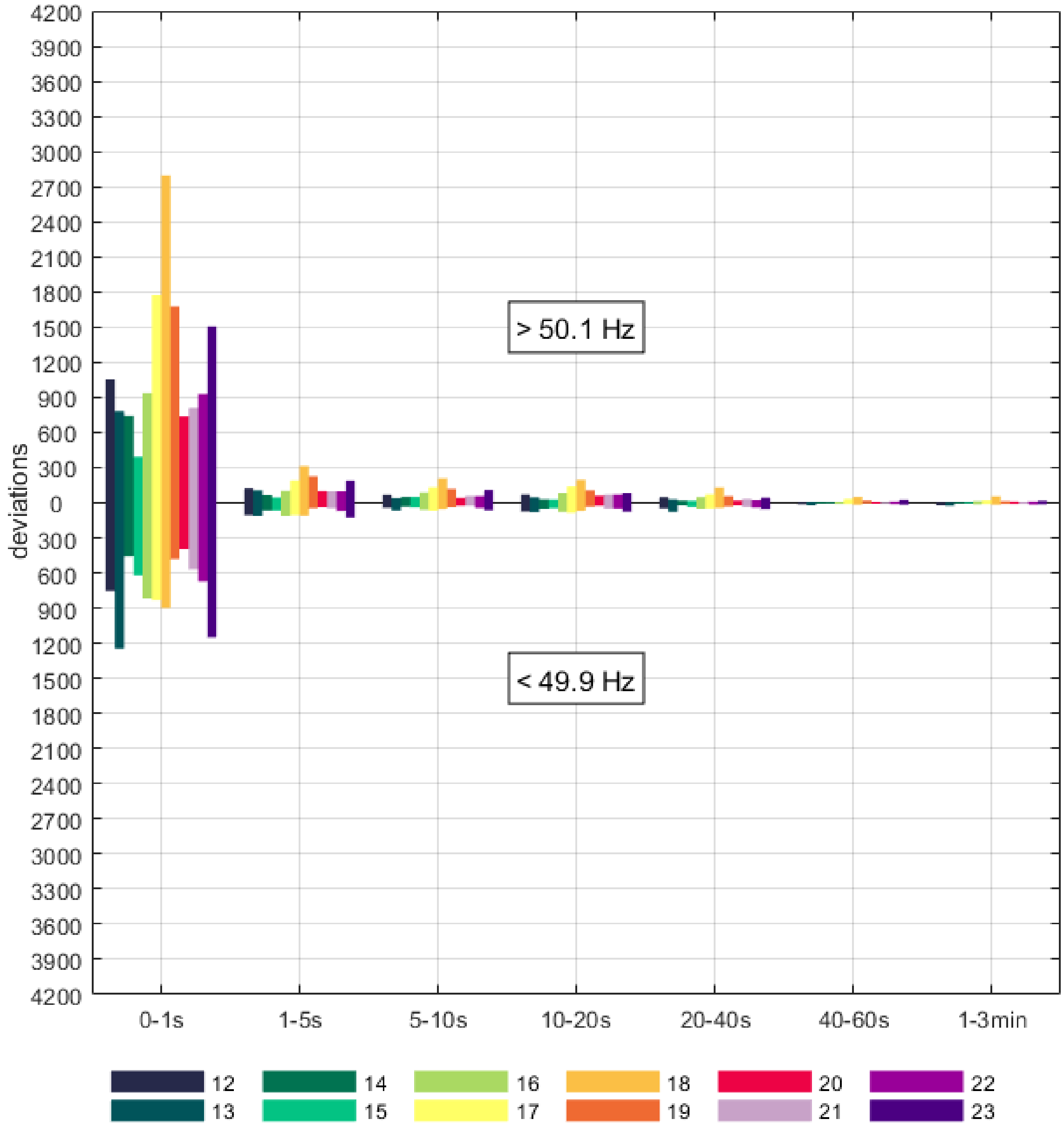
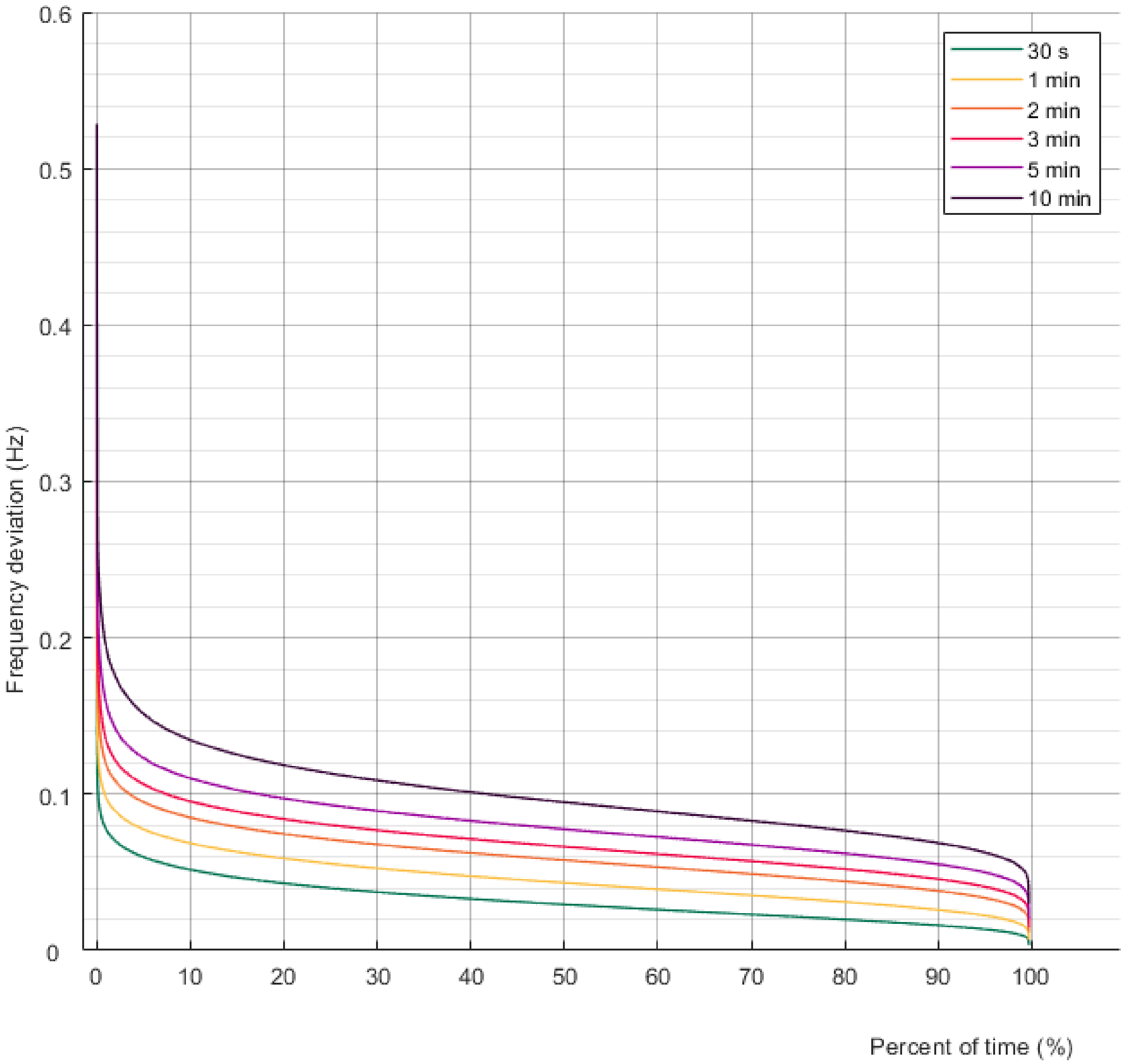


Figure 3.38 represents duration curves of the frequency variation observed within different moving time windows in 2025. For each time window length indicated in the legend, the difference between the maximum and minimum frequency values within the window was calculated while moving the window through the data one second at a time. The resulting values were then sorted in descending order to form duration curves. There have been some frequency disturbances of over 0.3 Hz, which are visible at the left end of the curves. Chapter 4 will go through these in detail.

***Figure 3.38**. Duration curve of maximum frequency deviation within different time windows in 2025*



3.5.2 Deviations with a duration of 1-3 min, 3-5 min, 5-10 min, 10-15 min, and > 15 min

The resolution of the frequency data used for these durations is one minute. Figure 3.39 shows the total number of over 1-minute deviations exceeding the standard frequency range for the years between 2020 and 2025. Compared to the previous year, the number of both over- and under-frequency deviations decreased in all duration categories, except for 15-minute deviations, where only over-frequency deviations decreased. The most significant change occurred in deviations lasting 1–3 minutes.

***Figure 3.39**. Total number of longer frequency deviations per duration between 2020-2025*

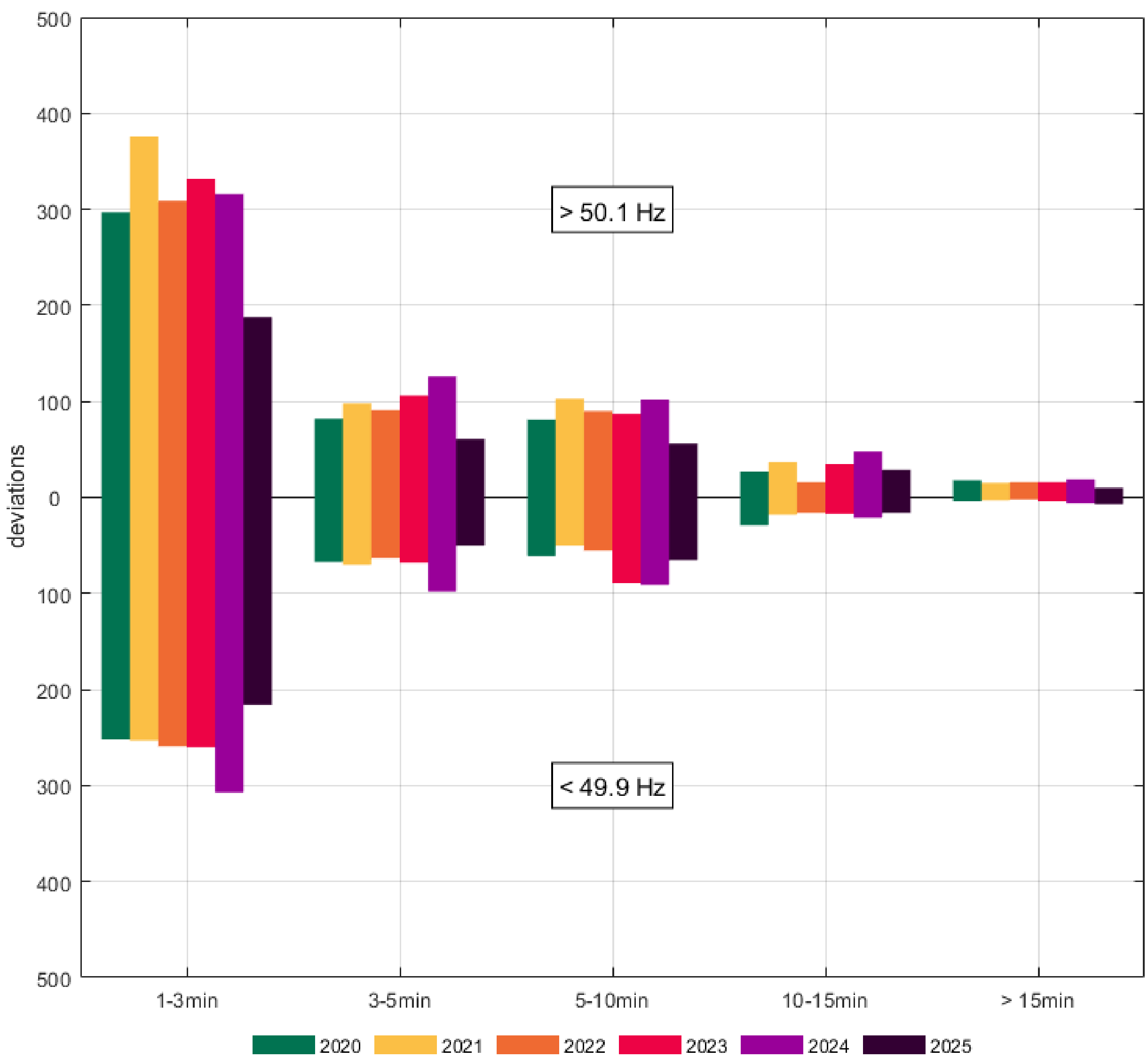


Figure 3.40 shows the total number of longer deviations exceeding the standard frequency range for each month in 2025. May, June, and August had the highest number of over-frequency deviations. Under-frequency deviations were also most common during the same months.

***Figure 3.40**. Total number of longer frequency deviations per duration for each month in 2025*

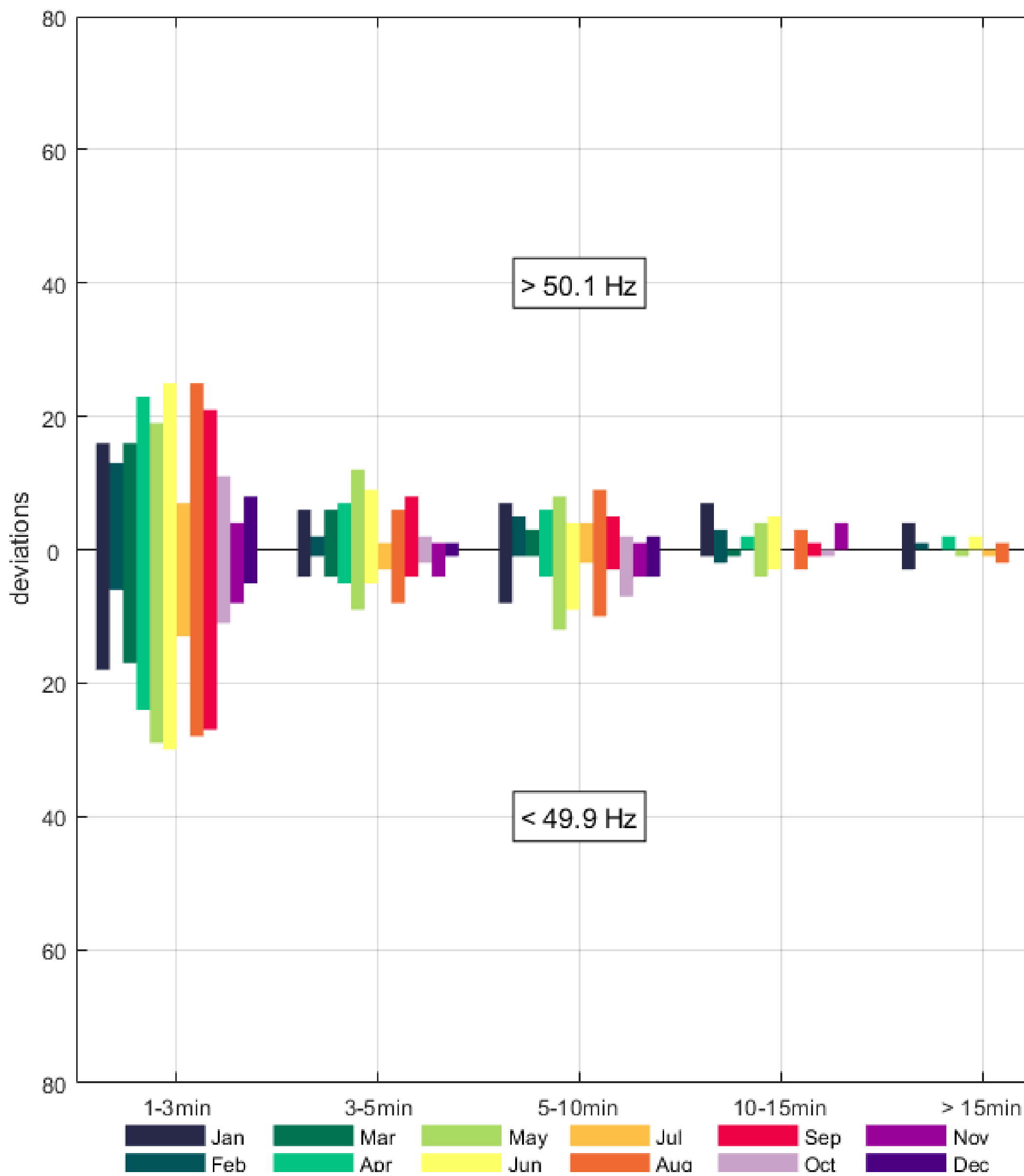
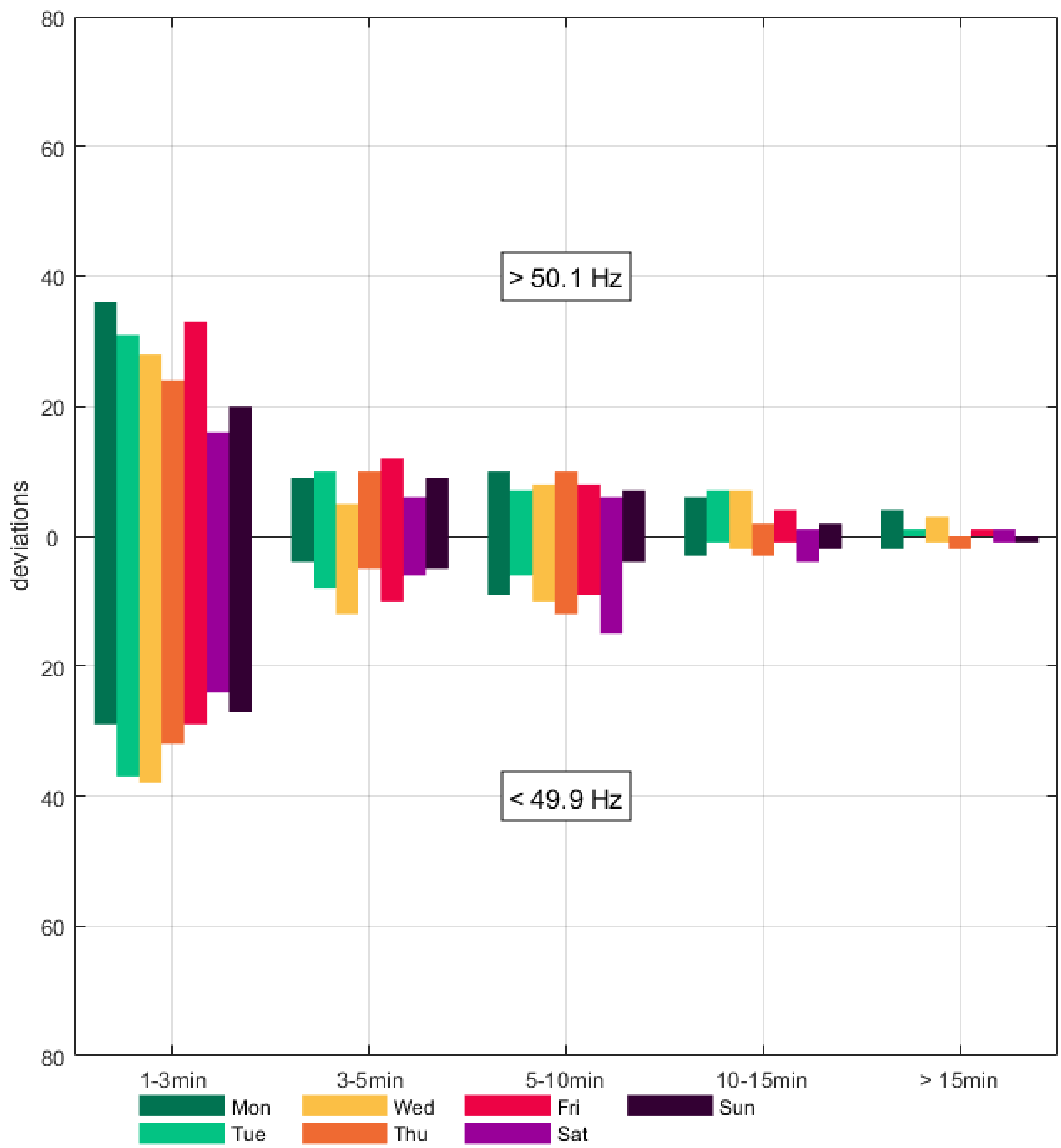


Figure 3.41 represents the number of deviations with different durations for each day of the week in 2025. The number of deviations varied considerably between weekdays across the different duration categories. Overall, fewer deviations occurred during weekends.

Figure 3.41. Total number of longer frequency deviations per duration for each day of the week in 2025



Figures 3.42 and 3.43 illustrate longer frequency deviations within the day. Deviations above the standard frequency range occurred most frequently around 7 am and during the afternoon around 5–6 pm. Deviations below the standard frequency range were most common around midnight, at 1 am, and at 1 pm.

***Figure 3.42**. Total number of longer frequency deviations per duration for hours 0-11 in 2025*

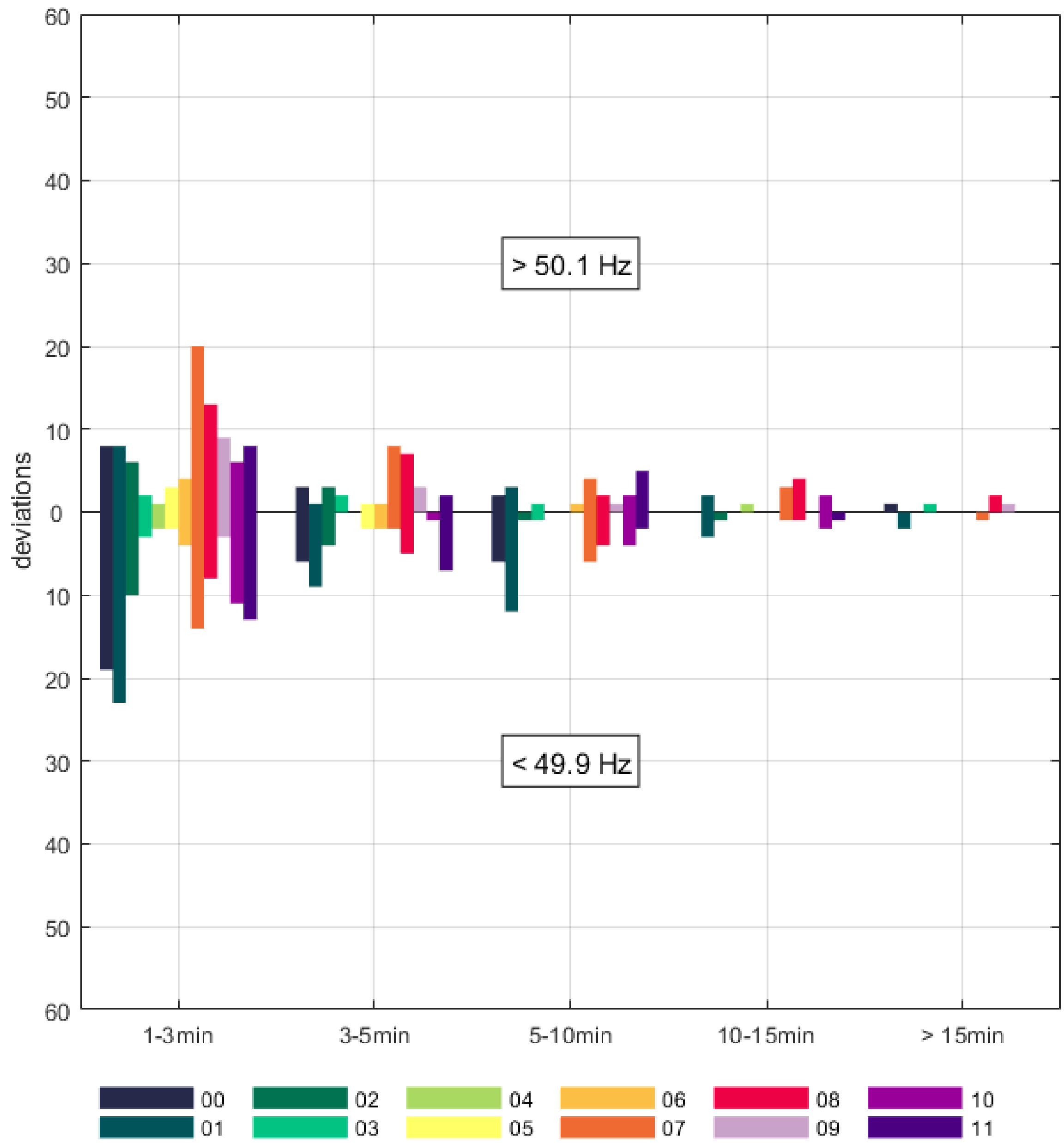
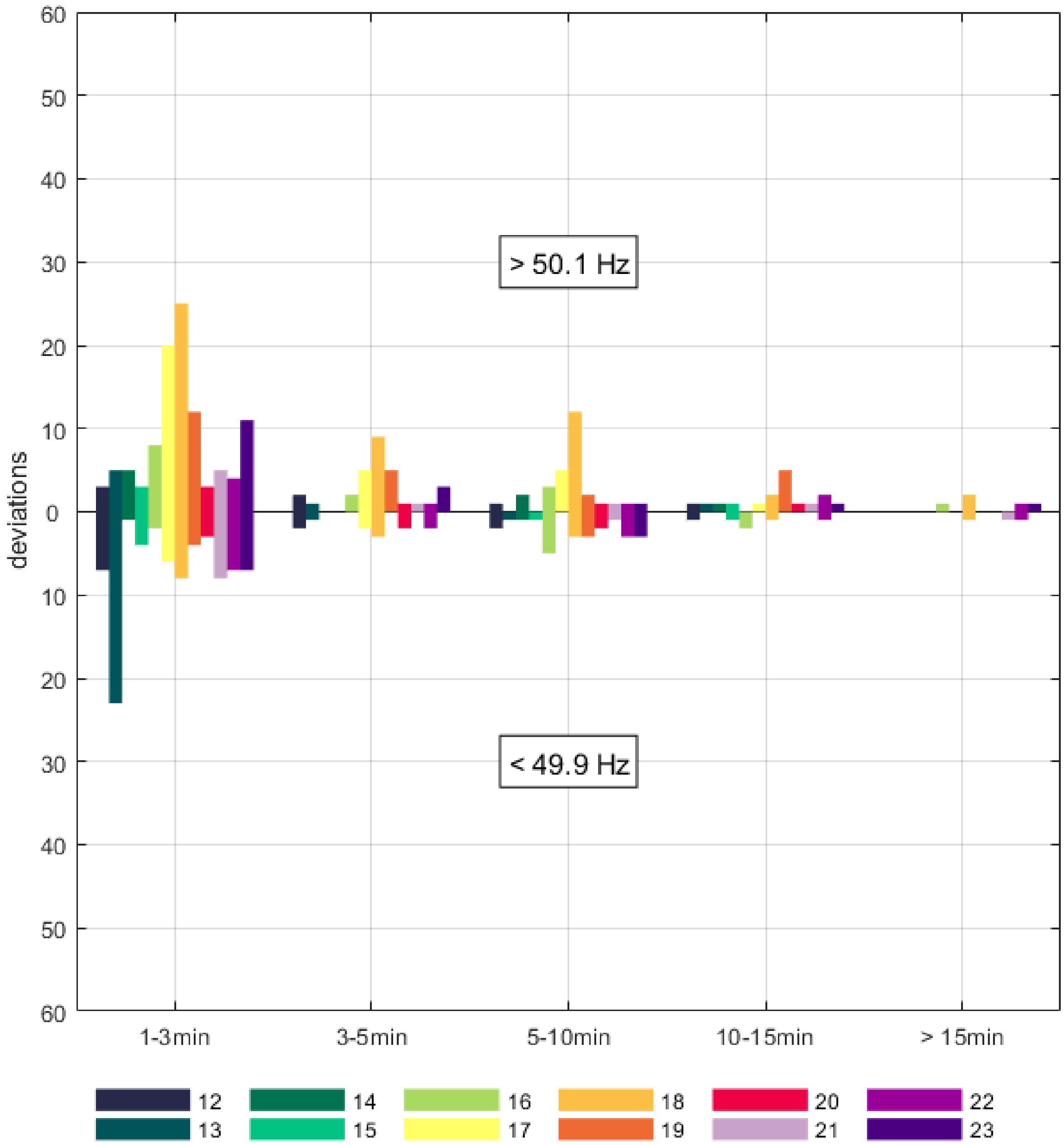


***Figure 3.43**. Total number of longer frequency deviations per duration for hours 12-23 in 2025*



3.6 Number of threshold crossings

The number of threshold crossings is calculated by counting the number of samples for which the frequency is outside the standard frequency range and the previous sample is inside the range. The number of threshold crossings is a good indicator of how many times, per given time period, the Frequency Containment Reserve for Disturbances (FCR-D) is activated. The crossings are calculated separately for the number of occasions the frequency goes above or below the standard frequency range. The resolution of the frequency data used is one second.

3.6.1 Number of 49.9-50.1 Hz crossings

Figure 3.44 shows the daily average number of threshold crossings from 2020 to 2025. In 2025, the number of threshold crossings was less than half of that in 2024. In every year, there have been more threshold crossings above 50.1 Hz than below 49.9 Hz.

***Figure 3.44**. Daily average number of threshold crossings for the years 2020-2025*

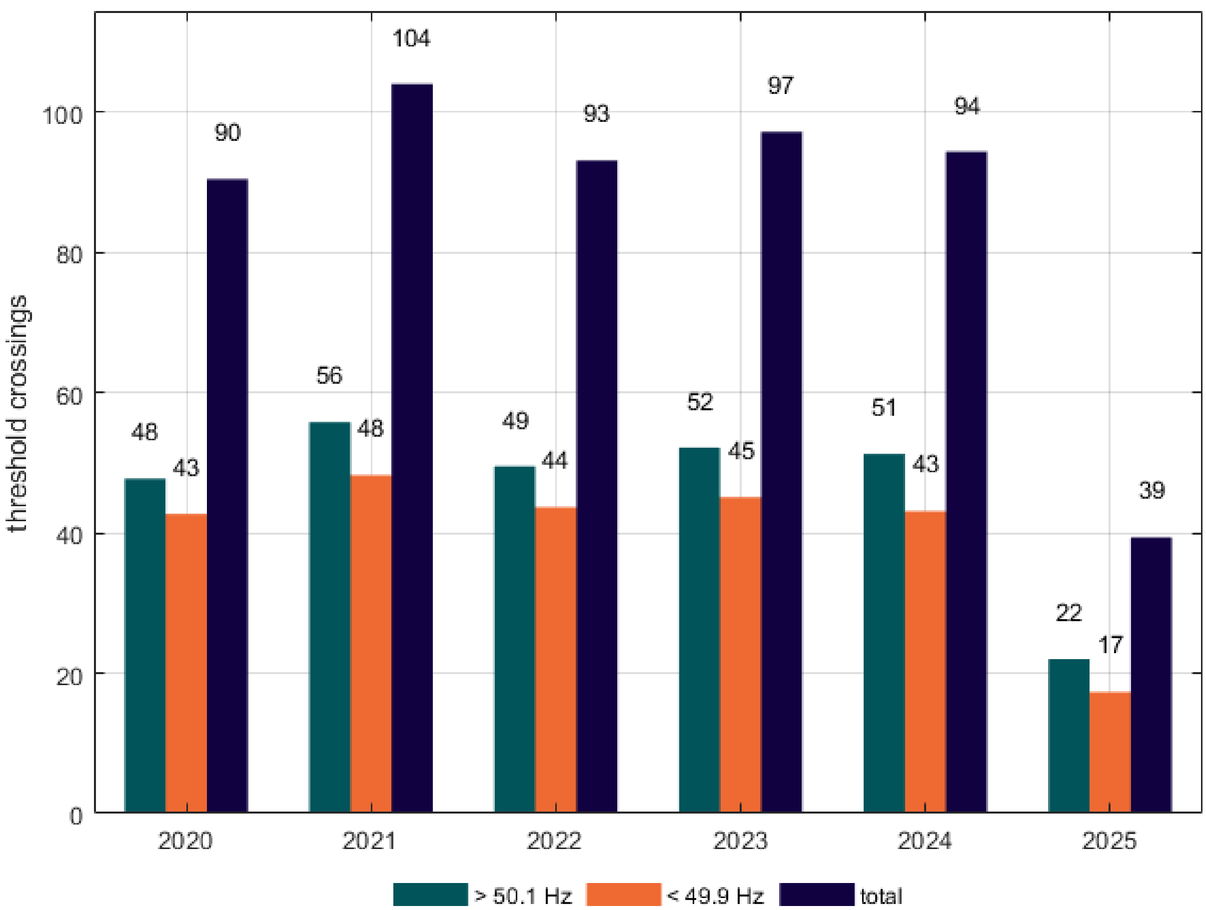


Figure 3.45 represents the daily average number of threshold crossings for each month in 2025. The frequency crossed the threshold most often in May and August. November and December had the smallest number of threshold crossings.

***Figure 3.45**. Daily average number of threshold crossings for every month in 2025*

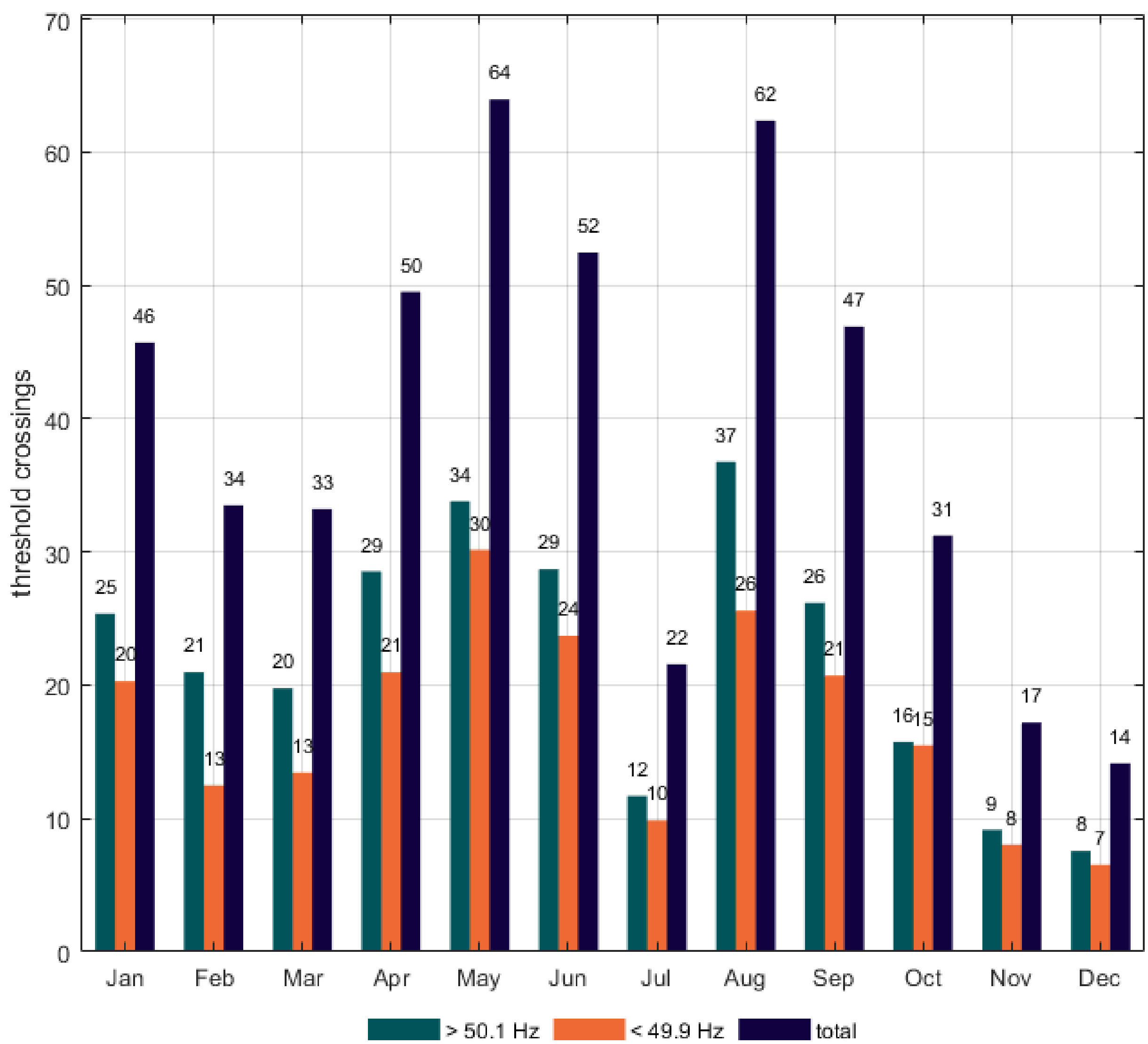
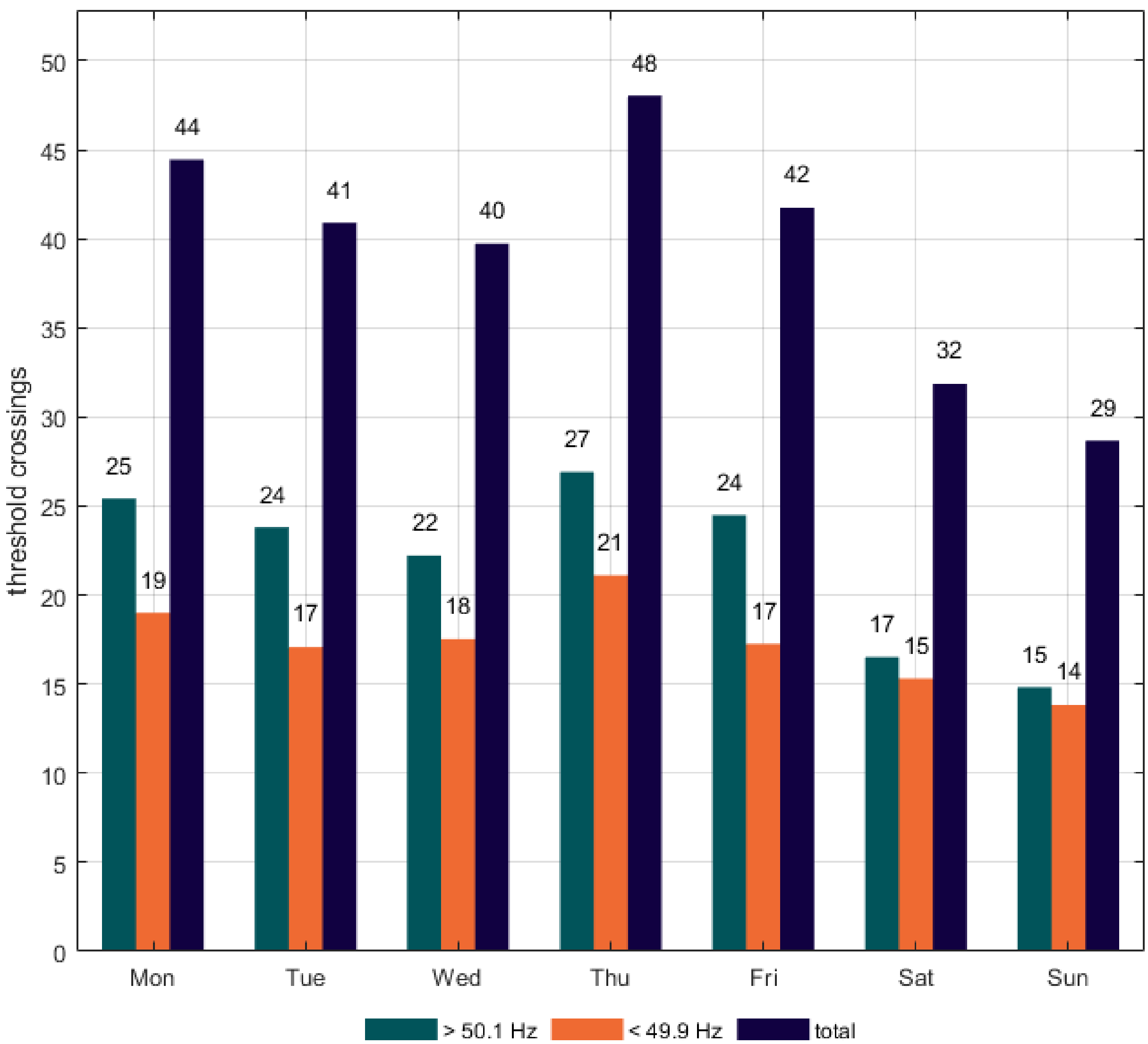


Figure 3.46 shows the number of threshold crossings for each day of the week in 2025. The number of crossings was higher on Monday and Thursday, with fewer crossings occurring during the weekend.

***Figure 3.46**. Daily average number of threshold crossings for every day of the week in 2025*



The hourly number of threshold crossings within an average day is presented in Figure 3.47. In 2025, the highest number of crossings occurred in the morning between 7–8 am and at 6 pm. The lowest number of crossings took place during the early morning hours between 3–5 am. The overall trend is similar to the previous year. However, the total number of threshold crossings has decreased, particularly during the early morning hours.

***Figure 3.47**. Average number of threshold crossings for every hour of the day in 2025*

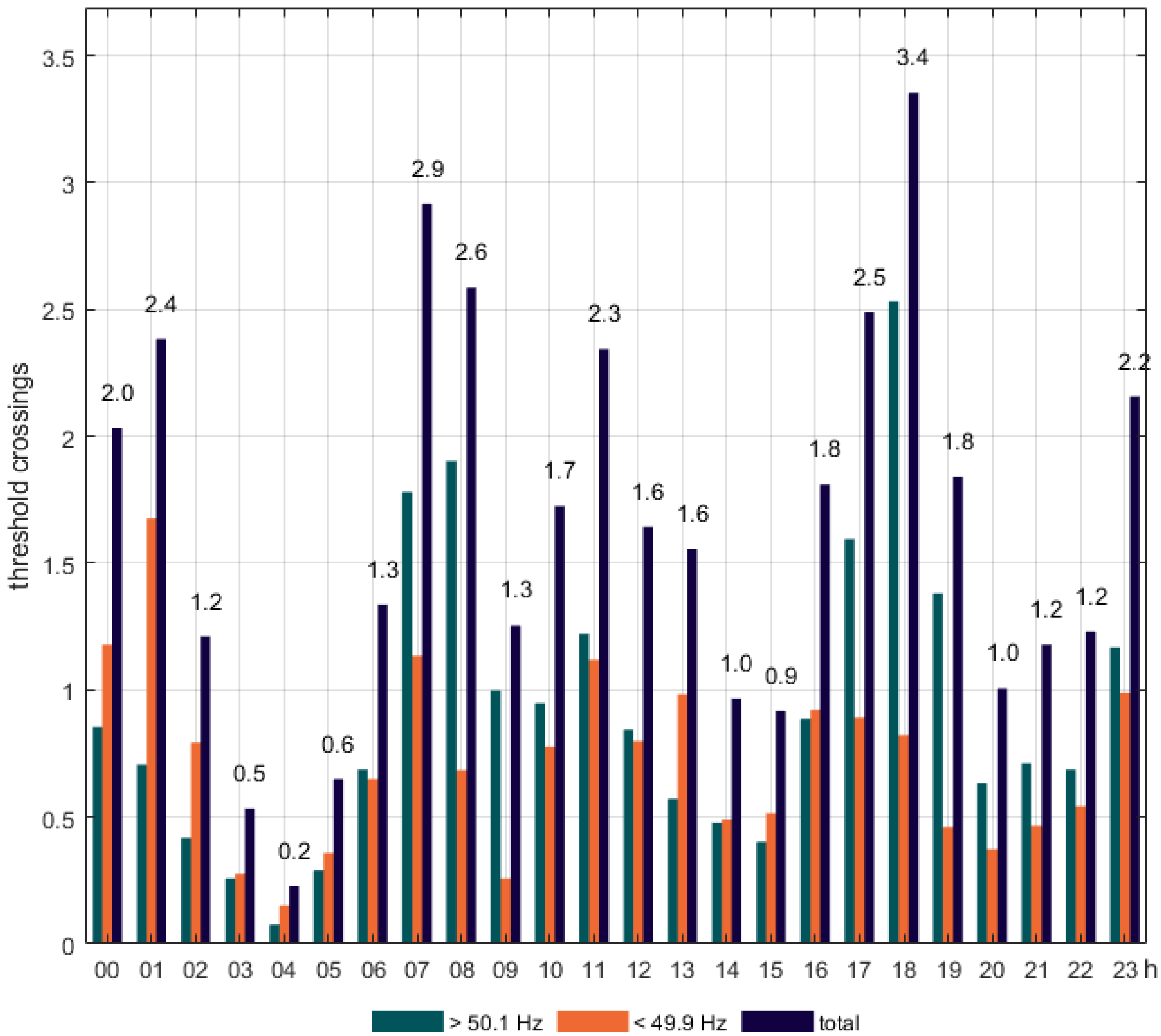
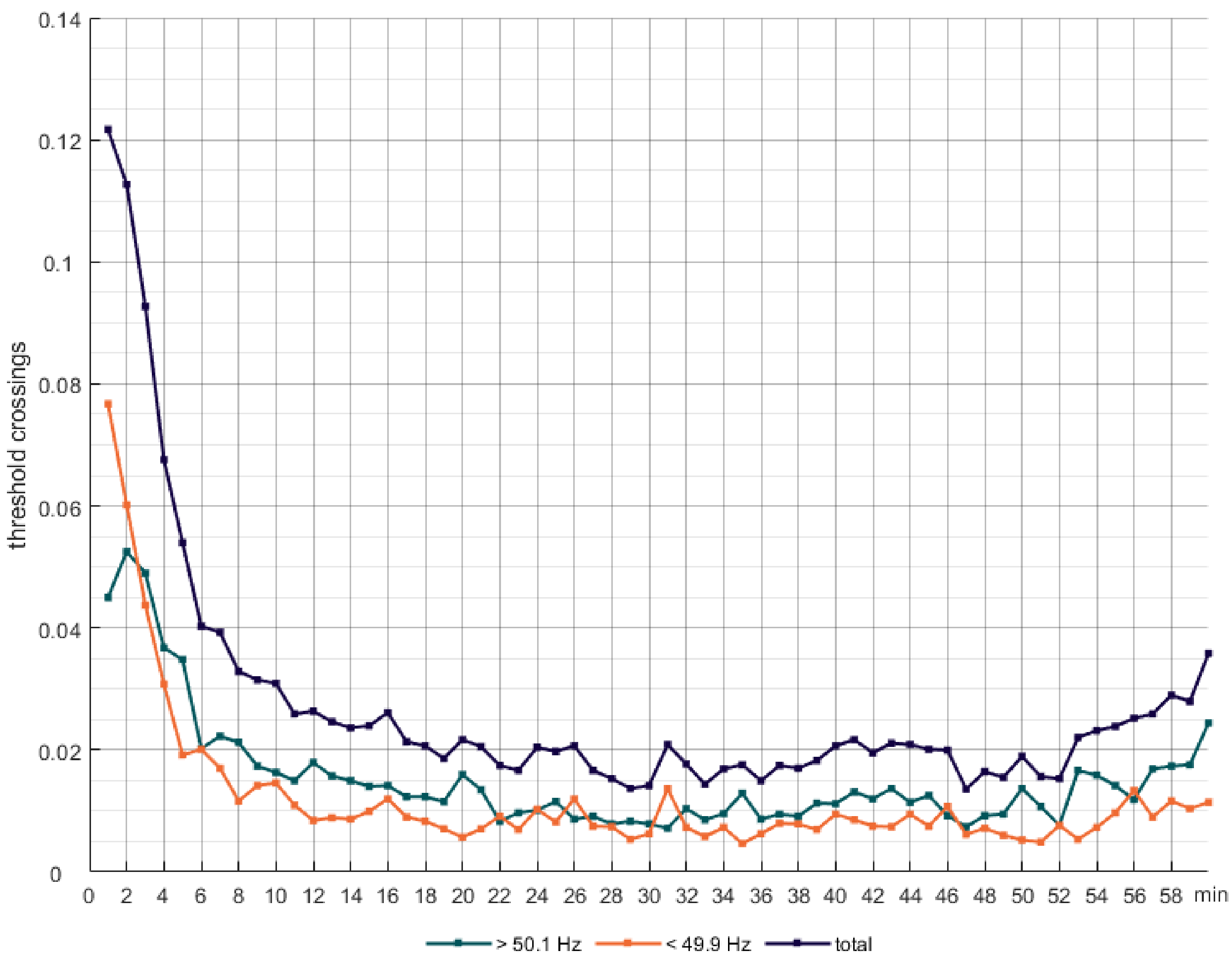


Figure 3.48 represents the average number of threshold crossings for every minute within the hour. Most crossings occurred in the first few minutes of the hour, while the lowest numbers were in the middle of the hour. Crossings above 50.1 Hz were generally more frequent than those below 49.9 Hz. The trend is broadly similar to 2024, although the number of crossings does not increase as clearly towards the end of the hour.

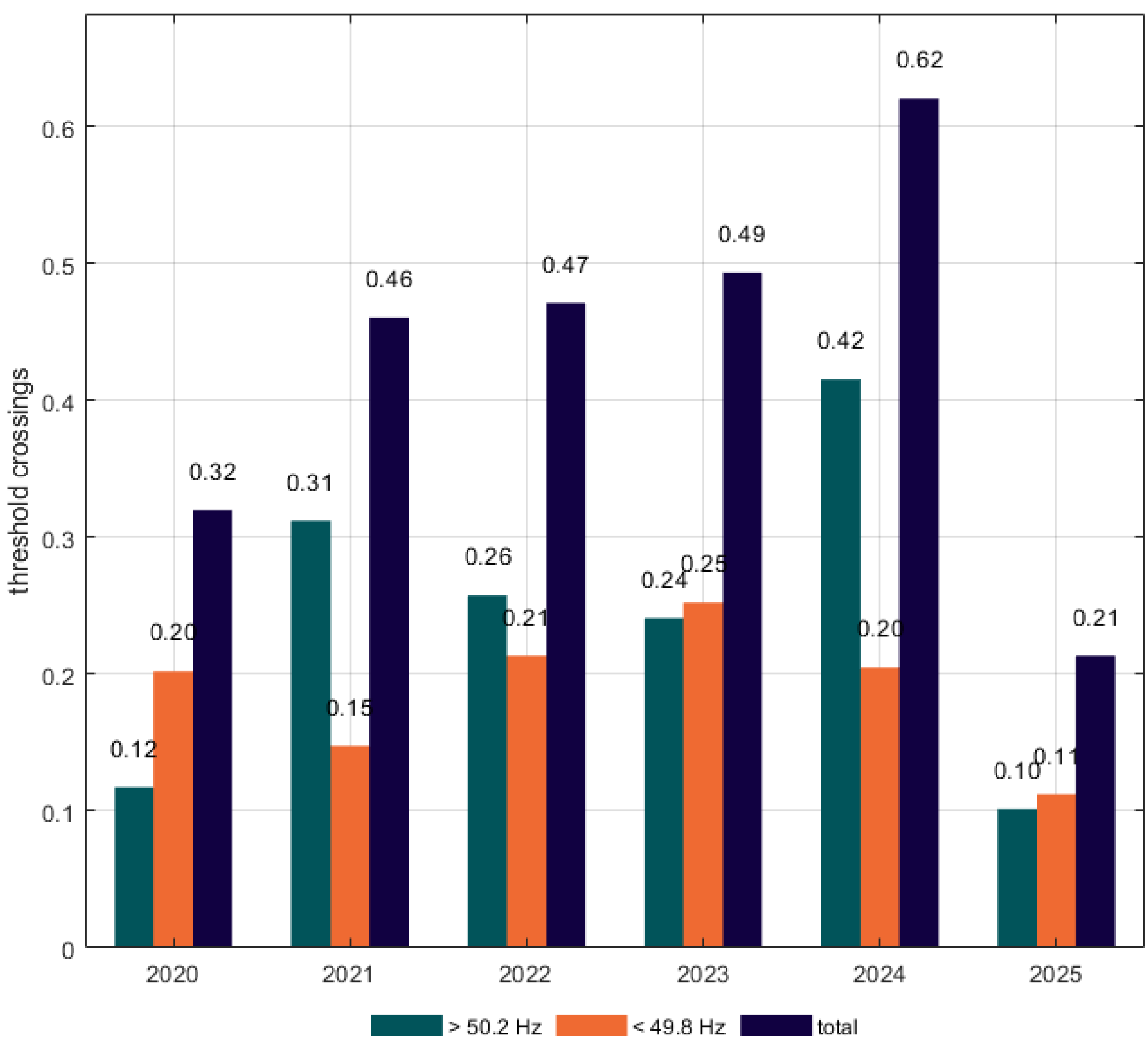
***Figure 3.48**. Average number of threshold crossings for every minute of the hour in 2025*



3.6.2 Number of 49.8-50.2 Hz crossings

Figure 3.49 represents the average number of threshold crossings per day that exceeded ±200 mHz. In 2025, the total number of crossings was less than half compared to the previous year and lower than in any of the previous years.

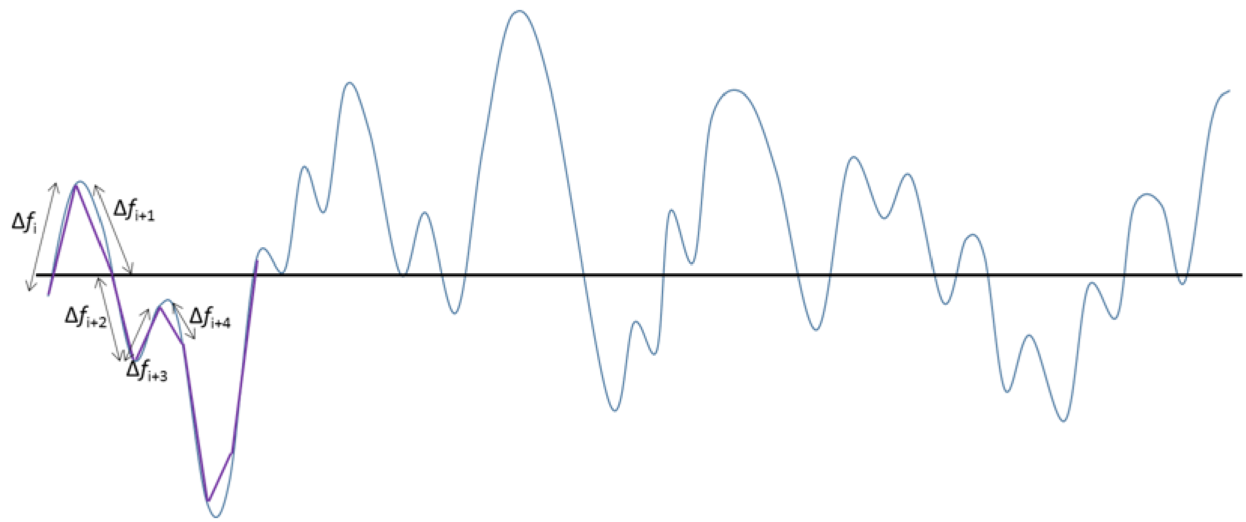
***Figure 3.49**. Daily average number of threshold crossings larger than ±200 mHz for years 2020-2025*



3.7 Length of frequency path

The length of the path that frequency takes shows how much the frequency travels around 50.0 Hz, as can be seen in Figure 3.50. The length of the path is calculated per time period, and the length of the time step is taken into account. The resolution of the frequency data used is 0.1 seconds. Under Figure 3.50 is the formula for frequency path, where Δt is the length of the time step (in this case, 0.1 s).

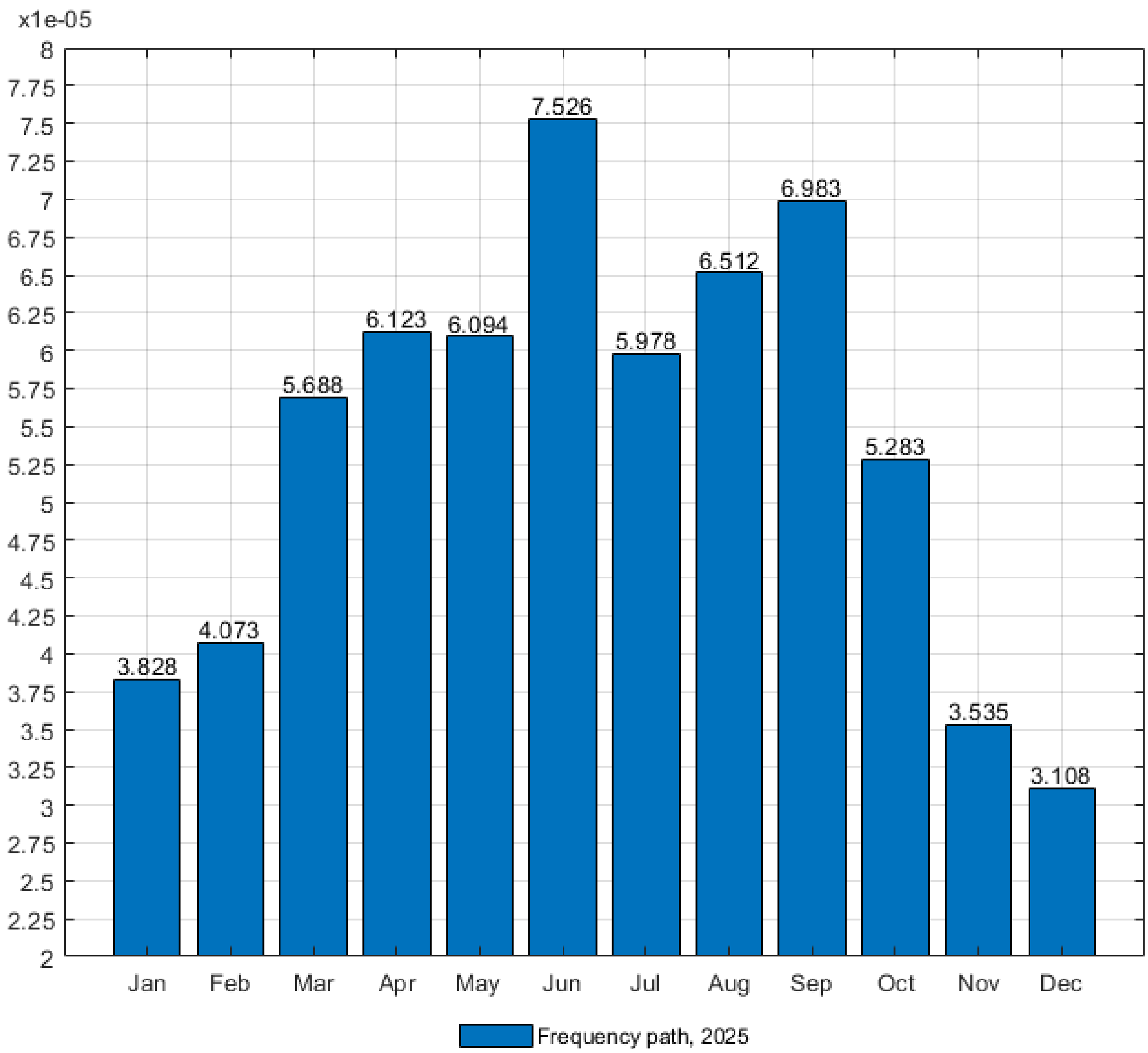
Figure 3.50. Frequency quality index: Length of the frequency path [7]



$$Frequency\ path = \left(\frac{\sum_i^n \sqrt{(f(i) - f(i-1))^2 + \Delta t^2}}{(n-1) * \Delta t}\right) - 1$$

Figure 3.51 represents the frequency path for each month in 2025. The highest values occurred in June, August, and September, while November and December had the lowest values. Compared to the previous year, the path length was higher in most months. The peak path length increased by roughly 9%. Compared to previous years, the frequency path was generally longer throughout the year, while the seasonal peak appears more distinct.

***Figure 3.51**. Length of the frequency path month by month in 2025*



The frequency path for each day of the week can be seen in Figure 3.52. There has been rather little variation in the frequency path length between the days. The frequency path length has been a little shorter towards the end of the week. The path was longest on average on Thursday. Once again, there is a clear increase compared to the previous year.

***Figure 3.52**. Length of the frequency path for every day of the week in 2025*

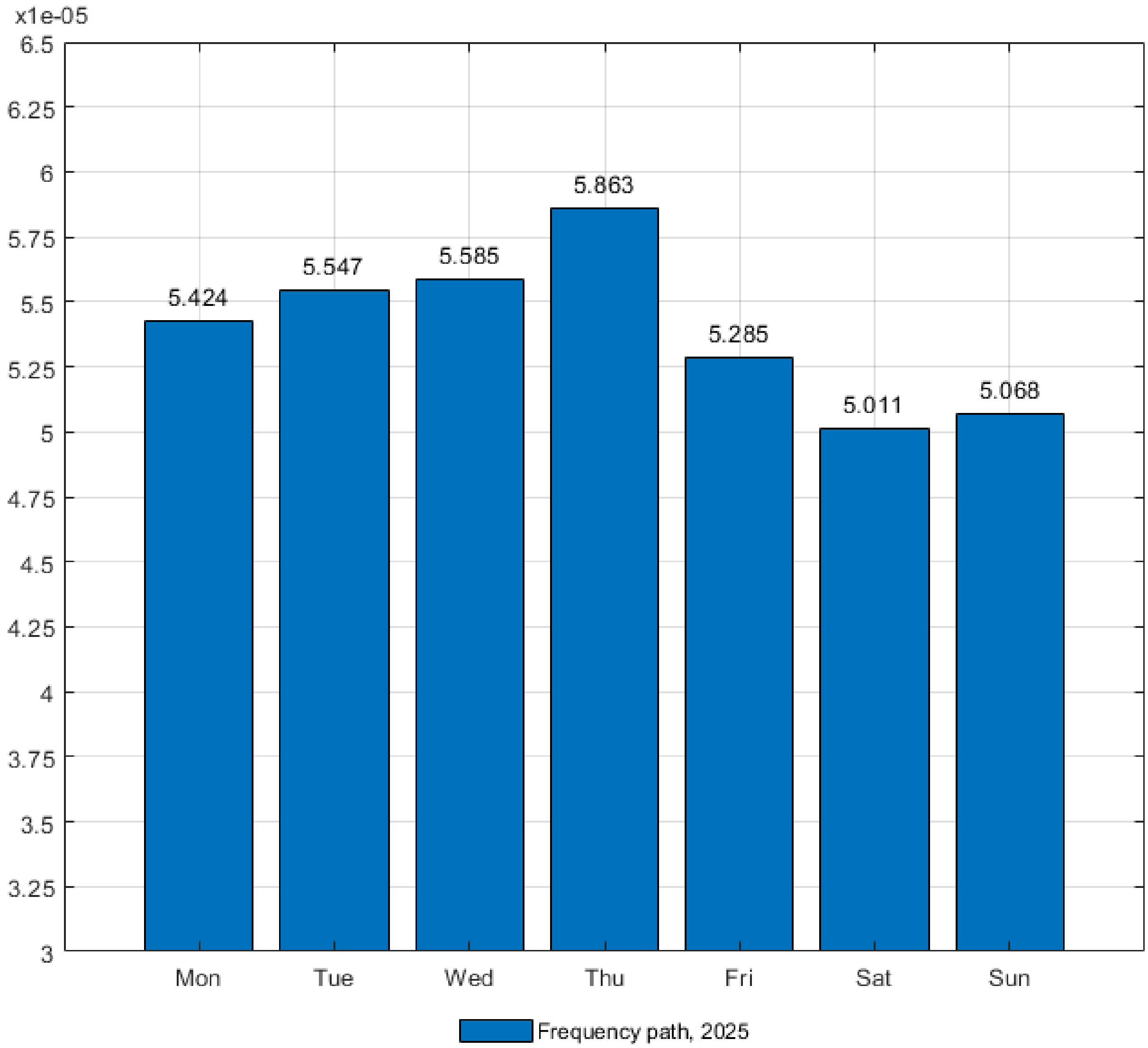


Figure 3.53 shows the frequency path for each hour within a day. The overall trend in 2025 is similar to 2024, although the values are generally higher. In particular, clear peaks can be seen around 1 am and 1 pm, which are higher than in the previous year. The lowest values occur between 8 am and 12 pm, following a similar pattern to 2024.

***Figure 3.53**. Length of the frequency path for every hour of the day in 2025*

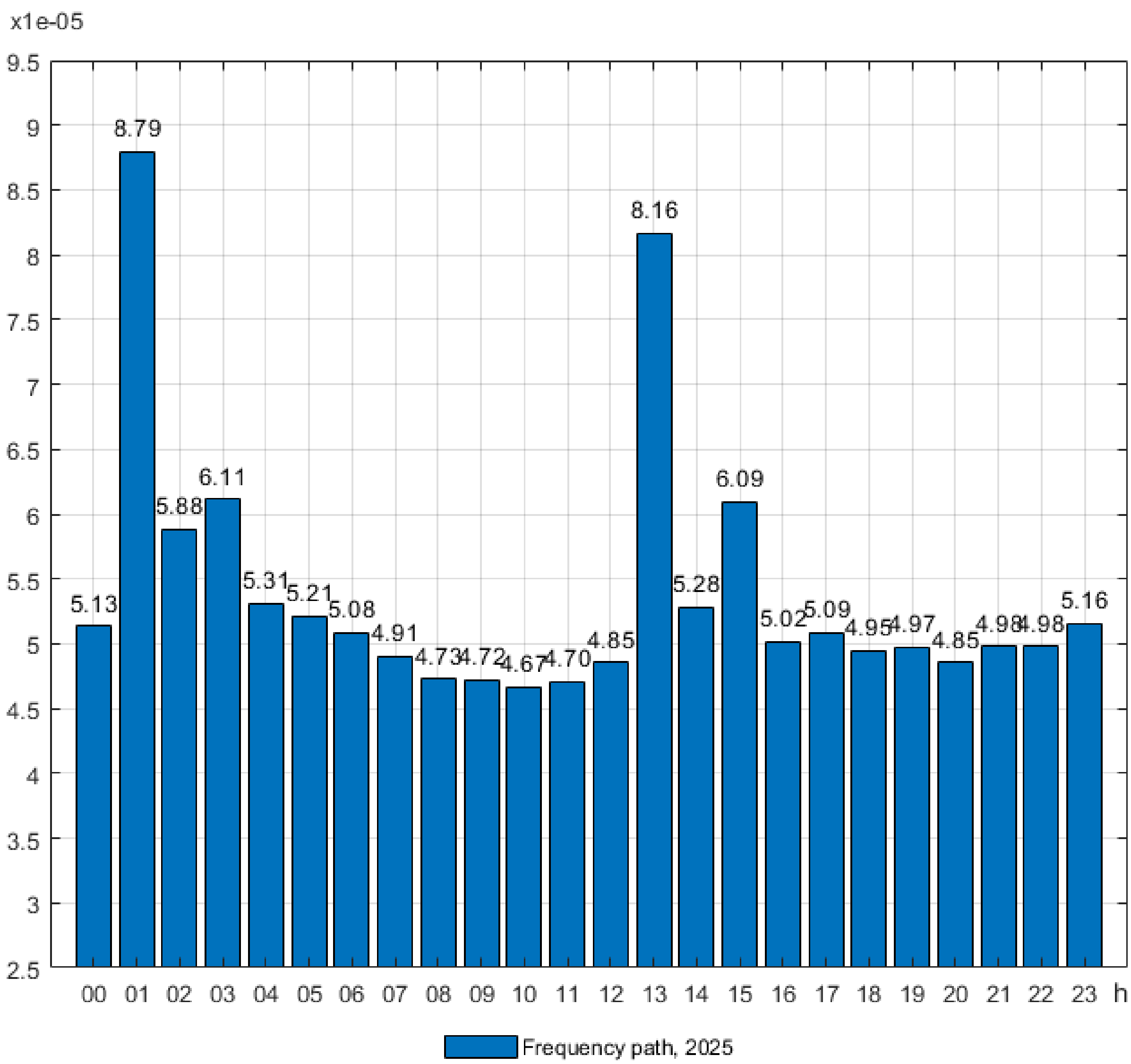
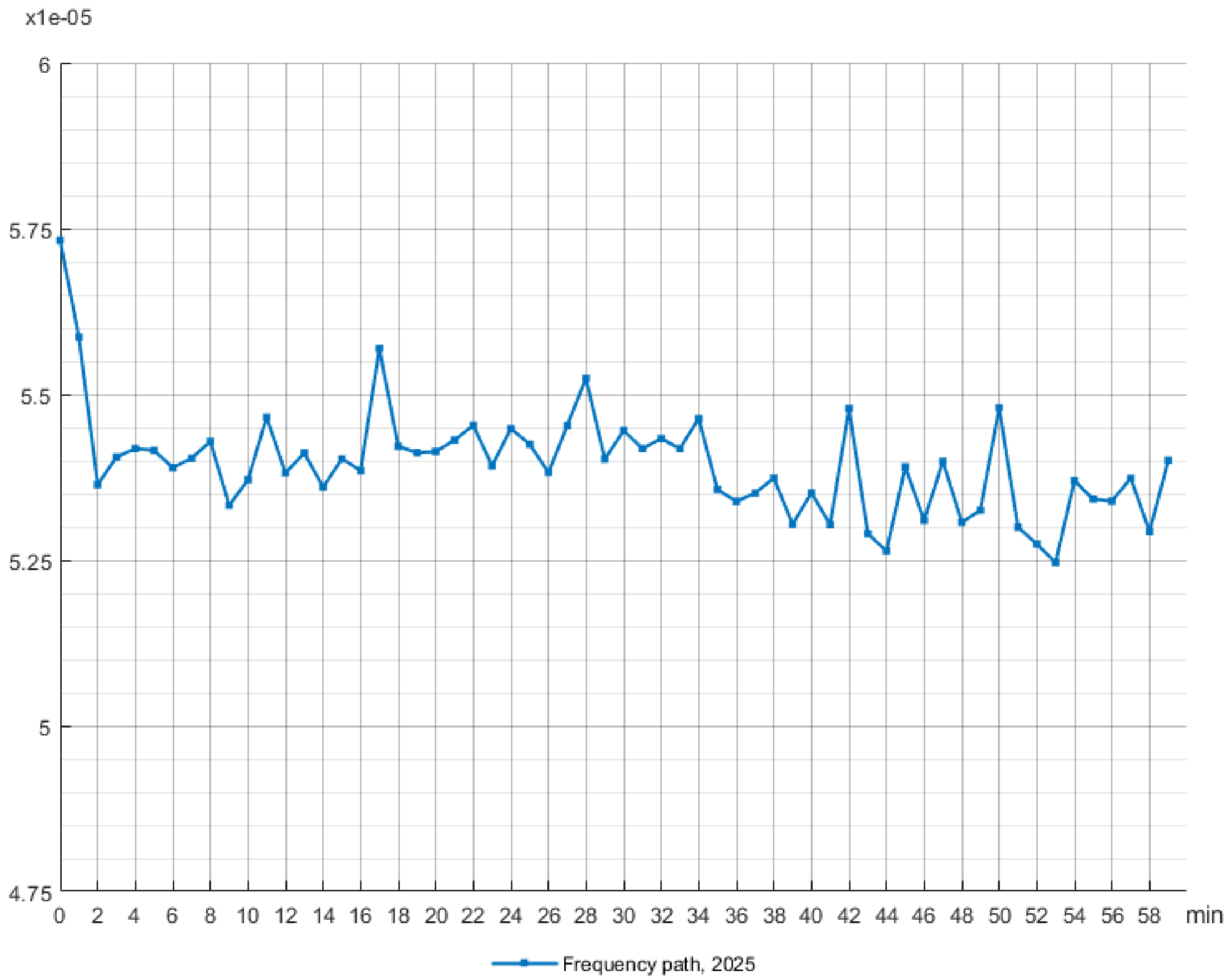


Figure 3.54 represents the average frequency path for every minute within an hour in 2025. The amount of variation in this graph has increased compared to previous years since 2020. The highest peak occurs at the beginning of the hour, within the first minute. The overall trend differs from the previous year, with lower values towards the end of the hour.

***Figure 3.54**. Length of the frequency path for every minute of the hour in 2025*



3.8 Amount of frequency oscillation

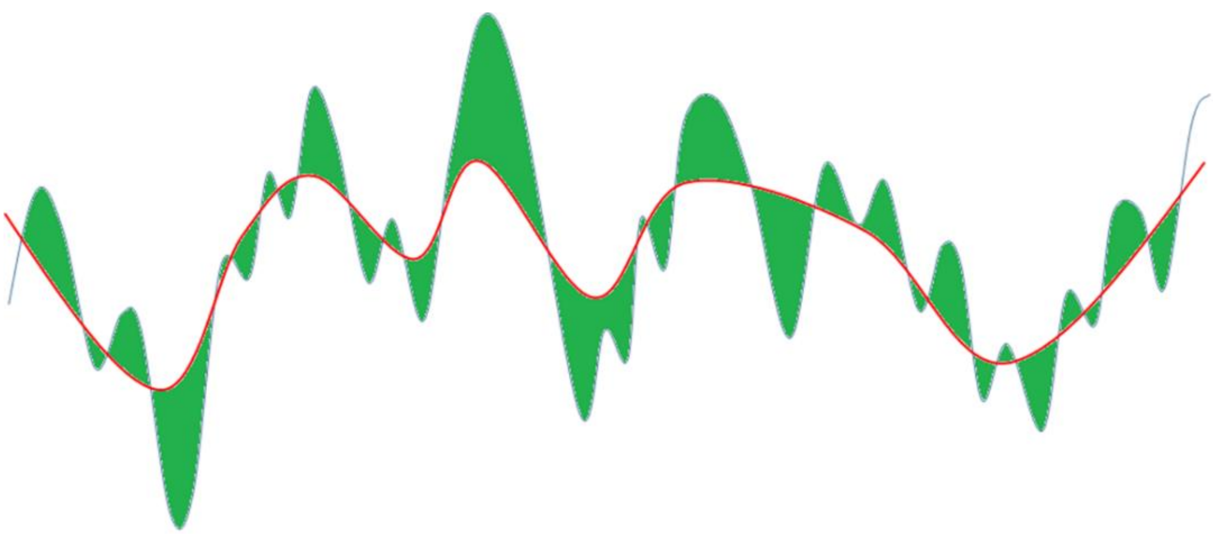
The frequency of the Nordic synchronous system oscillates constantly. The time period of the oscillation is approximately 40 to 90 seconds. This behavior is a natural characteristic of the system, but it can be influenced through adequate settings of system reserves. Oscillation has an increasing effect on time outside the standard frequency range. It also causes wear of reserve machines when controller settings are not optimal for the machine.

3.8.1 Methodology

The 60-second oscillation was studied using the Fourier transform, which can be used to decompose time series signals such as frequency measurements into sinusoidal frequency components. In other words, the sum of these sinusoidal components forms the original signal. Each of the frequency components has an amplitude and a phase. The amplitude of a certain frequency component represents the amount of sinusoidal oscillation at that frequency. It is possible to modify the signal in the frequency domain and then construct a time domain representation of the modified signal. [8]

The method used is such that the desired frequency band is filtered from the frequency data in order to estimate what the frequency would look like without the oscillation. It is possible to filter desired frequency components only partially or entirely remove them. In this study, as well as in reports from previous years [2, 3, 4, 5, 6], the frequency components were removed. The area between the filtered frequency signal and the original signal is used to represent the amount of oscillation. The approach is shown in Figure 3.57.

***Figure 3.55**. Frequency quality index: Amount of frequency oscillation [7]*



The filtering band used in all studies was 30-240 s. Choice is based on a comparison between different bands in the oscillation analysis for years 2011 and 2012 [8]. The frequency spectrum calculated from a sample containing the first 20 minutes of December 2012 is shown in Figure 3.56. Frequency bands corresponding to the 40-90 s and 30-240 s bands are marked on the figure. Figure 3.57 is an estimation of the frequency when these bands are filtered. In the studies, the Fourier transform was calculated for time intervals of one hour. The actual used band is 30-225 s, and due to the nature of FFT, it might vary slightly depending on the length of the data sample.

For the FFT-filtering calculation, there were two requirements for the data: there had to be at least 90% of eligible data for each hour, and the measurement frequency had to stay at least at 4 Hz. If these requirements were not fulfilled, the hour was skipped and removed from the calculations.

Figure 3.56. Frequency spectrum representing the first 20 minutes of December 2012 (UTC+2). The green line corresponds to the 40-90 s band, and the red line corresponds to the 30-240 s band. [8]

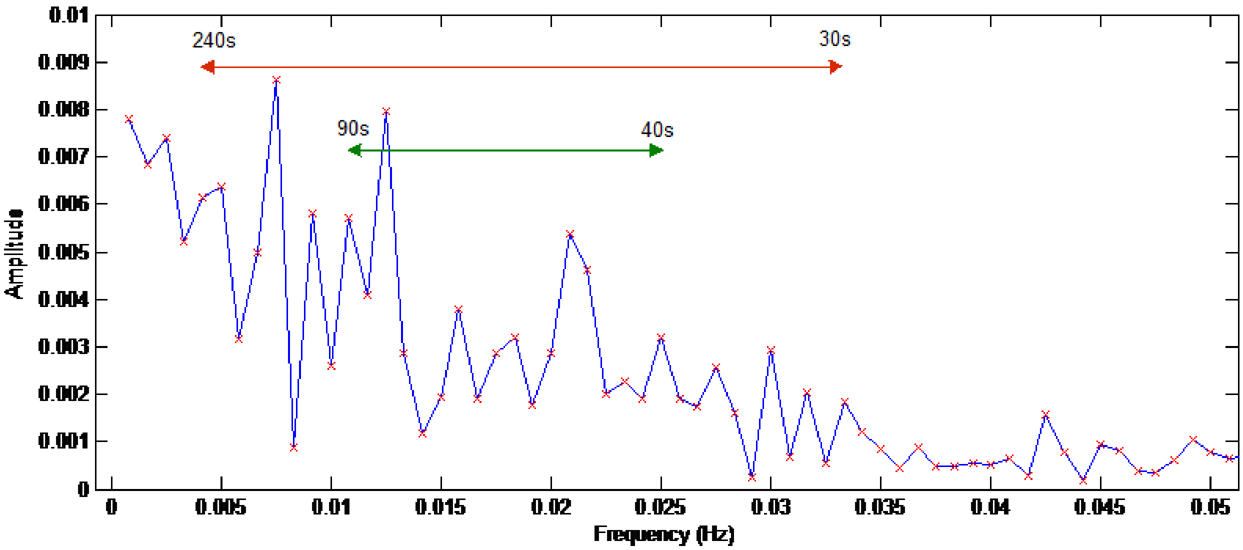
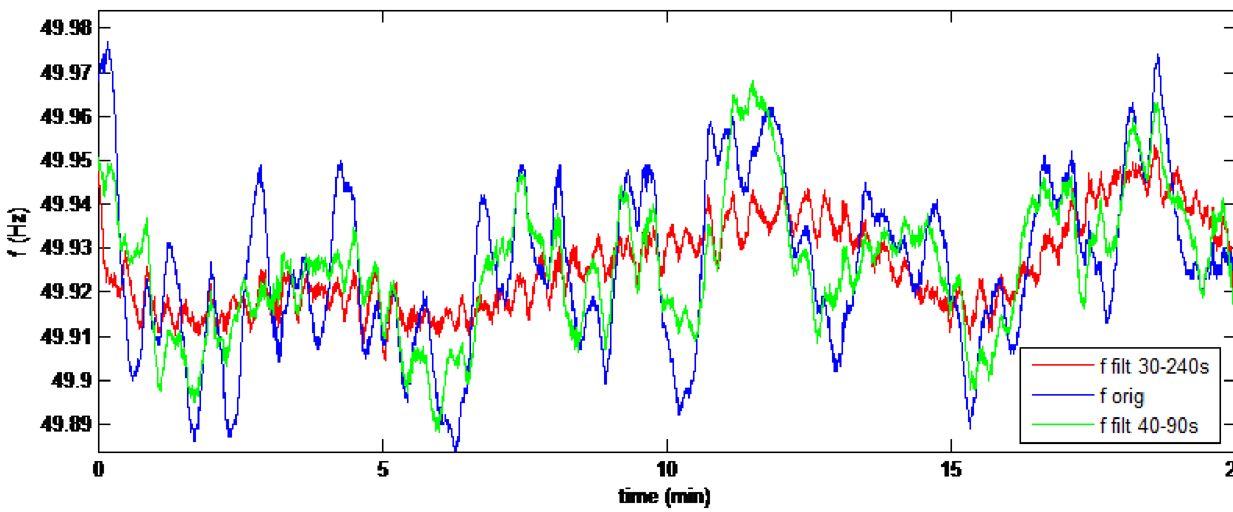


Figure 3.57. Original frequency (blue), frequency with 40-90 s band filtered (green), and frequency with 30-240 s band filtered (red). The first 20 minutes of December 2012 are shown (UTC+2). [8]



3.8.2 Amount of oscillation

Figure 3.58 shows hourly values and 24-hour moving averages for the amount of oscillation in 2025. The 24-hour moving averages were calculated if there was enough eligible data for at least 12 hours in the 24-hour frame. Gaps in the following curves indicate that there was not enough eligible data for the calculations.

The 24-hour moving average reached its highest values in May and November. The lowest values occurred at the beginning and end of the year, similar to 2024. However, unlike the previous year, low values were also recorded in July. Overall, the level of oscillation has decreased notably compared to 2024. In addition, the mid-year increase in oscillation was smaller in 2025, while previous years showed a clearer rise around the middle of the year. Figures 3.59 and 3.60 present the previously mentioned 24-hour moving averages for the periods 2020–2022 and 2023–2025, respectively.

Figure 3.58. Amount of oscillation in 2025

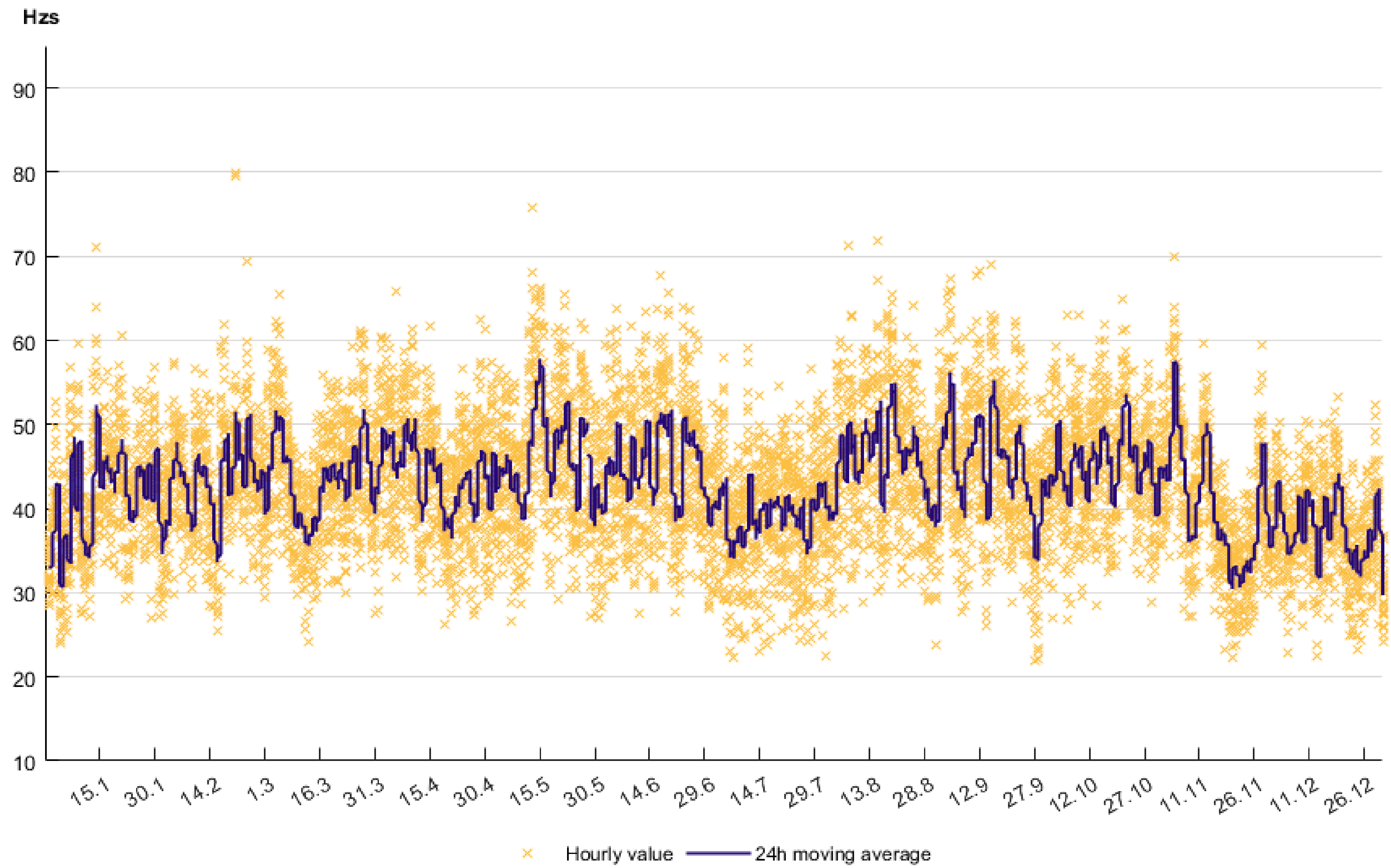


Figure 3.59. Amount of oscillation in 2020-2022

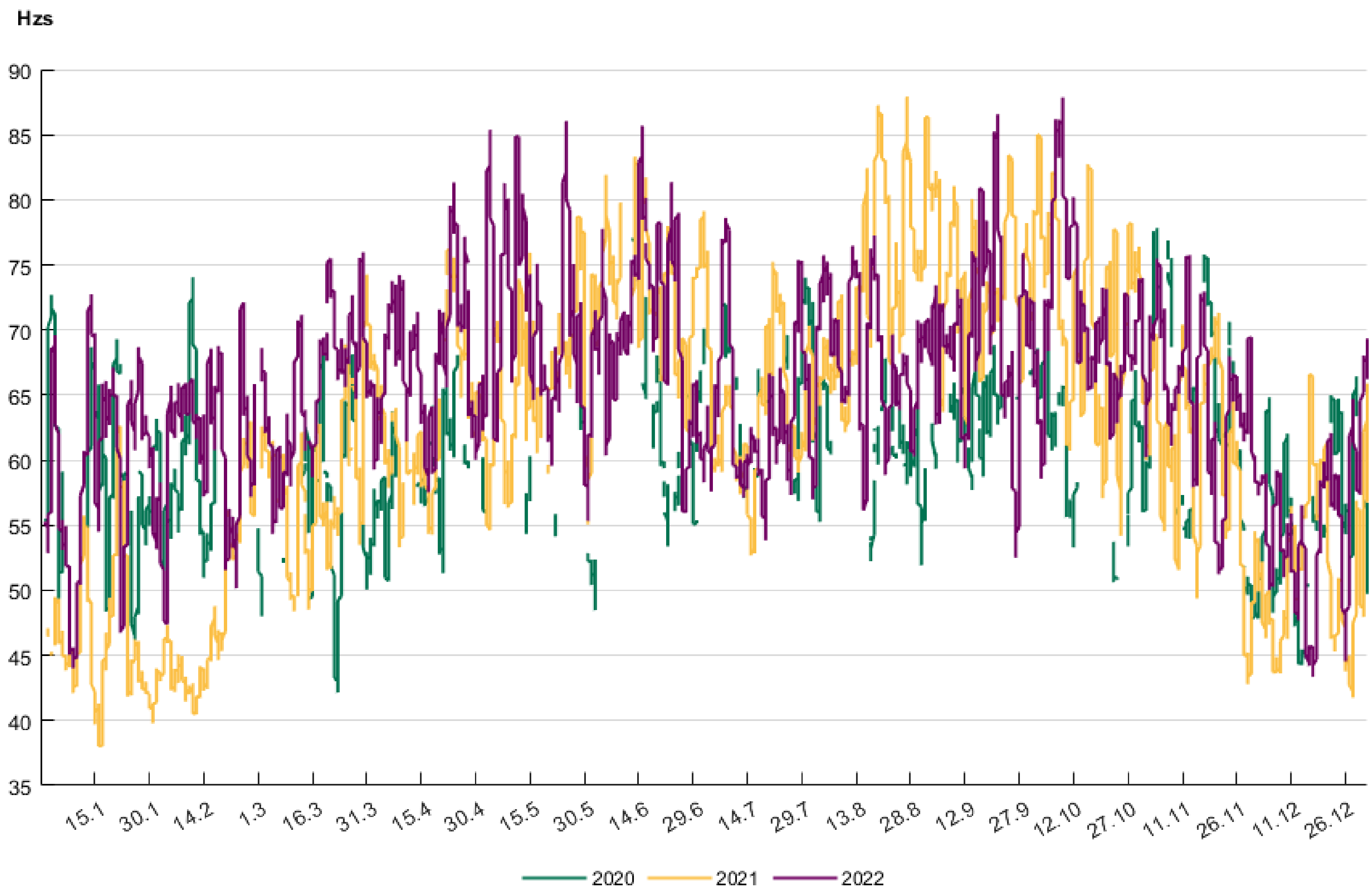
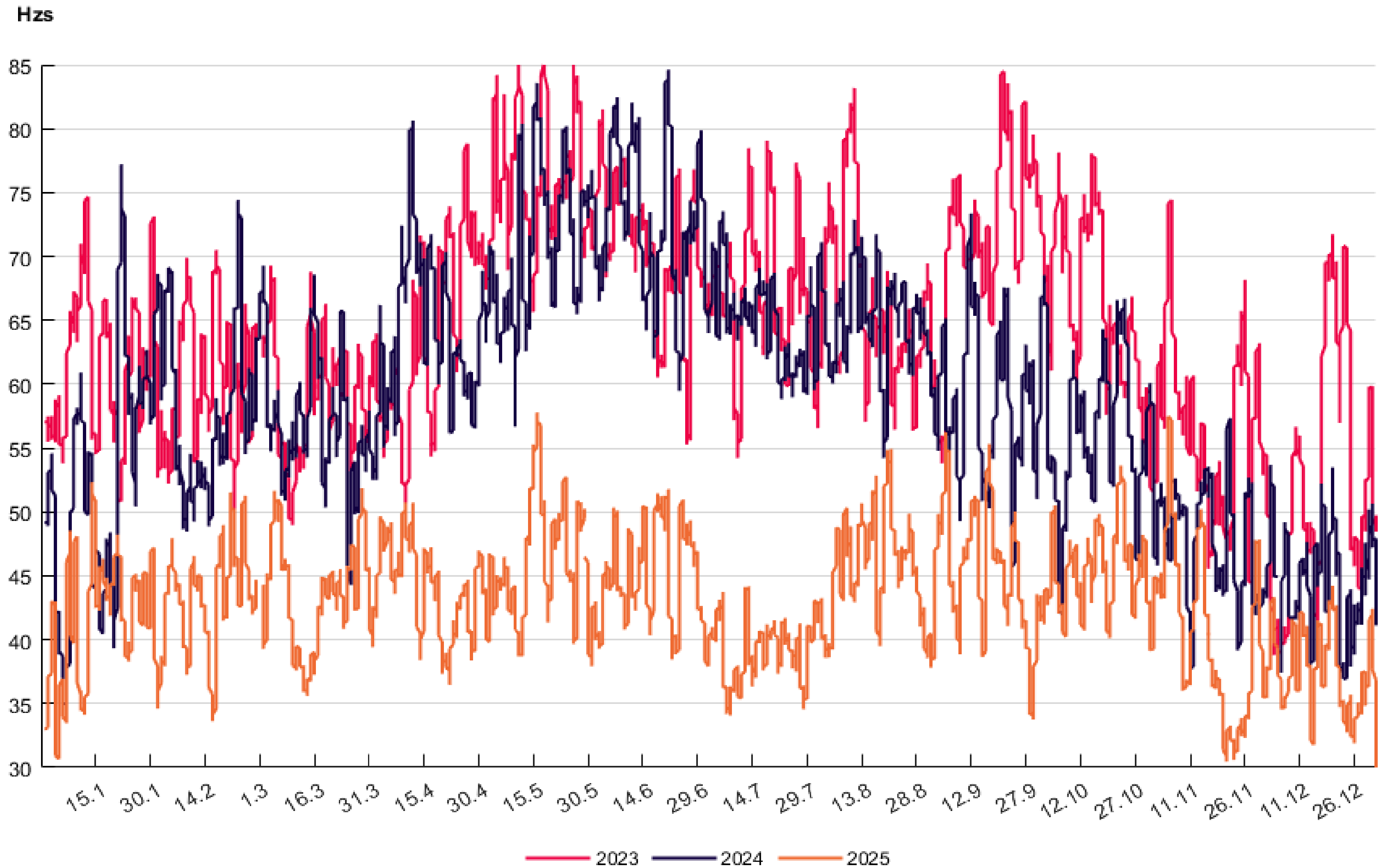


Figure 3.60. Amount of oscillation in 2023-2025



The mean value and standard deviation of the oscillation for each month from 2020 to 2025 are shown in Tables 3.22 and 3.23. Figure 3.61 represents the same information in a visual form. The frequency oscillated the most in May and from August to October. Both the mean value and standard deviation are lower than in the previous years within the observation period.

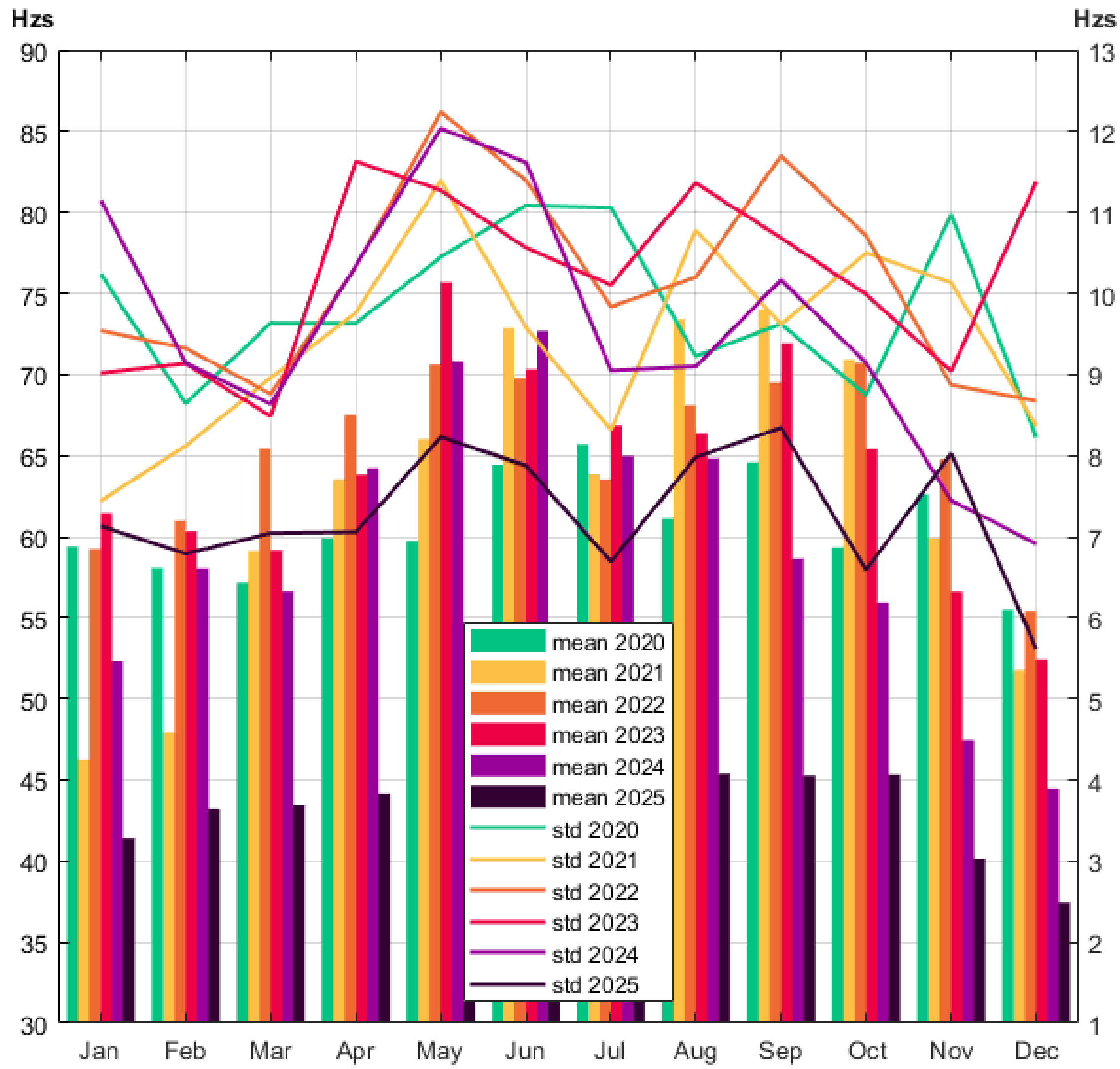
***Table 3.22**. Mean values and standard deviations for oscillation in years 2020-2022*

	Mean value (Hzs)			**Standard deviation (Hzs)**		
Month	**2020**	**2021**	**2022**	**2020**	**2021**	**2022**
January	59.4	46.2	59.2	10.2	7.4	9.5
February	58.1	47.9	61.0	8.6	8.1	9.3
March	57.2	59.1	65.4	9.6	9.0	8.8
April	59.9	63.5	67.5	9.6	9.8	10.3
May	59.7	66.0	70.6	10.4	11.4	12.2
June	64.4	72.9	69.8	11.1	9.6	11.4
July	65.7	63.9	63.5	11.1	8.3	9.8
August	61.1	73.4	68.1	9.2	10.8	10.2
September	64.6	74.0	69.5	9.6	9.6	11.7
October	59.3	70.9	70.7	8.7	10.5	10.7
November	62.6	59.9	64.8	11.0	10.1	8.9
December	55.5	51.8	55.4	8.2	8.4	8.7
Entire year	**60.6**	**62.5**	**65.5**	**9.8**	**9.4**	**10.1**

Table 3.23. Mean values and standard deviations for oscillation in years 2023-2025

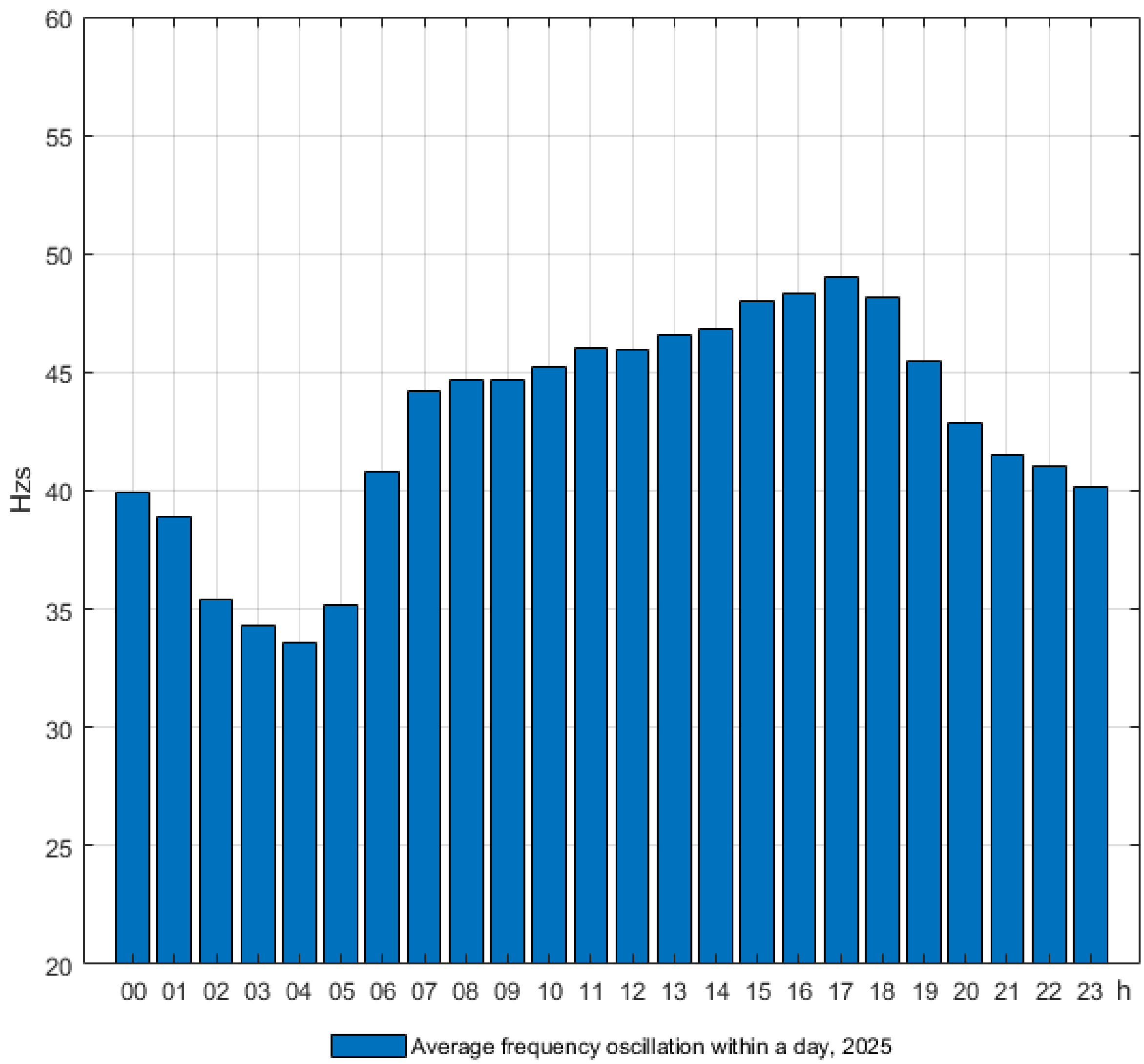
	Mean value (Hzs)			**Standard deviation (Hzs)**		
Month	**2023**	**2024**	**2025**	**2023**	**2024**	**2025**
January	61.4	52.3	41.4	9.0	11.1	7.1
February	60.3	58.1	43.2	9.1	9.1	6.8
March	59.2	56.6	43.4	8.5	8.6	7.0
April	63.8	64.2	44.1	11.6	10.3	7.1
May	75.7	70.8	45.5	11.3	12.0	8.2
June	70.3	72.7	45.2	10.6	11.6	7.9
July	66.9	65.0	39.3	10.1	9.0	6.7
August	66.4	64.8	45.4	11.4	9.1	8.0
September	71.9	58.6	45.3	10.7	10.2	8.3
October	65.4	55.9	45.3	10.0	9.1	6.6
November	56.6	47.5	40.1	9.0	7.4	8.0
December	52.4	44.5	37.4	11.4	6.9	5.6
Entire year	**64.2**	**59.2**	**43.0**	**10.2**	**9.6**	**7.3**

***Figure 3.61**. Mean values (left y-axis) and standard deviations (right y-axis) for oscillation in years 2020-2025*



The average oscillation within a day in 2025 is shown in Figure 3.62. Oscillation peaks in the afternoon, with the highest values between 3 pm and 6 pm. The lowest values occur at night, from 1 am to 5 am. The overall trend is very similar to previous years.

Figure 3.62. Average frequency oscillation within a day in 2025

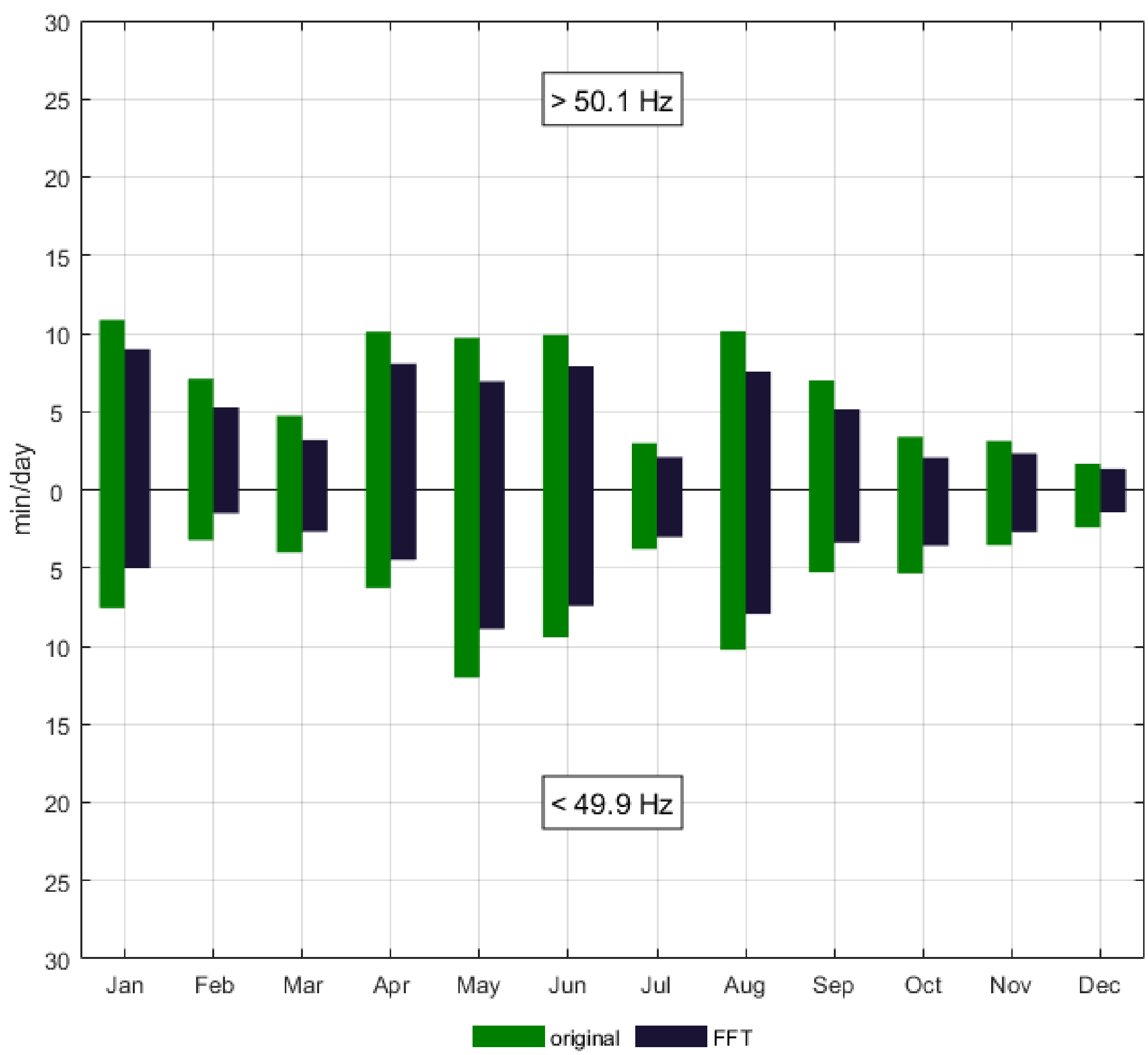


3.8.3 Influence of oscillation on frequency variations

The aim of this section is to analyze to what extent the deviations from the standard frequency range have been caused by the 60 second oscillation of the frequency.

Figure 3.63 shows the average minutes per day outside the standard frequency range in 2025 without filtering and after applying FFT-filtering. Only the parts that had enough consecutive samples for the FFT-algorithm within one hour, are taken into account.

***Figure 3.63**. Average time per day outside the standard frequency range in 2025*



In Figure 3.64, the reduction of time outside the standard frequency range in 2025 through filtering is presented as percentages of the original values. The results show that filtering leads to a significant reduction in time outside the standard frequency range. The reduction is largest in February and October and smallest in June. The values are notably lower compared to 2024.

***Figure 3.64**. Reduction in time per month outside the standard frequency range after filtering in 2025*

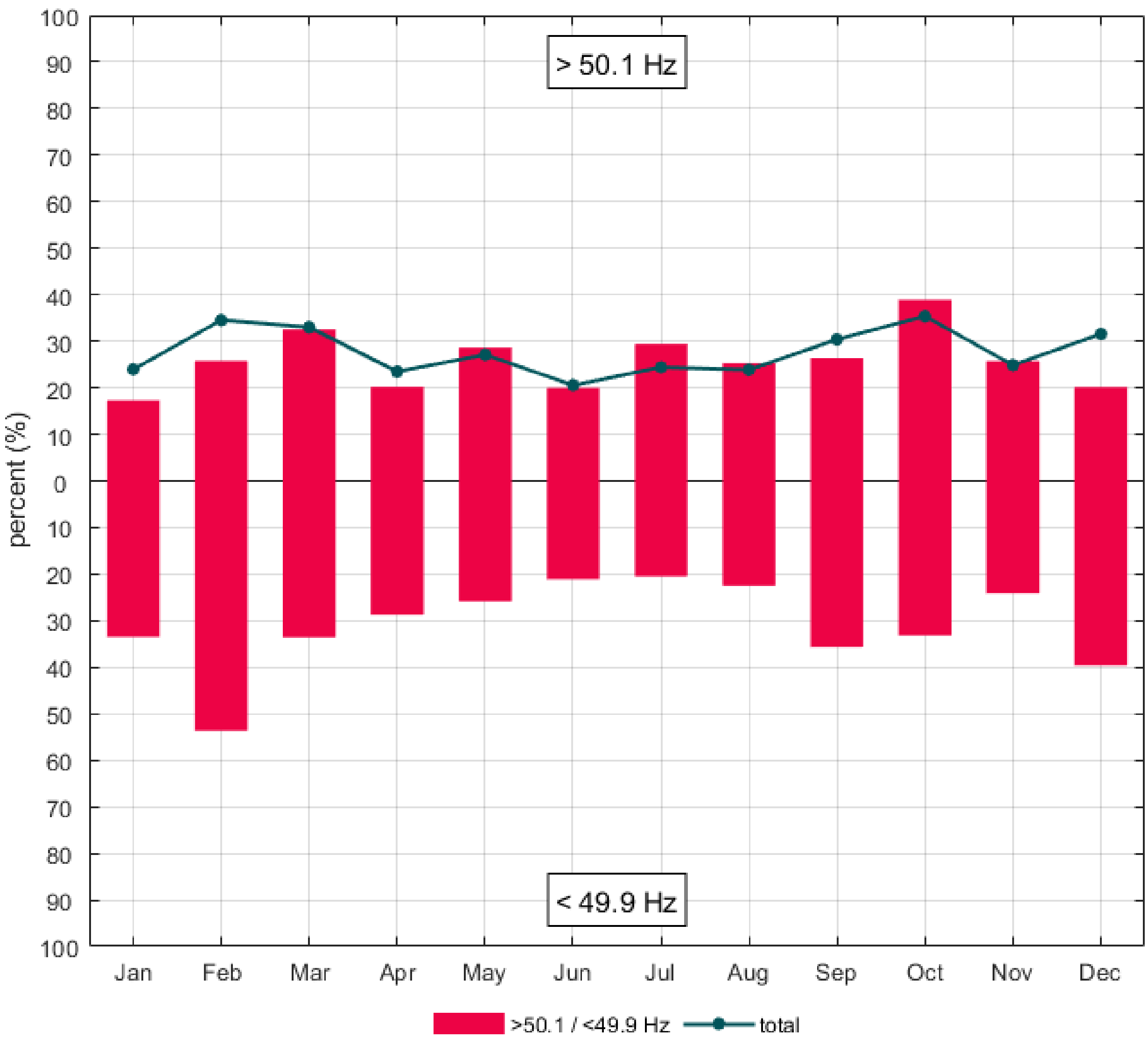
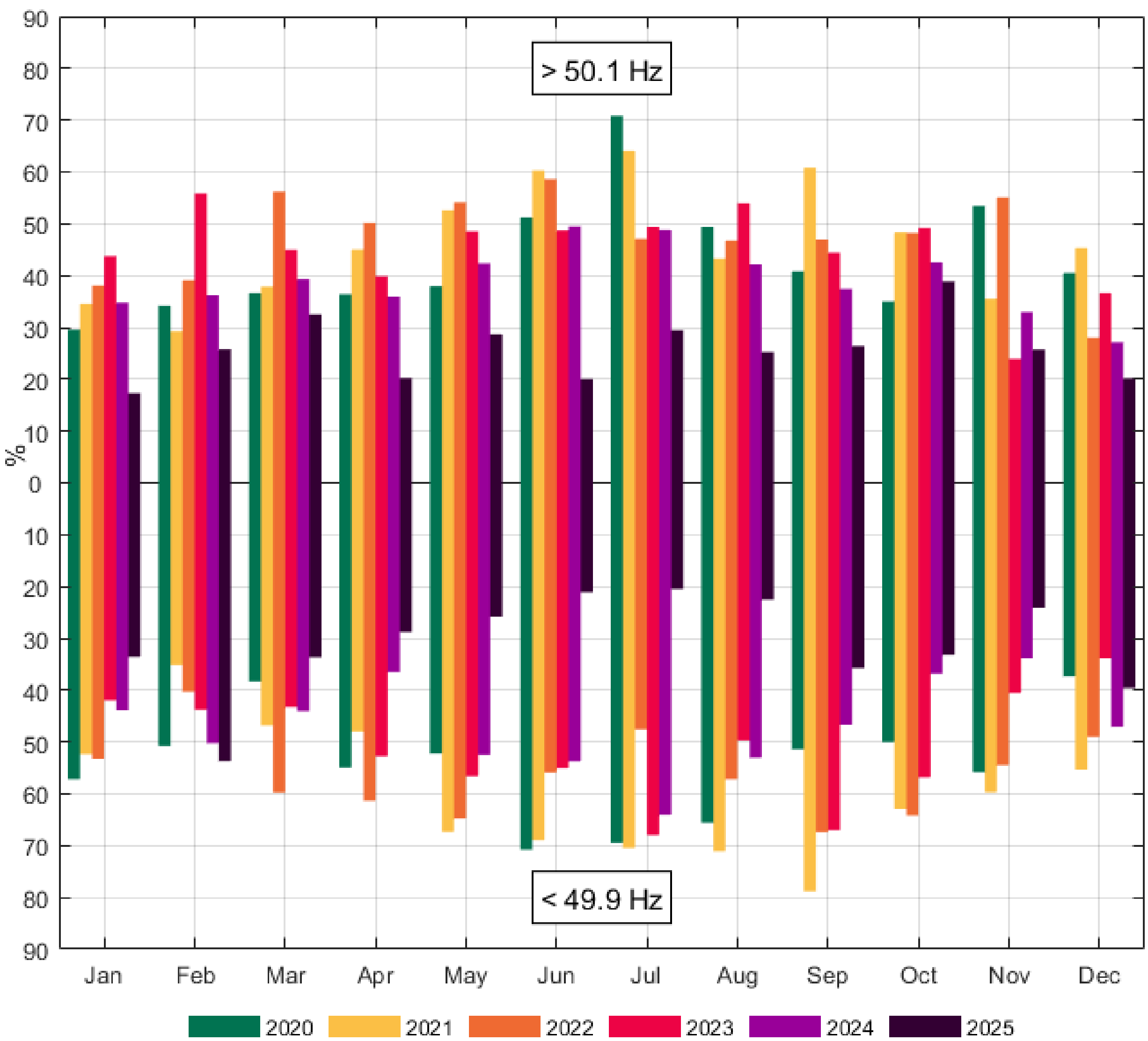


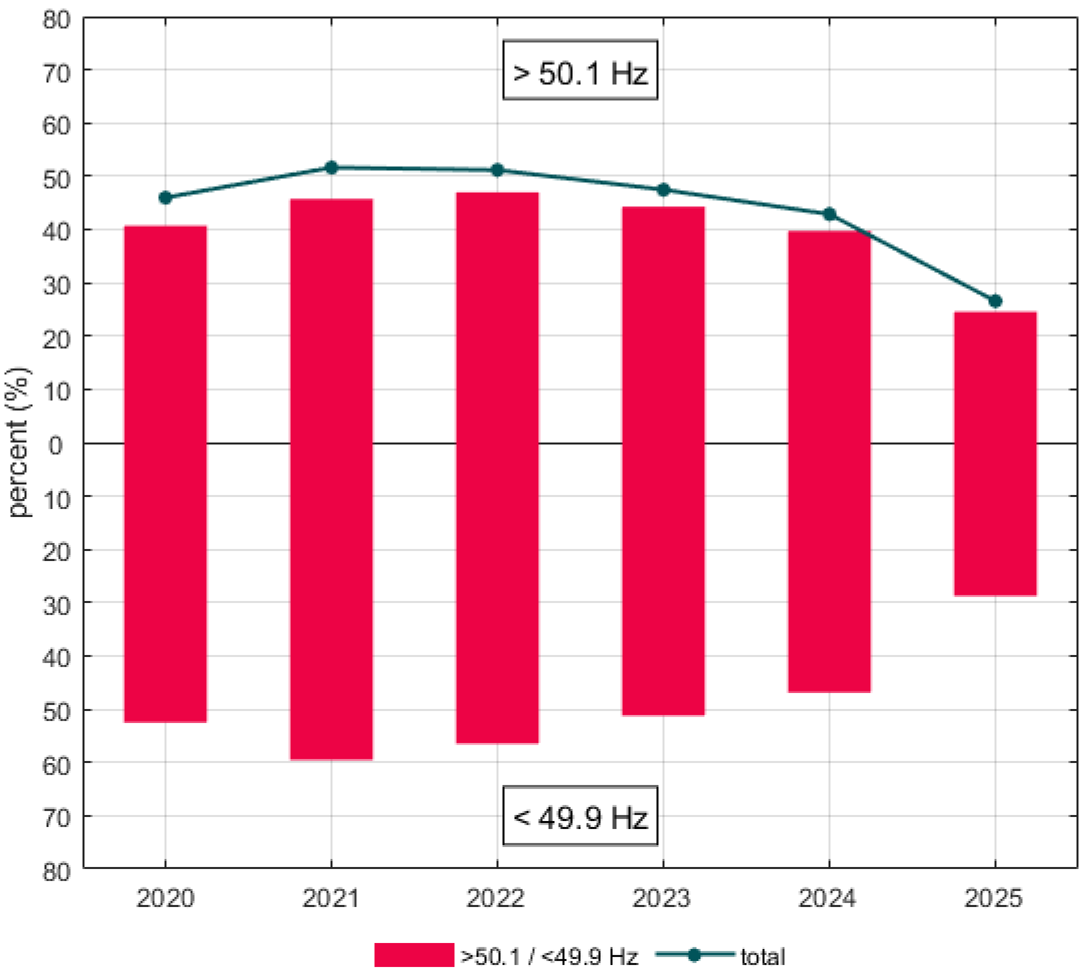
Figure 3.65 represents the reduction in time outside the standard frequency range in percentages month by month for years 2020 to 2025.

***Figure 3.65**. Reduction in time per month outside the standard frequency range after filtering in years 2020-2025*



In addition to the monthly values presented in the previous figure, results for the entire year in 2020-2025 are shown below in Figure 3.66. Filtering the oscillation reduces the duration of frequency deviations by slightly less than 30% in 2025. A slight yearly growth in reduction can be seen from 2020 up to 2022, after which the values decrease from 2022 to 2025. The time below 49.9 Hz is affected more by oscillation, as the reduction values are higher for under-frequency deviations.

***Figure 3.66**. Reduction in time outside the standard frequency range after filtering for years 2020-2025*



3.9 Frequency step around the hour shift

The frequency step around the hour shift is defined by the difference between the highest and lowest frequency during the period from 5 minutes before to 5 minutes after the hour shift. A negative sign is added if the highest frequency takes place before the lowest frequency. The frequency step is calculated for every hour shift in 2025. Of the total samples in a period, the 1st, 5th, 10th, 50th, 90th, 95th, and 99th percentiles are determined. Figure 3.67 shows the definition of deterministic frequency deviation. The resolution of the frequency data was 1 second.

Figure 3.67. Definition of deterministic frequency deviation [7]

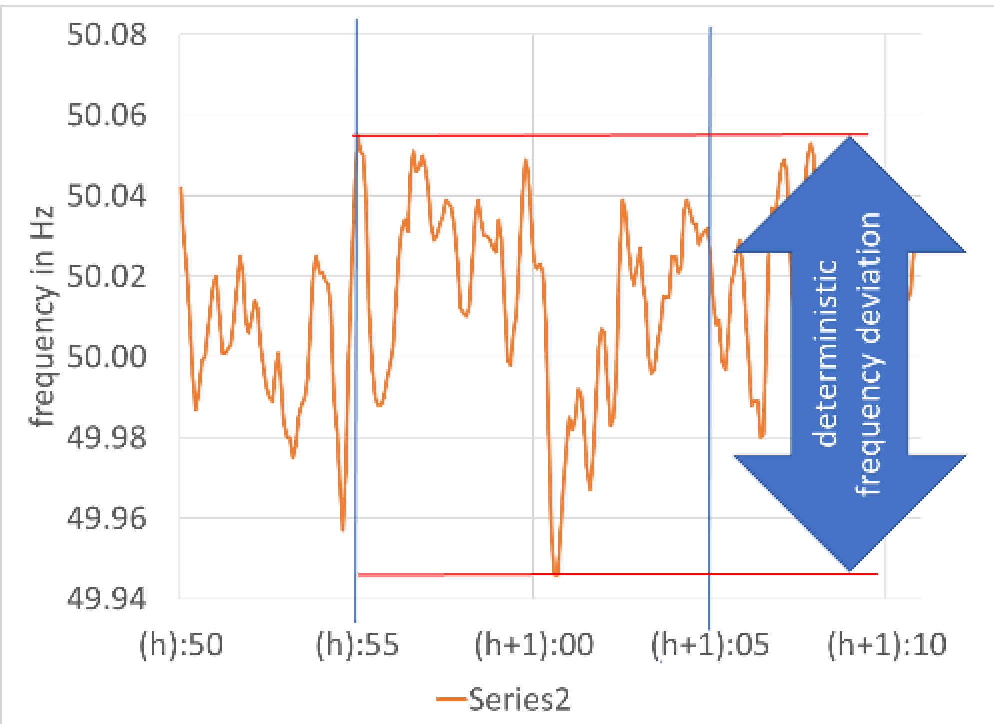


Figure 3.68 represents the deterministic frequency deviation per month in 2025. The 50th percentile remains below zero throughout the year, indicating that the highest frequency occurred before the lowest in more than half of the hour shifts. The percentiles are furthest from zero from April to June and again in August. In July, a clear peak towards zero appears, which was not as evident in 2024. Overall, the results are similar to the previous year, although the percentiles are generally closer to zero.

***Figure 3.68**. The 1st, 5th, 10th, 50th, 90th, 95th, and 99th percentiles of deterministic frequency deviation for every month in 2025*

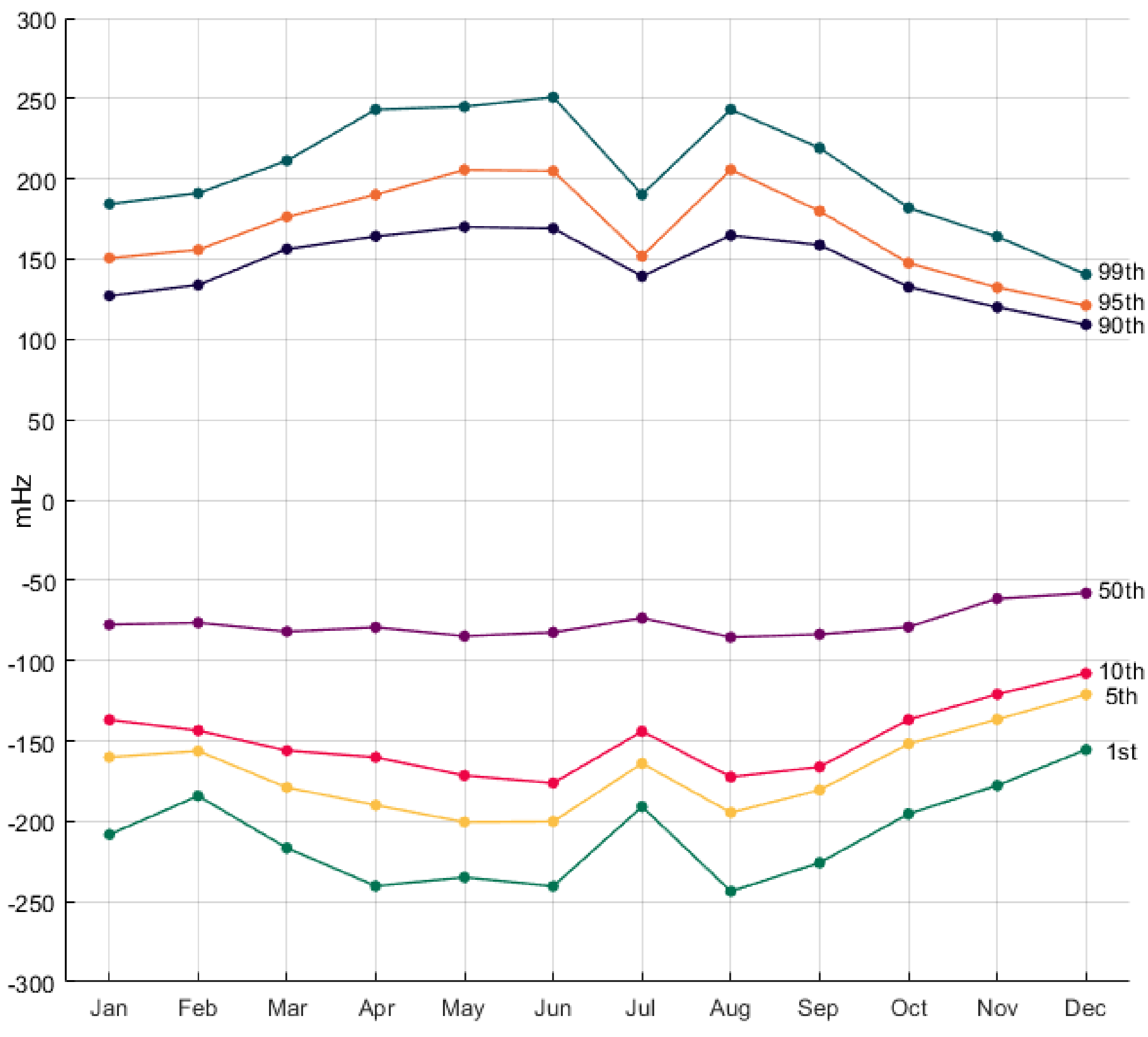
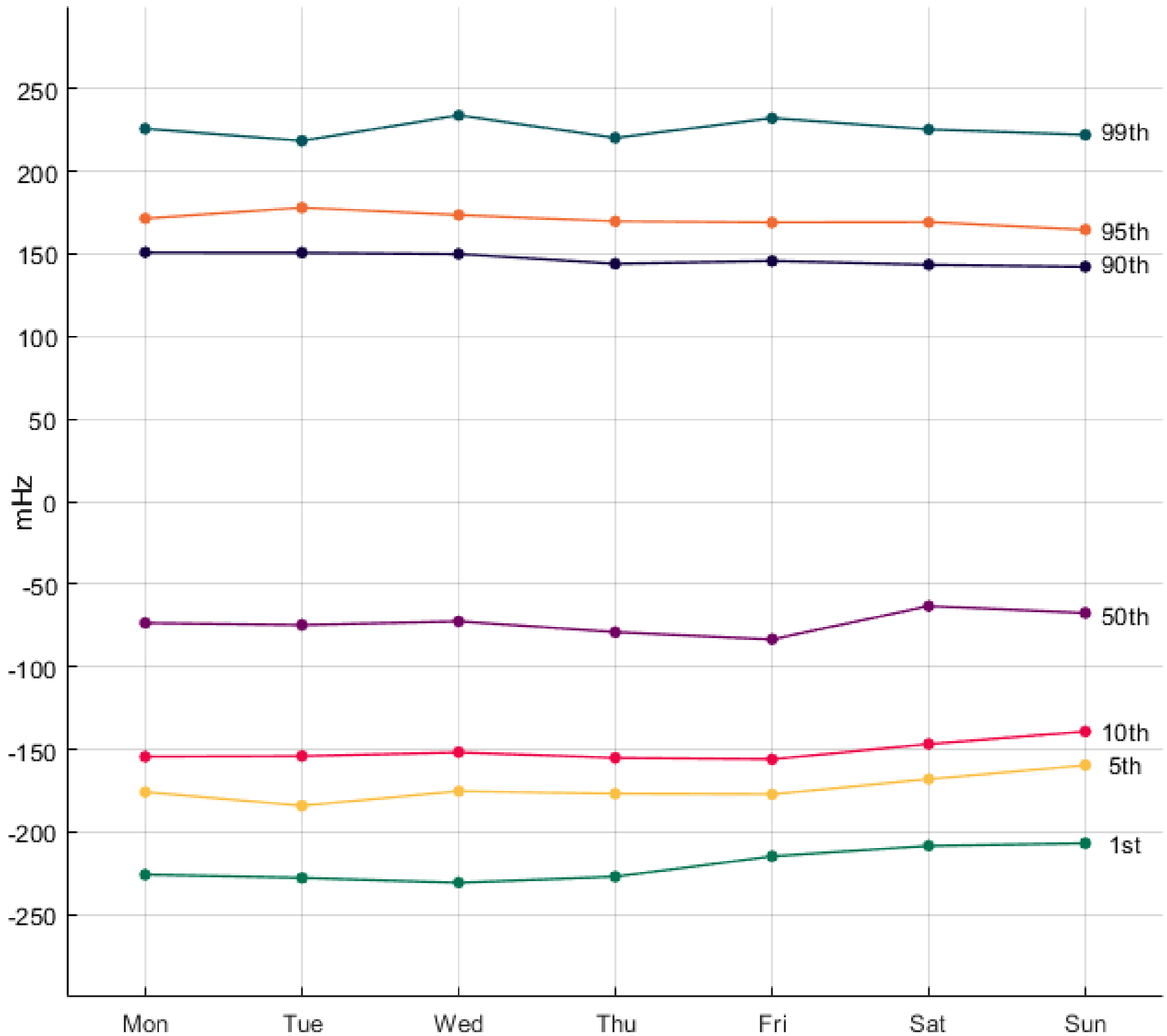


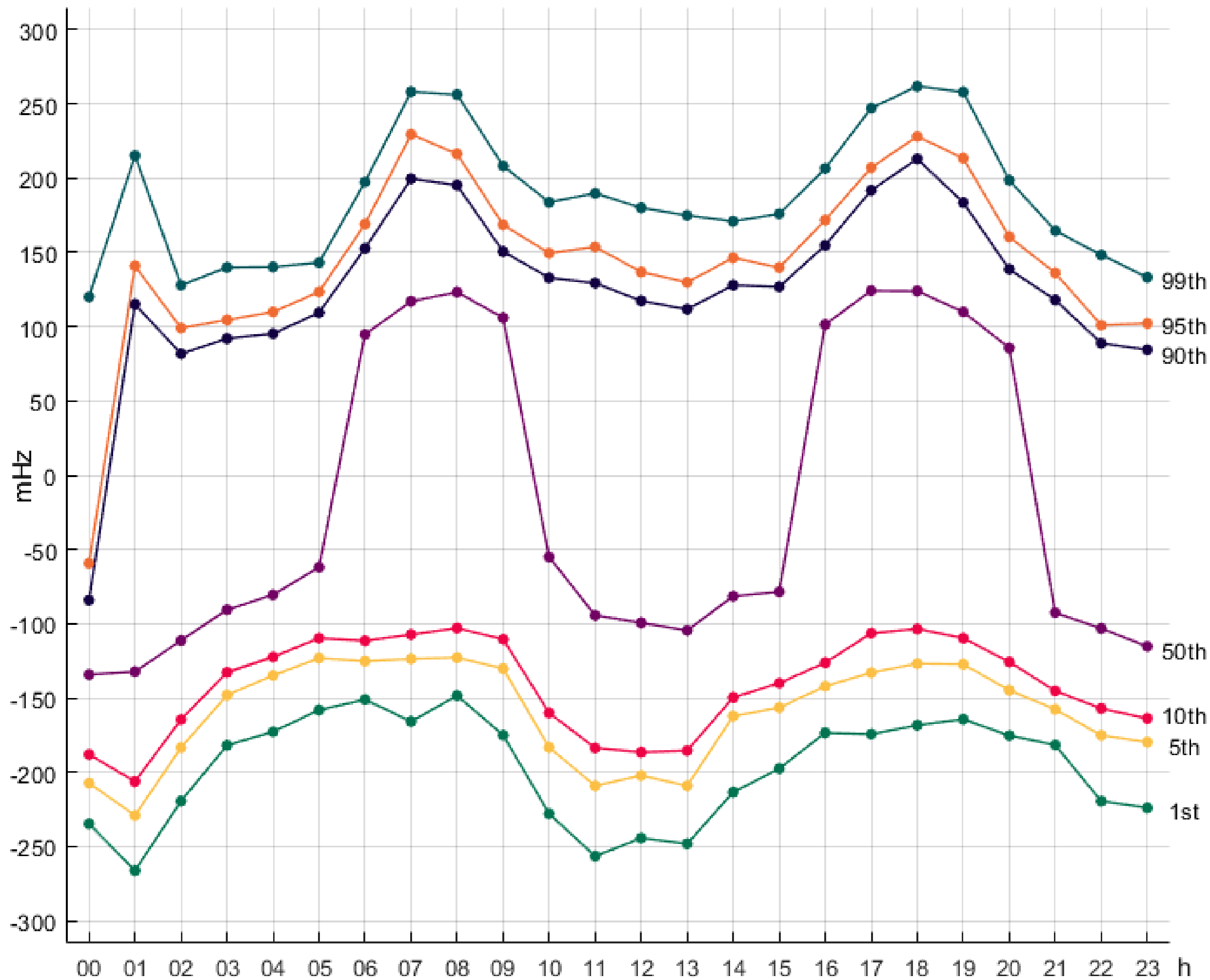
Figure 3.69 shows the percentiles around the hour shift for every day of the week in 2025. The 99th percentile is slightly higher on Wednesday and Friday. Otherwise, the percentiles are fairly evenly distributed throughout the week, while moving closer to zero towards the weekend.

***Figure 3.69**. The 1st, 5th, 10th, 50th, 90th, 95th, and 99th percentiles of deterministic frequency deviation for every day of the week in 2025*



The percentiles of the frequency step around the hour shift for each hour of the day have more variety than the previous figures, as can be seen from Figure 3.70. During the morning hours from 6 to 9 and in the evening from 16 to 20, the values for the 50th percentile are positive, which means the lowest frequency has taken place before the highest in more than half of the hour shifts during these hours. All the other percentiles follow the same pattern, where the values are higher during these hours.

***Figure 3.70**. The 1st, 5th, 10th, 50th, 90th, 95th, and 99th percentiles of deterministic frequency deviation for every hour of the day in 2025*



Chapter 4. Frequency disturbances exceeding 300 mHz frequency deviation

This chapter offers information on the major frequency disturbances in the Nordic synchronous system in 2025. Over 300 mHz frequency deviations, according to Fingrid's PMU located in Kangasala, are included. The measurement frequency for the PMU was 10 Hz. This data describes, at a fair level of accuracy, the frequency of the whole Nordic system.

There were 3 frequency disturbances in 2025 where the deviation exceeded 300 mHz. All of the disturbances were caused by failures in HVDC links. The number of 300 mHz deviations decreased by 72.3% from the previous year and by 78.6% compared to 2023. Compared to the previous years 2020–2024, the number of disturbances in 2025 was the lowest, and unlike the other years, all disturbances were caused by HVDC links. One of the reported events had a frequency deviation below 300 mHz, but it was still included in this report because the 300 mHz threshold was exceeded at another measurement point in Southern Finland. This fault was temporary, and the reported ΔP corresponds to the maximum value of the power imbalance.

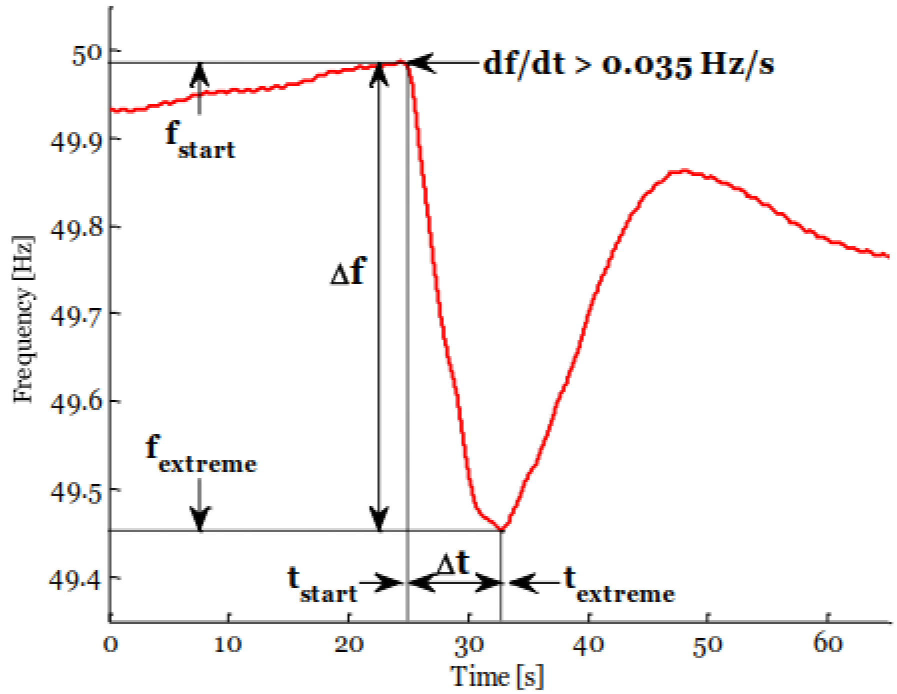
The largest over-frequency deviation was 0.444 Hz, and it occurred on the 13th of June. All of the disturbances were over-frequency events.

The following part of the chapter will go into more detail on every disturbance that took place in 2025. This will include figures of the frequency at the major disturbances and information about the disturbance in table form. Table 4.1 contains a short summary of the studied disturbances. The times presented are in Finnish time (UTC+2 / UTC+3 in the summer). The information given is based on proposed indices from the FQ2 Project Report and will include:

- date
- f_{start} = frequency at the start of the disturbance
- $f_{extreme}$ = the minimum or maximum instantaneous frequency
- Δf = maximum frequency deviation
- Δt = time to reach the maximum frequency deviation
- ΔP = maximum power deviation
- E_k = synchronously connected kinetic energy before disturbance
- cause of the disturbance
- $f_{steady\ state}$ = average of the frequency between 90 and 150 s after the disturbance
- $\Delta f_{steady\ state}$ = absolute difference between $f_{steady\ state}$ and f_{start}
- $f_{extreme2}$ = second extreme in the other direction as $f_{extreme}$
- $f_{extreme3}$ = third extreme in the same direction as $f_{extreme}$
- damping of the frequency after disturbance = $| (f_{extreme3} - f_{extreme2}) / (f_{extreme2} - f_{extreme}) |$
- Frequency Bias Factor (FBF) = $\Delta P / \Delta f_{steady\ state}$

The frequency response indicators mentioned above are visually illustrated in Figure 4.1.

***Figure 4.1**. Graphical representation of frequency response indicators [9]*



For a frequency disturbance to be reported as an over 300 mHz distubance, the frequency gradient (a momentary change in frequency divided by the change in time) must be over 0.035 Hz/s at the beginning of the disturbance, as seen in Figure 4.1.

Kinetic energy (E_k) is an estimation of the rotation energy of synchronously connected generators in the Nordic synchronous system. The value for kinetic energy is given because it affects the system's inertia, which describes the system's ability to resist changes in frequency. Higher kinetic energy provides higher inertia and, therefore, a better ability to oppose frequency deviations. [9] More detailed descriptions of the events listed in Table 4.1 are presented afterwards in Figures 4.2-4 and Tables 4.2-4.

Table 4.1. List of disturbance events in 2025

Event date	Δf (Hz)	ΔP (MW)	Δt (s)	E_k (GWs)	Cause	Page
02-Feb-2025 16:24:29	0.314	1135	5.6	257	HVDC	105
13-Jun-2025 16:17:39	0.444	1400	3.9	156	HVDC	106
09-Sep-2025 09:26:13	0.296	1440	1.8	194	HVDC	107

Figure 4.2. Disturbance 02-Feb-2025 16:24:29

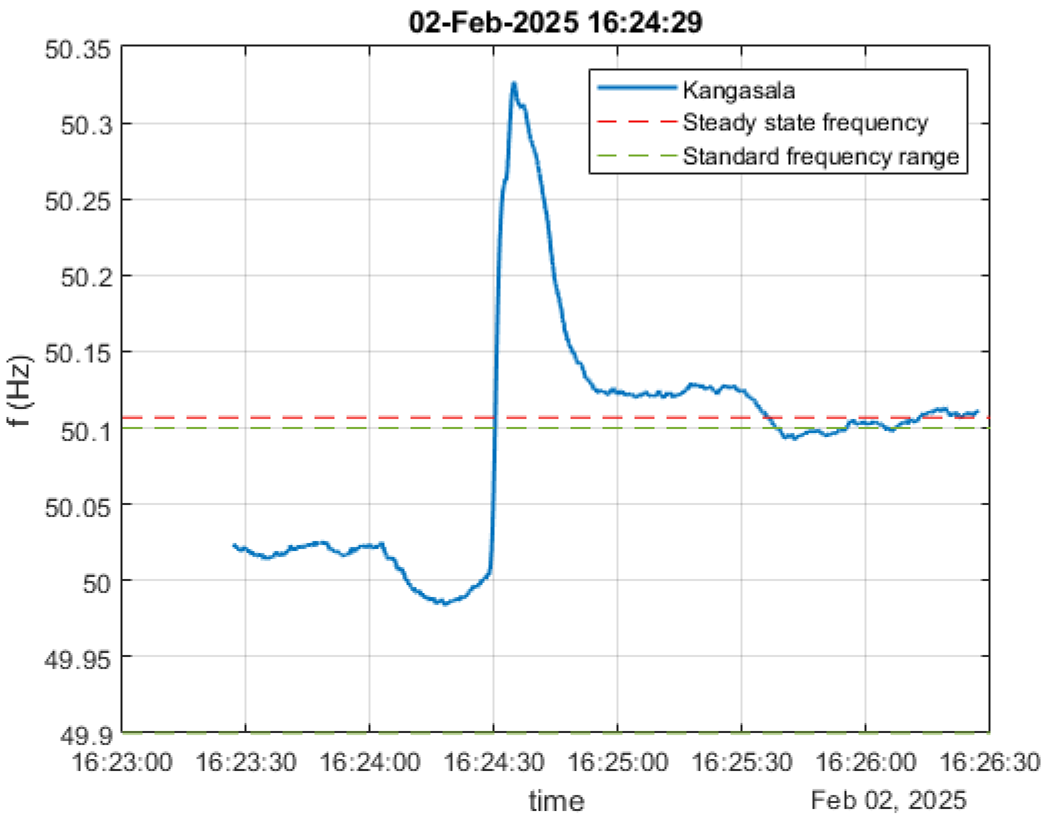


Table 4.2. Disturbance 02-Feb-2025 16:24:29

Date		**02-Feb-2025 16:24:29**	
f_{start}	50.012 Hz	$f_{steady\ state}$	50.107 Hz
$f_{extreme}$	50.326 Hz	$\Delta f_{steady\ state}$	0.095 Hz
Δf	0.314 Hz	$f_{extreme2}$	50.110 Hz
Δt	5.6 s	$f_{extreme3}$	50.093 Hz
ΔP	1135 MW	damping	7.71 %
E_k	257 GWs	FBF	11964 MW/Hz
cause		HVDC	

Figure 4.3. Disturbance 13-Jun-2025 16:17:39

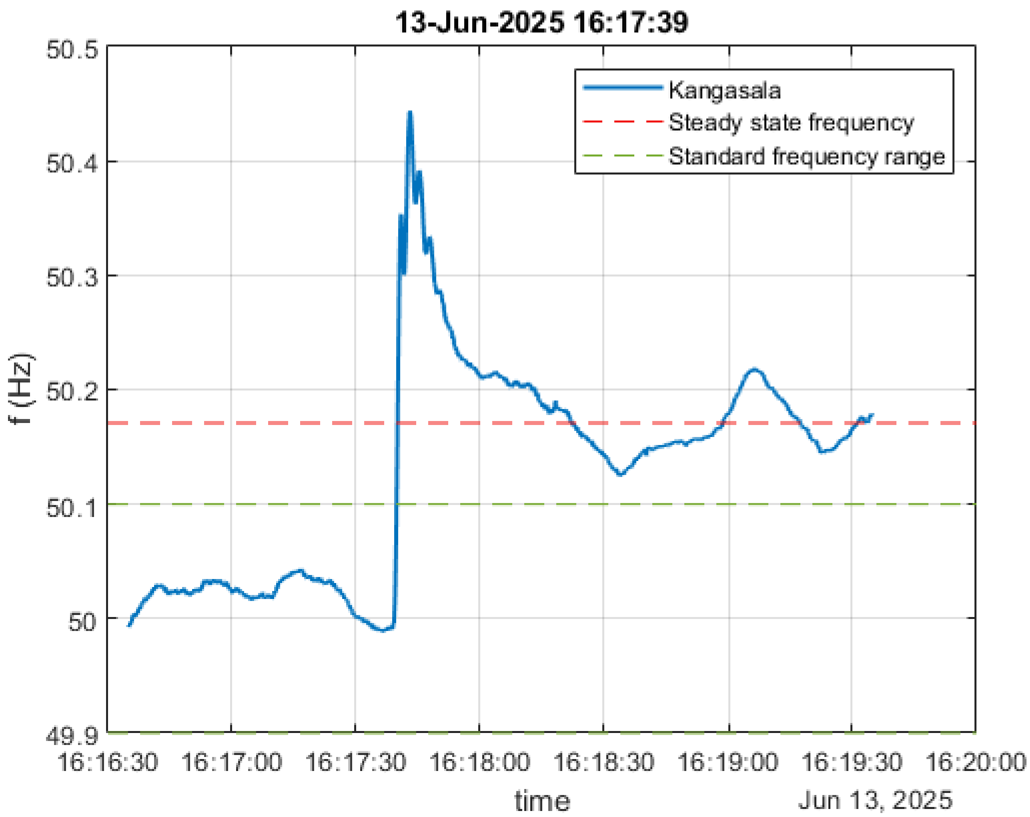


Table 4.3. Disturbance 13-Jun-2025 16:17:39

Date		**13-Jun-2025 16:17:39**	
f_{start}	49.997 Hz	$f_{steady\ state}$	50.171 Hz
$f_{extreme}$	50.441 Hz	$\Delta f_{steady\ state}$	0.174 Hz
Δf	0.444 Hz	$f_{extreme2}$	50.125 Hz
Δt	3.9 s	$f_{extreme3}$	50.218 Hz
ΔP	1400 MW	damping	29.26 %
E_k	156 GWs	FBF	8054 MW/Hz
cause		HVDC	

Figure 4.4*. *Disturbance 09-Sep-2025 09:26:13

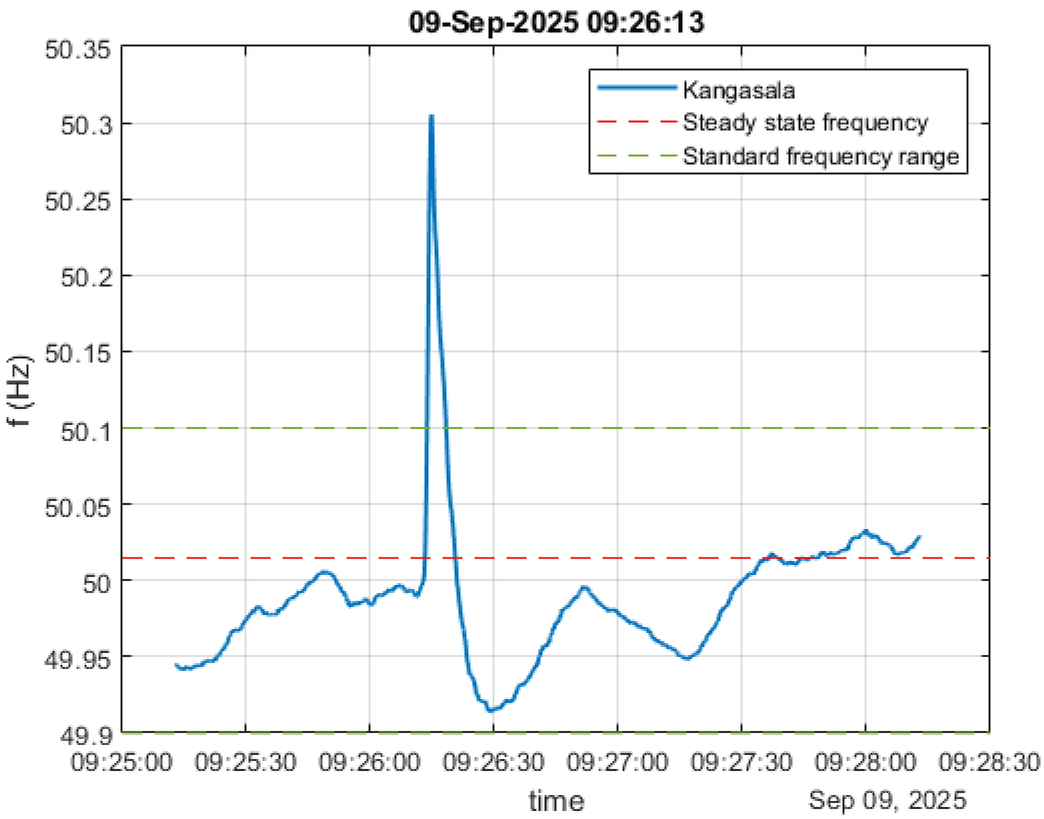


Table 4.4*. *Disturbance 09-Sep-2025 09:26:13

Date		**09-Sep-2025 09:26:13**	
f_{start}	50.005 Hz	$f_{steady\ state}$	50.015 Hz
$f_{extreme}$	50.301 Hz	$\Delta f_{steady\ state}$	0.010 Hz
Δf	0.296 Hz	$f_{extreme2}$	49.914 Hz
Δt	1.8 s	$f_{extreme3}$	49.998 Hz
ΔP	1440 MW	damping	21.70 %
E_k	194 GWs	FBF	84819 MW/Hz
cause		HVDC	

Chapter 5. Summary

The aim of this report was to analyze frequency variation and oscillation in the Nordic synchronous system in 2025. Overall, frequency quality was better in 2025 than in 2024 and the previous years within the observation period. Compared to 2024, the most notable change was the reduction in the time spent outside the 49.9–50.1 Hz and 49.8–50.2 Hz frequency ranges. In addition, the number of frequency deviations, threshold crossings, and oscillatory behaviour were all lower than in previous years.

The improvement was particularly visible in metrics describing the occurrence of frequency deviations. The daily average number of minutes spent outside the standard frequency range was approximately half of the 2024 level. The average number of seconds per day outside 49.8–50.2 Hz decreased by 69.7% compared to 2024. The number of frequency deviations declined across all duration categories, and threshold crossings of the standard frequency range decreased to less than half of the level observed in 2024. These results indicate a clear improvement in frequency quality compared to 2024.

The amount of oscillation in 2025 was the lowest during the period 2020–2025. While oscillation had already decreased somewhat in 2024 compared to earlier years, the reduction in 2025 was substantially larger. Removing oscillatory components from the frequency signal reduced the time outside the standard frequency range by slightly less than 30% when using the FFT filtering method. This reduction was smaller than in previous years, reflecting the lower overall level of oscillation. The seasonal increase in oscillation towards mid-year was also less pronounced than in earlier years.

All major disturbances were associated with failures in HVDC links. Compared to 2024, when eleven disturbances exceeding 300 mHz were recorded and nuclear power plant failures accounted for most of the events, the number of large disturbances was substantially lower. The number of events was lower than during 2021–2024, when at least ten such disturbances occurred each year, and lower than during 2017–2020, when approximately six disturbances were recorded annually.

In terms of mean value, January was the best month, with an average frequency of 50.000 Hz, while December had the lowest monthly mean value at 49.9984 Hz. Despite this, December had the lowest standard deviation, whereas May had the highest. Overall, frequency variability was lower in 2025 than in 2024, with monthly mean values remaining closer to 50 Hz. This was also reflected in the frequency area, which was lower in every month compared to 2024. The frequency path was longer in most months despite the lower overall variability.

Frequency quality also varied by day of the week and time of day. Based on the analysed performance metrics, quality was slightly better towards the end of the week, with Sunday showing the strongest performance. The hourly analysis showed the largest variability around 7 am and 6 pm, while the clearest improvement compared to previous years was observed during the early morning hours. Within the hour, frequency quality was generally best around the half-hour mark and weakest close to the hour shift, particularly at the beginning of the hour.

Chapter 6. Sources

[1] Frequency measurement data, Fingrid Oyj, available at https://data.fingrid.fi (Organizations / Fingrid / Frequency - historical data)

[2] Valli V.: "Frequency quality analysis for year 2020", Fingrid Oyj, 14.9.2021

[3] Pesonen J.: "Frequency quality analysis for year 2021", Fingrid Oyj, 15.8.2022

[4] Pesonen J.: "Frequency quality analysis for year 2022", Fingrid Oyj, 22.8.2023

[5] Mäki-Turja S.: "Frequency quality analysis for year 2023", Fingrid Oyj, 11.9.2024

[6] Piha A.: "Frequency quality analysis for year 2024", Fingrid Oyj, 14.7.2025

[7] Frequency quality phase 2 Project Report, NAG (Nordic Analysis Group), 16.5.2017 internal report

[8] Kuivaniemi M.: "40-90 second oscillation analysis for years 2011 and 2012", Fingrid Oyj, 30.8.2013

[9] Nordic report: Future system inertia, ENTSO-E, 2015, available at https://www.entsoe.eu/publications/system-operations-reports/