Frequency quality analysis

2024

FINGRID

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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 2024. 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 2024 is presented in Table 2.1. The yearly availability of data for years 2019 to 2024 can be seen in Table 2.2 [2,3,4,5,6]. In 2024, there was valid measurement data for 99.95% 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 October, but well over 99.5 %. Overall, the availability in 2024 has been high throughout the year, and the yearly average is highest of all the years 2019-2024.

Table 2.1. The amount of valid measurement data available per month in 2024

Month	Available data
January	99.96 %
February	99.95 %
March	99.97 %
April	99.96 %
May	99.96 %
June	99.97 %
July	99.97 %
August	99.97 %
September	99.97 %
October	99.83 %
November	99.97 %
December	99.94 %

Table 2.2. The amount of valid measurement data available for years 2019-2024

Year	Available data
2019	98.47 %
2020	97.82 %
2021	99.92 %
2022	99.56 %
2023	99.58 %
2024	99.95 %

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 2024. 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 has been close to 50 Hz, with the greatest mean deviation of approximately 0.4 mHz occurring in September. The average frequency in 2024 was slightly worse than the year before, since the number of over 0.25 mHz deviations was greater in 2024. In addition, the average frequency has been above 50 Hz every month, which is similar to years 2022 and 2023, but different from the previous years, where the averages were more evenly distributed around 50 Hz.

***Figure 3.1**. Average frequency for each month in 2024*

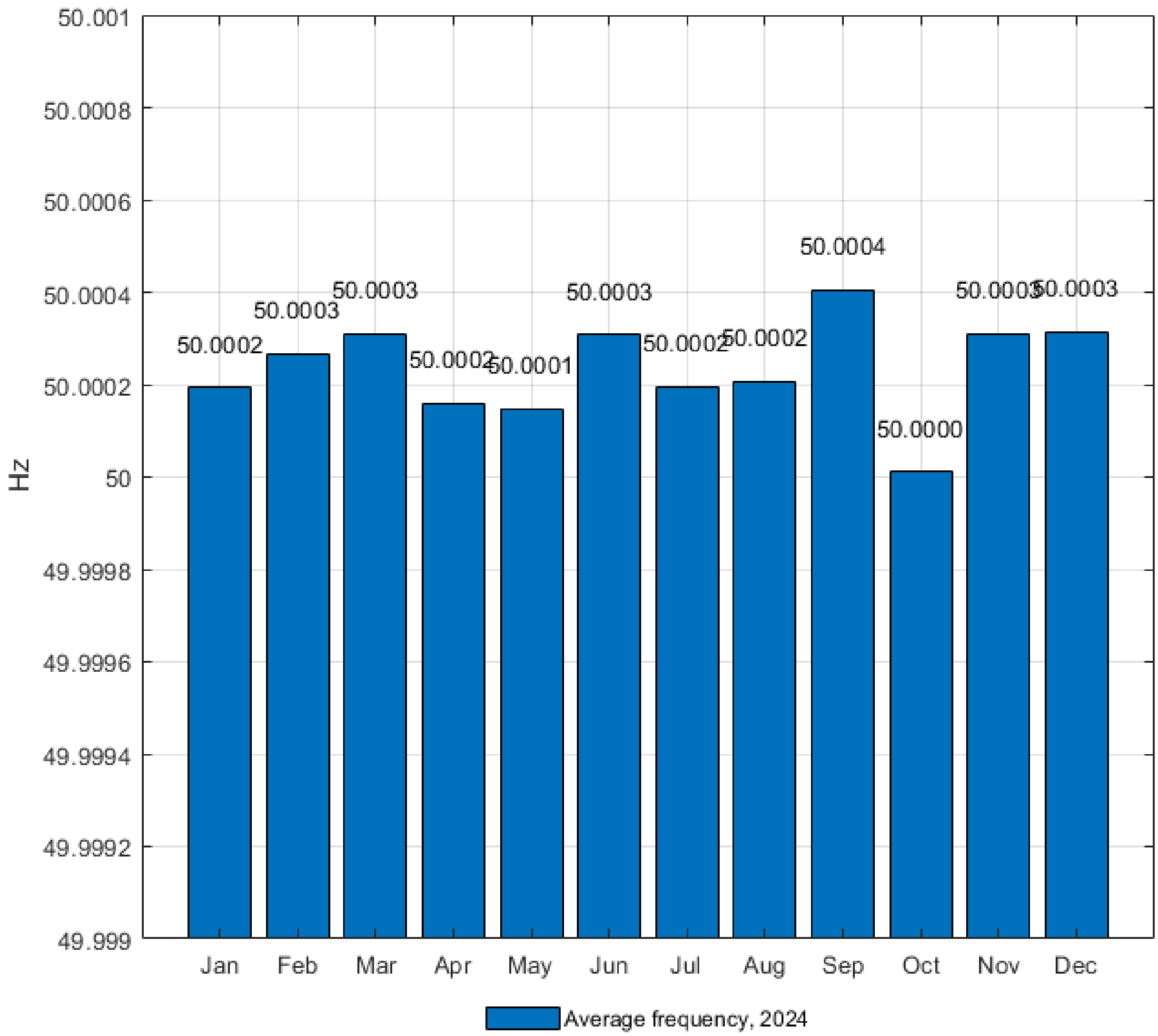


Figure 3.2 shows the average frequencies for each day of the week. The highest average frequency occurred on Thursday and the lowest on Wednesday.

***Figure 3.2**. Average frequency for each day of the week in 2024*

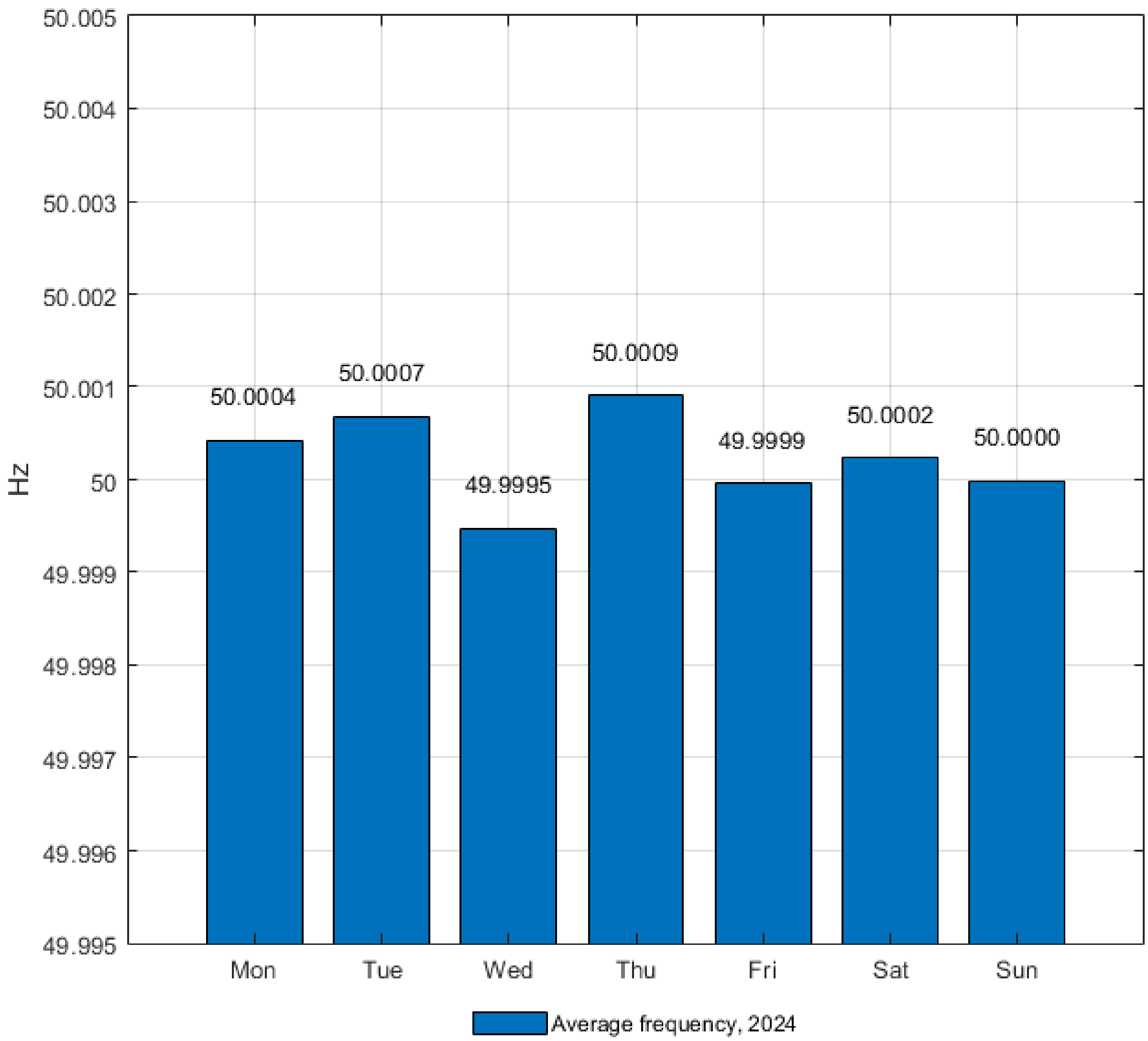


Figure 3.3 shows the average frequencies during each hour of the day. The frequency has been lowest at 7 am and 4 pm. The frequency has been higher around noon, in the evening, apart from 10 pm, and around midnight. The trend is very similar to the year 2023, down to the hours when local minimums and maximums occur.

***Figure 3.3**. Average frequency for each hour of the day in 2024*

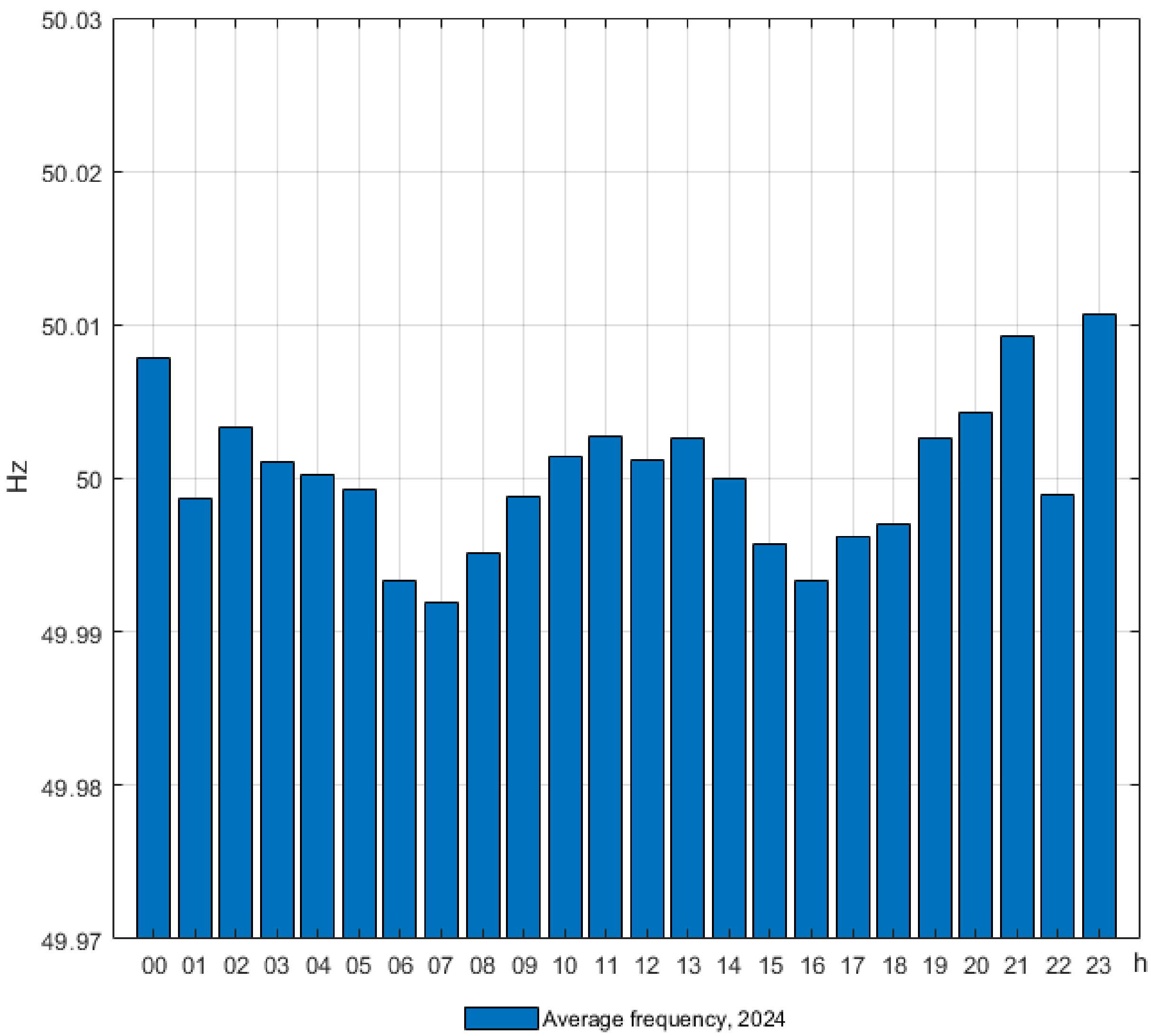
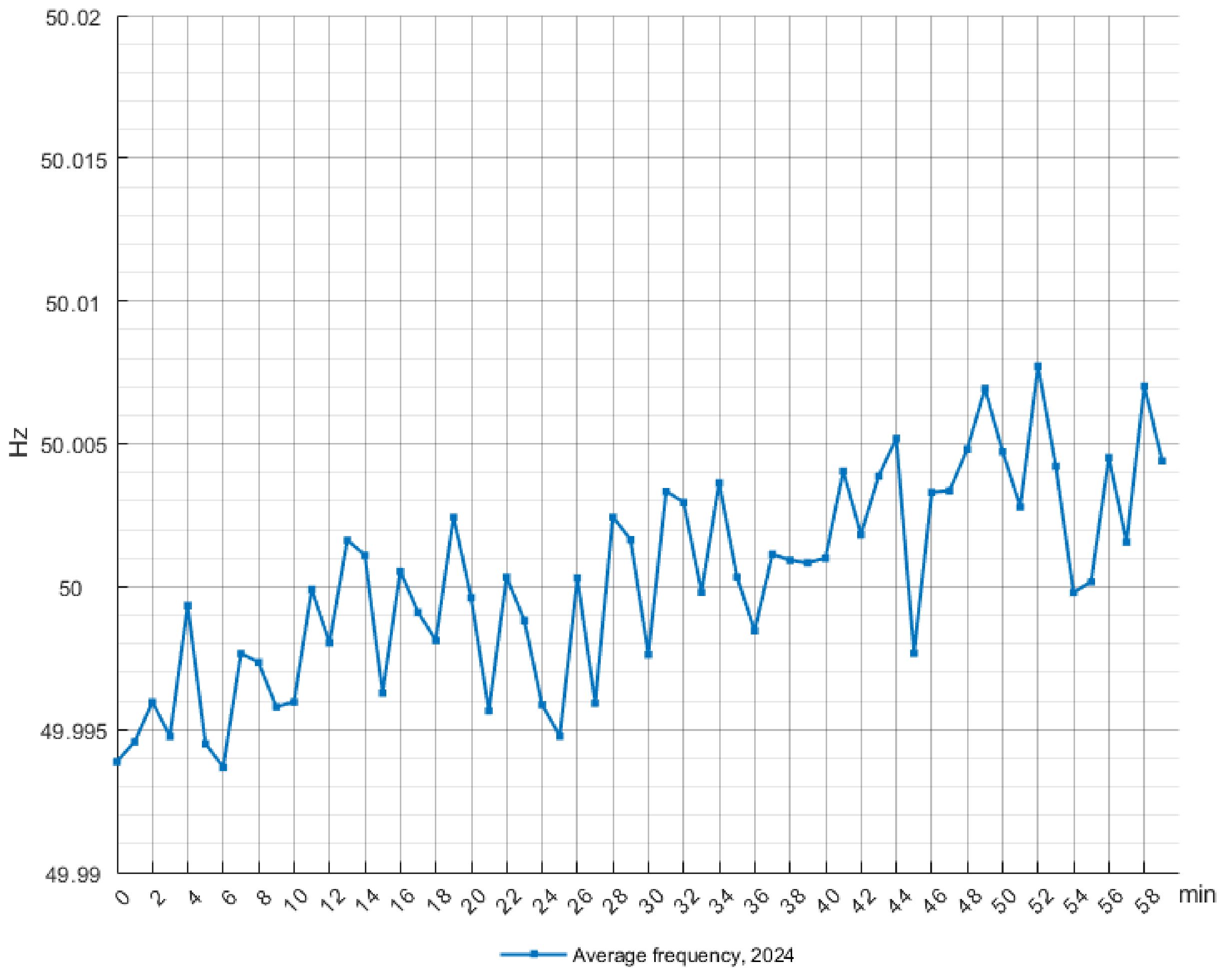


Figure 3.4 shows the average frequency within the hour. In general, the frequency has been higher in the latter part of the hour. The difference between consecutive minutes varies between 0.0 and 7.5 mHz. The largest difference has decreased slightly from the year 2023, where the largest difference was 8.5 mHz.

***Figure 3.4**. Average frequency for each minute of the hour in 2024*



3.1.2 Standard deviation

This section includes the figures representing the standard deviation of frequency during the year 2024. 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 2024. 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 frequency has deviated approximately as much as in 2023 with a similar month-by-month trend.

Figure 3.5. Standard deviation of the frequency for every month in 2024

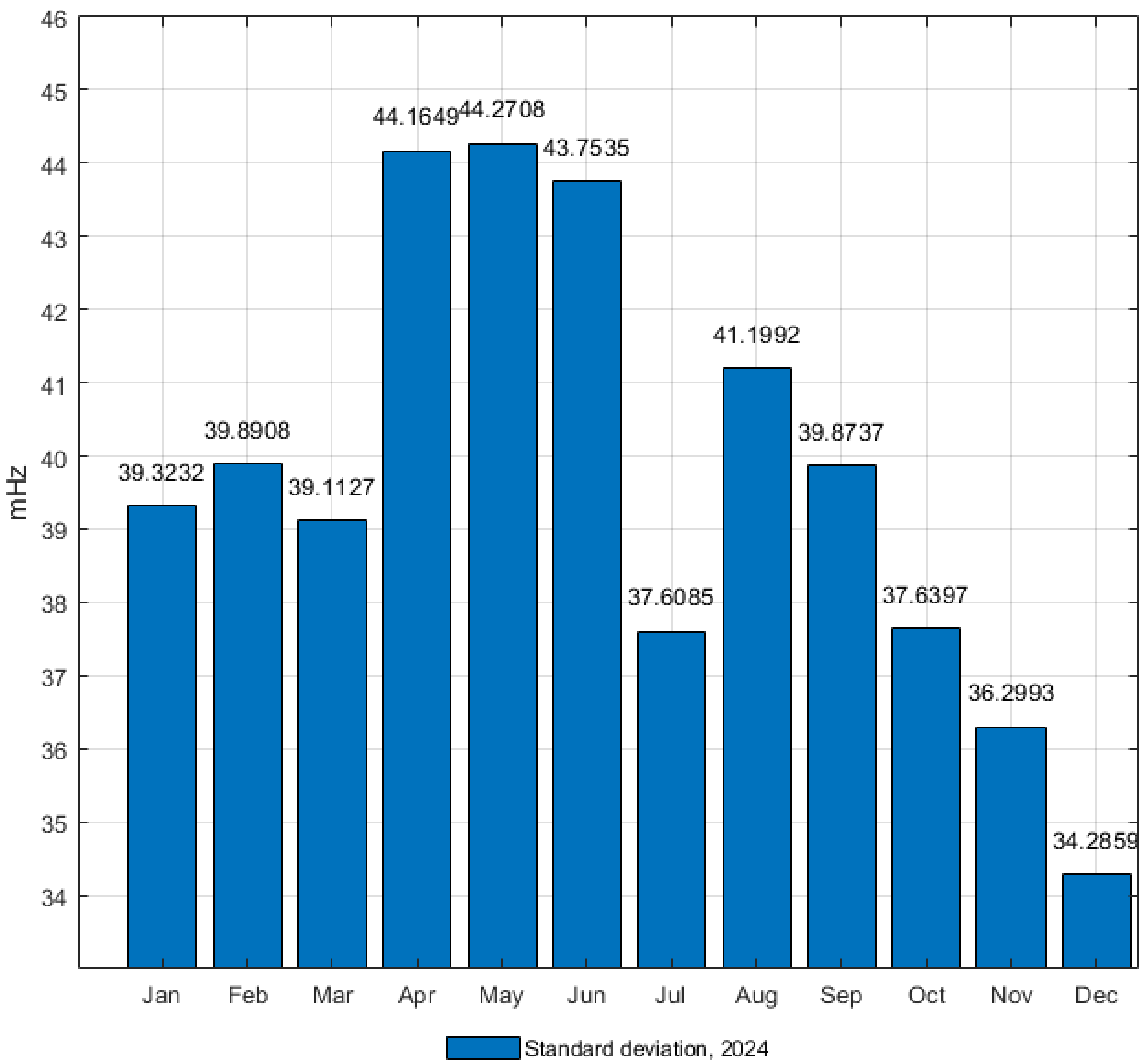


Figure 3.6 represents the standard deviation for each day of the week. Based on the standard deviation, frequency quality has been fairly stable throughout the week, with Monday having notably worse frequency quality compared to other days. Overall, the frequency quality is more even throughout the week compared to the year 2023.

***Figure 3.6**. Standard deviation of the frequency for every day of the week in 2024*

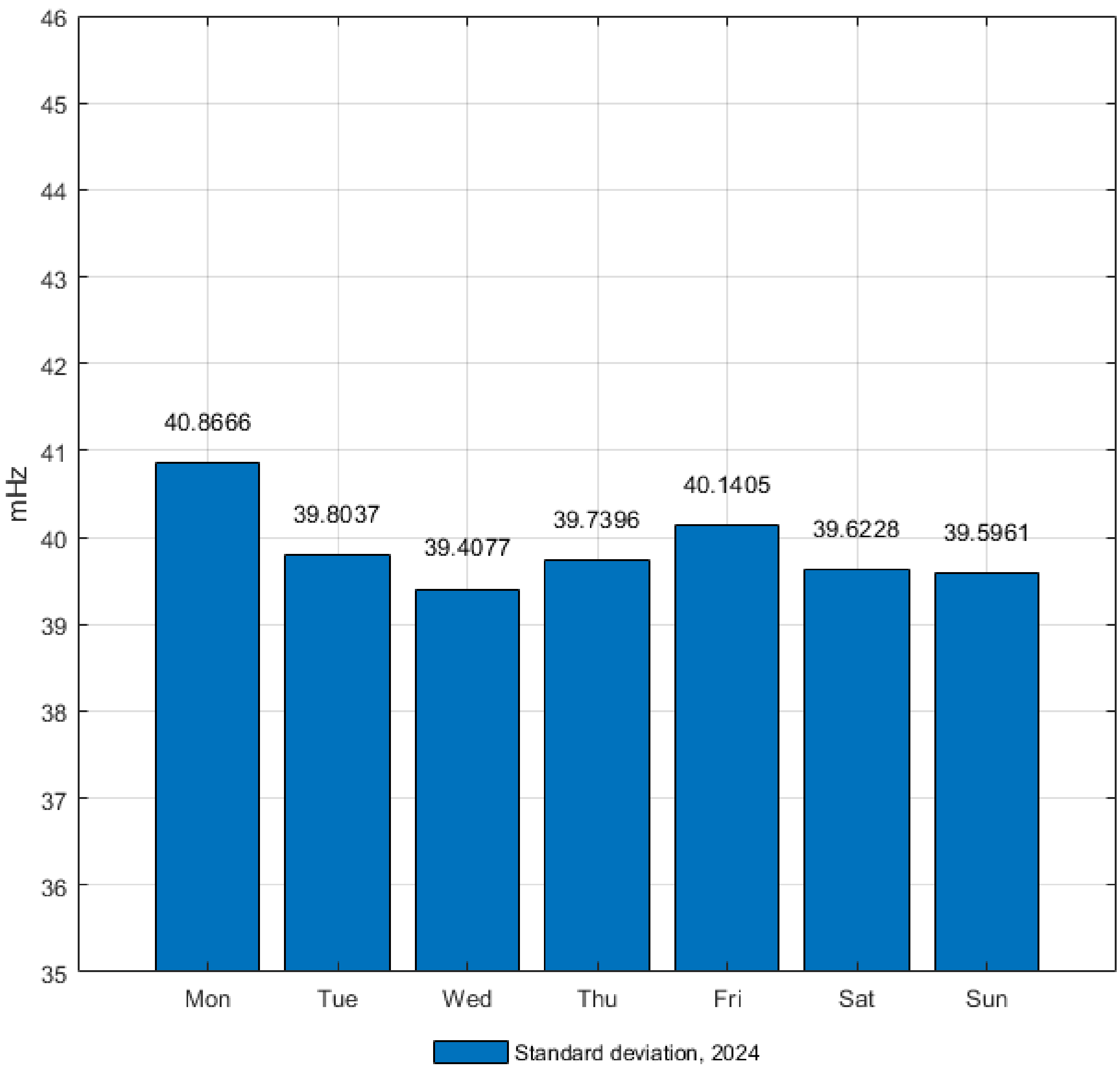


Figure 3.7 shows the standard deviation during each hour of an average day. The standard deviation values have been higher after midnight and lower around noon. The highest values were experienced in the early morning at 1 am to 5 am, 7 am, 5 pm and 11 pm. The lowest values were experienced at 6 am and 10 pm. The values are similar to those of 2023, although the deviations during the early morning hours have decreased.

Figure 3.7**. **Standard deviation of the frequency for every hour of the day in 2024

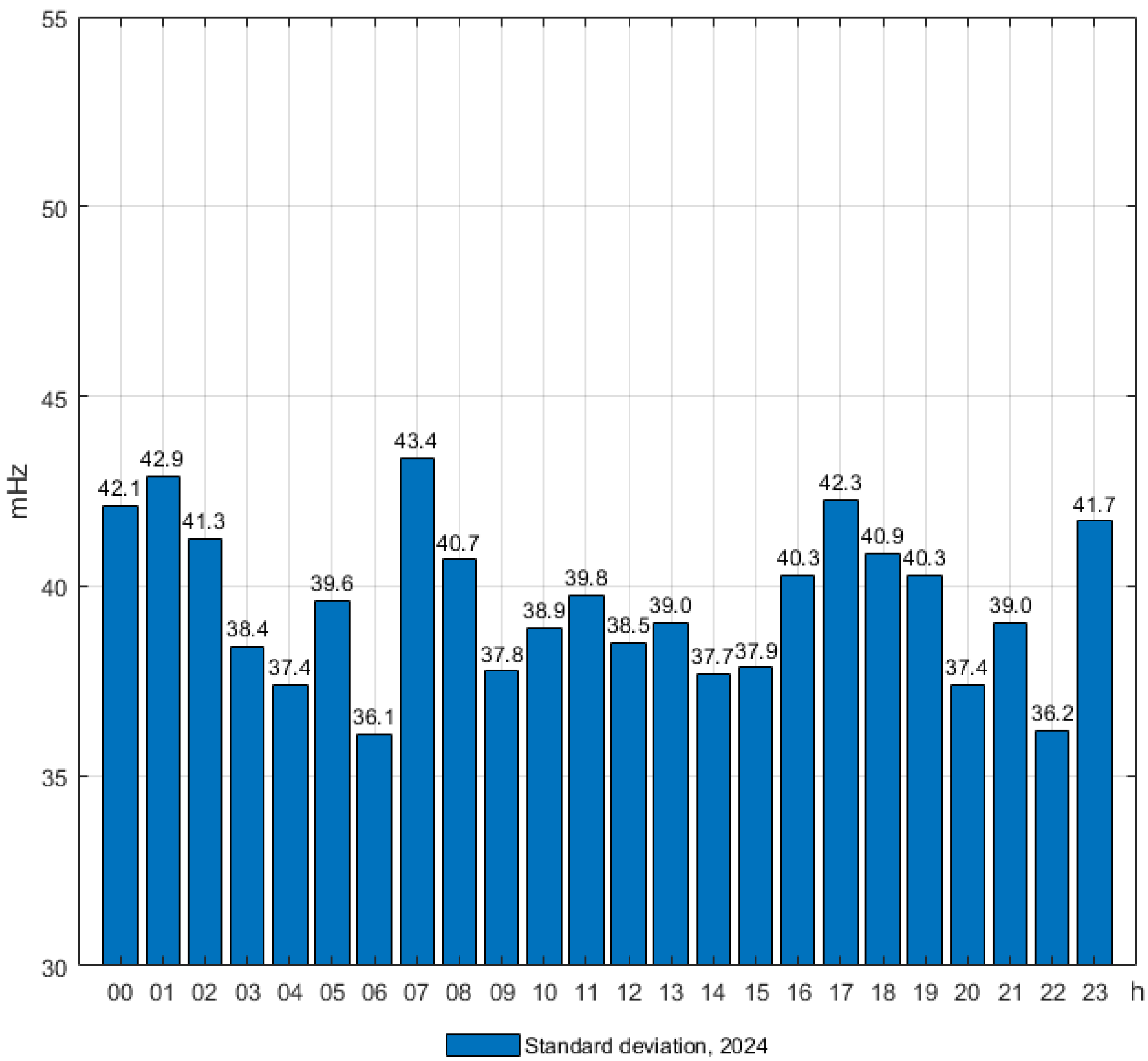
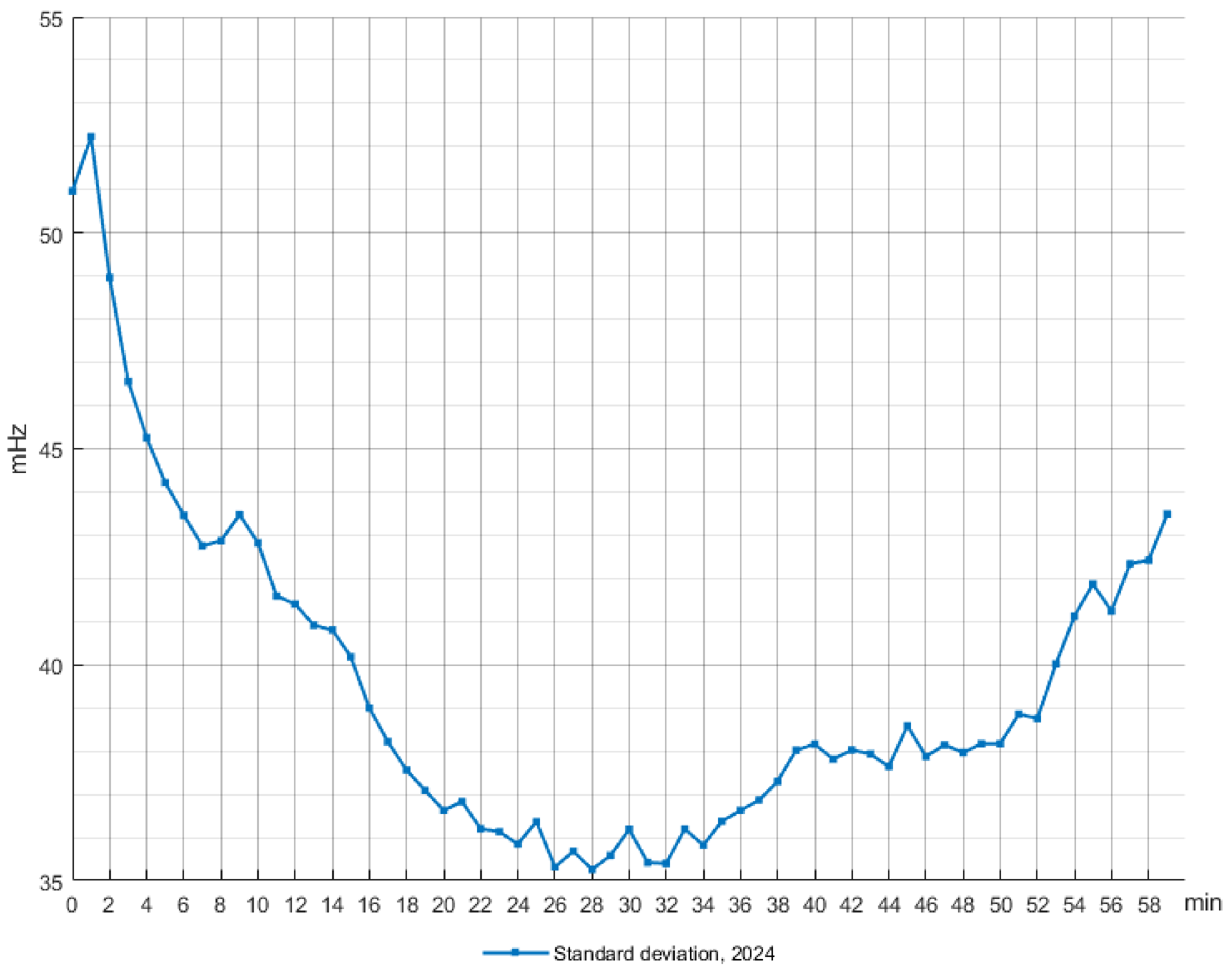


Figure 3.8 represents the standard deviation within an hour. The standard deviation has the highest values at the beginning of the hour, which indicates a weaker quality of frequency during that time. The standard deviation decreases approximately until the half-hour mark, from where it increases again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

Figure 3.8. Standard deviation of the frequency for every minute of the hour in 2024



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 2019 to 2024, 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.

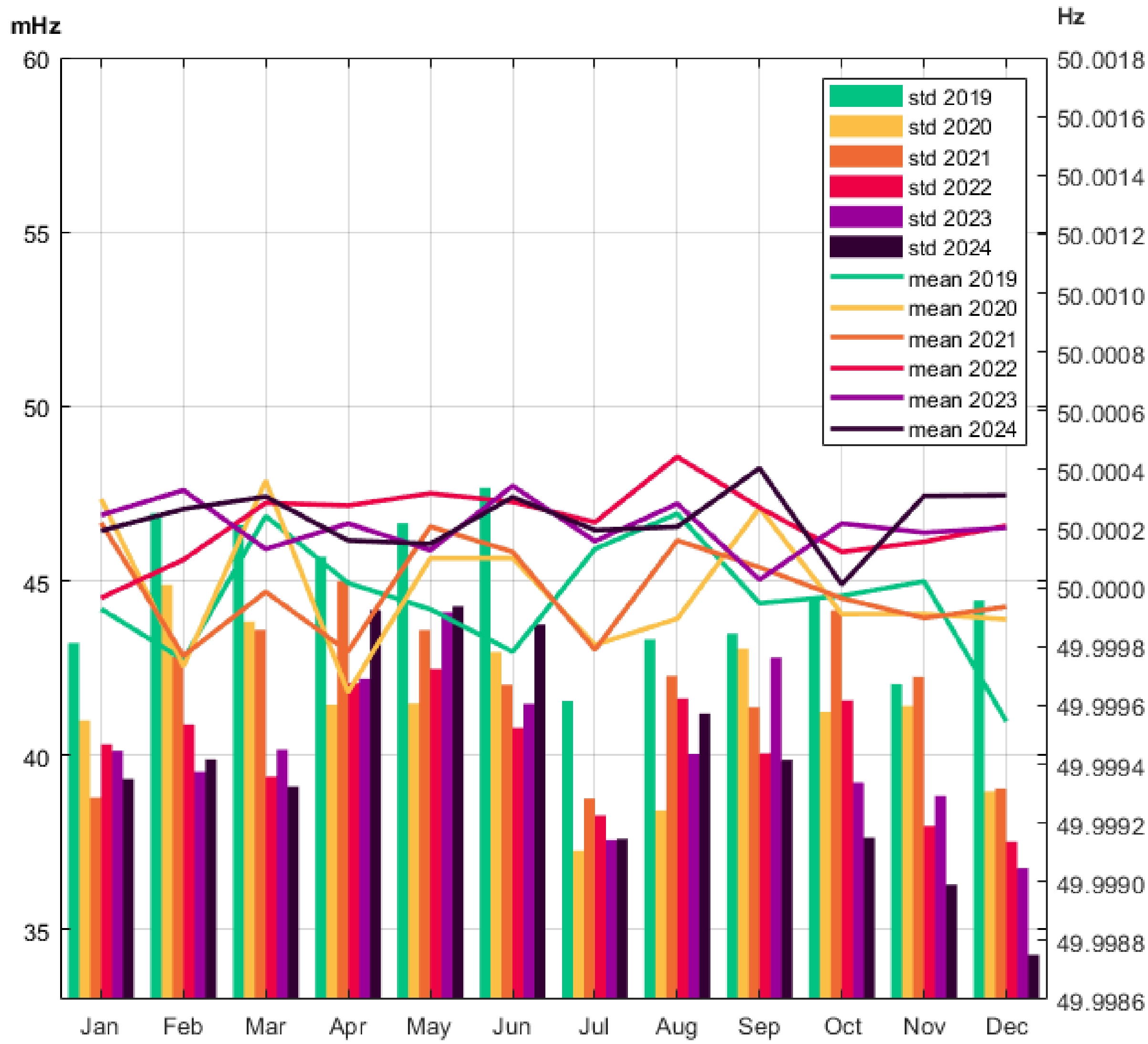
Table 3.1. Mean values and standard deviations for years 2019-2021

	2019		**2020**		**2021**	
Month	**Mean value (Hz)**	**Standard deviation (mHz)**	**Mean value (Hz)**	**Standard deviation (mHz)**	**Mean value (Hz)**	**Standard deviation (mHz)**
January	49.9999	43.2	50.0003	41.0	50.0002	38.8
February	49.9998	46.9	49.9997	44.9	49.9998	42.8
March	50.0002	46.6	50.0004	43.8	50.0000	43.6
April	50.0000	45.7	49.9996	41.5	49.9998	45.0
May	49.9999	46.7	50.0001	41.5	50.0002	43.6
June	49.9998	47.7	50.0001	43.0	50.0001	42.0
July	50.0001	41.6	49.9998	37.3	49.9998	38.8
August	50.0003	43.3	49.9999	38.4	50.0002	42.3
September	49.9999	43.5	50.0003	43.1	50.0001	41.4
October	50.0000	44.5	49.9999	41.2	50.0000	44.2
November	50.0000	42.0	49.9999	41.4	49.9999	42.3
December	49.9995	44.4	49.9999	39.0	49.9999	39.1
Entire year	**50.0000**	**44.7**	**50.0000**	**41.4**	**50.0000**	**42.0**

***Table 3.2.** Mean values and standard deviations for years 2022-2024*

	2022		**2023**		**2024**	
Month	**Mean value (Hz)**	**Standard deviation (mHz)**	**Mean value (Hz)**	**Standard deviation (mHz)**	**Mean value (Hz)**	**Standard deviation (mHz)**
January	50.0000	40.3	50.0002	40.1	50.0002	39.3
February	50.0001	40.9	50.0003	39.5	50.0003	39.9
March	50.0003	39.4	50.0001	40.2	50.0003	39.1
April	50.0003	42.1	50.0002	42.2	50.0002	44.2
May	50.0003	42.5	50.0001	44.1	50.0001	44.3
June	50.0003	40.8	50.0003	41.5	50.0003	43.8
July	50.0002	38.3	50.0002	37.6	50.0002	37.6
August	50.0004	41.6	50.0003	40.0	50.0002	41.2
September	50.0003	40.1	50.0000	42.8	50.0004	39.9
October	50.0001	41.6	50.0002	39.2	50.0000	37.6
November	50.0002	38.0	50.0002	38.8	50.0003	36.3
December	50.0002	37.5	50.0002	36.8	50.0003	34.3
Entire year	**50.0002**	**40.3**	**50.0002**	**40.3**	**50.0002**	**39.9**

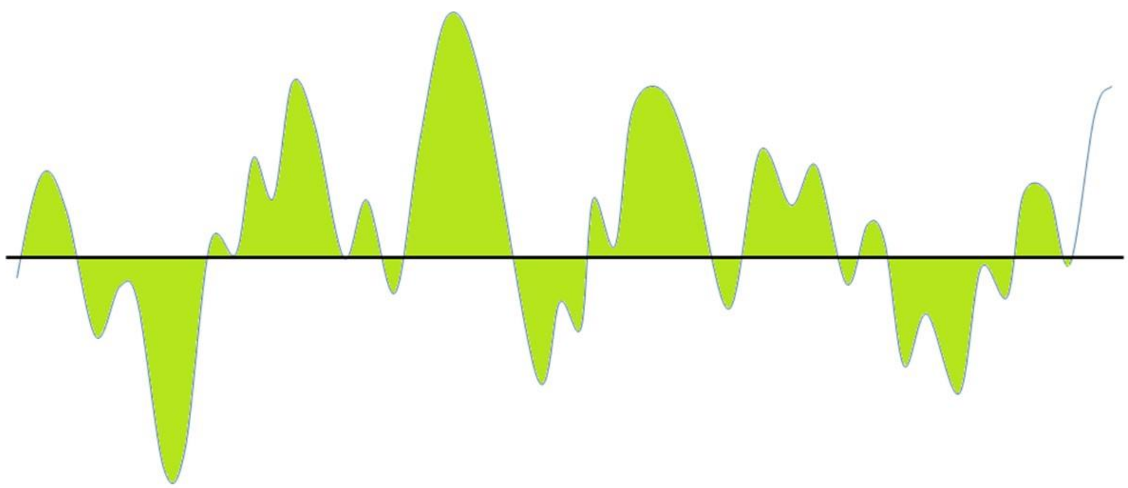
***Figure 3.9**. Mean values and standard deviations for years 2019-2024*



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.

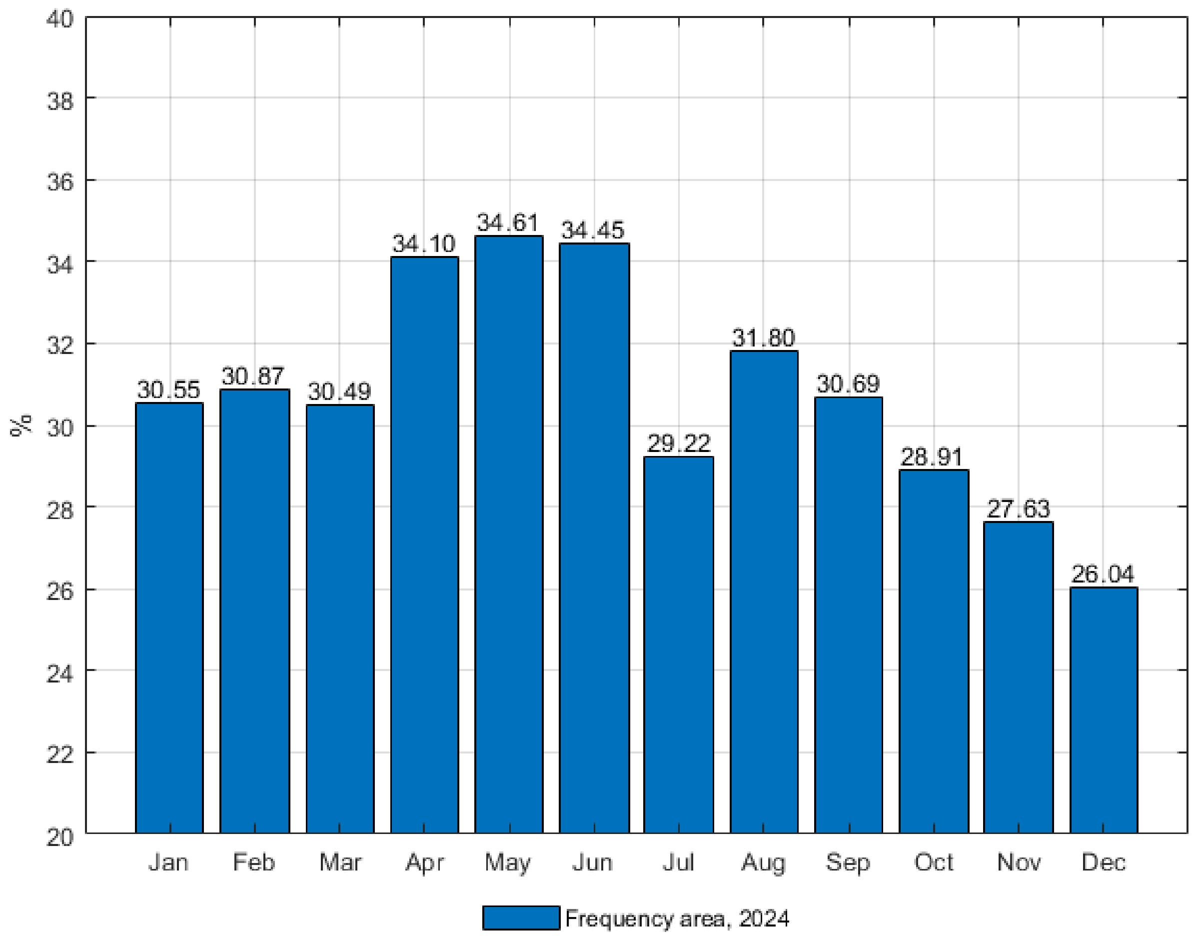
Figure 3.10**. **Frequency quality index: Frequency area [7]



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

Figure 3.11 represents the average frequency area for every month in 2024. The frequency area has been the largest in April, May and June, and smallest in July and December.

***Figure 3.11**. The average frequency area for every month in 2024*



The frequency area during each day of the week can be seen in Figure 3.12. The quality of the frequency has been fairly level, with highest deviations on Monday and Friday. Contrary to the previous year, there is no clear trend of the quality improving toward the end of the week.

***Figure 3.12**. The average frequency area for every day of the week in 2024*

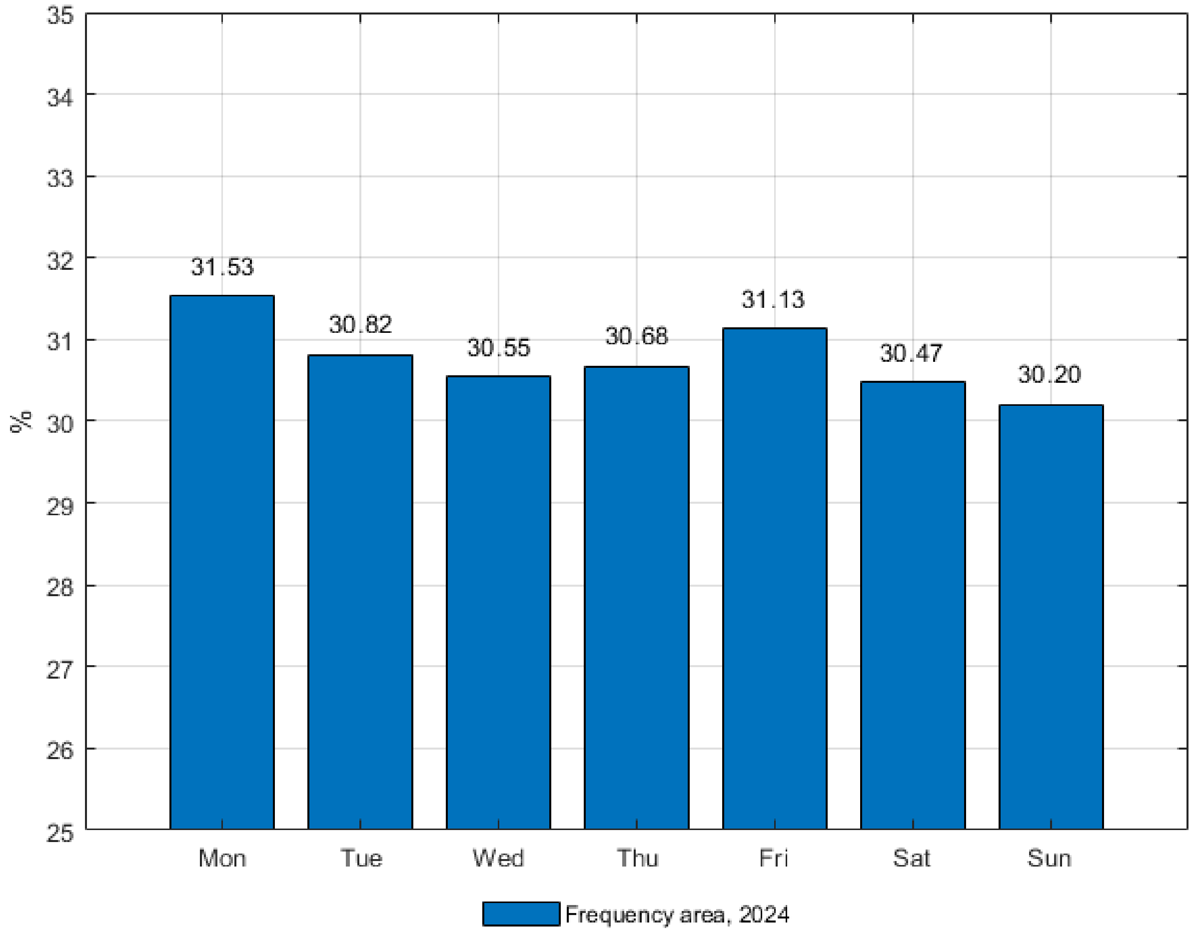


Figure 3.13 represents the frequency area for every hour of the day. The figure shows that the frequency area has been slightly greater in the morning and noon. This is similar to the previous two years, but the quality during the early morning hours has notably improved.

***Figure 3.13**. The average frequency area for every hour inside the day in 2024*

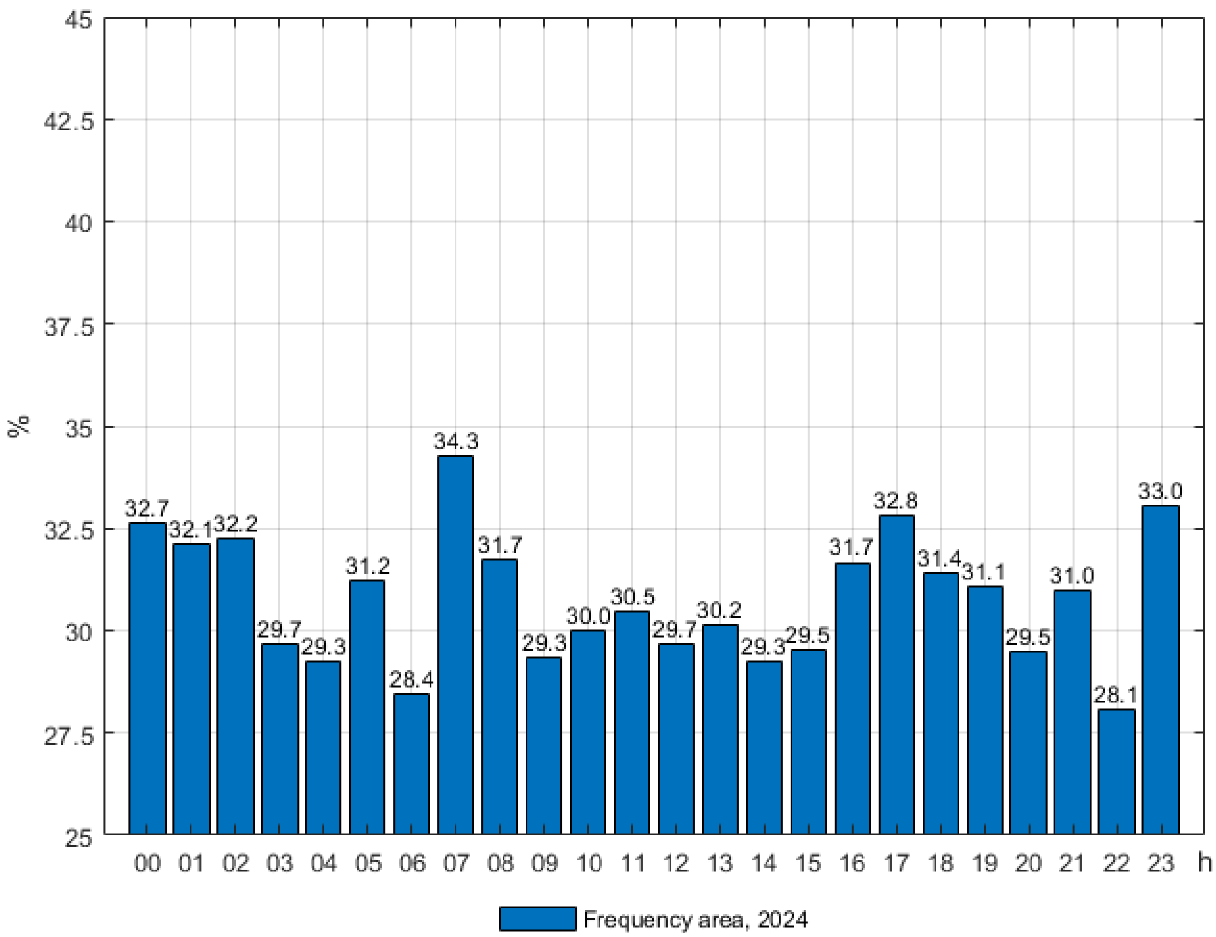
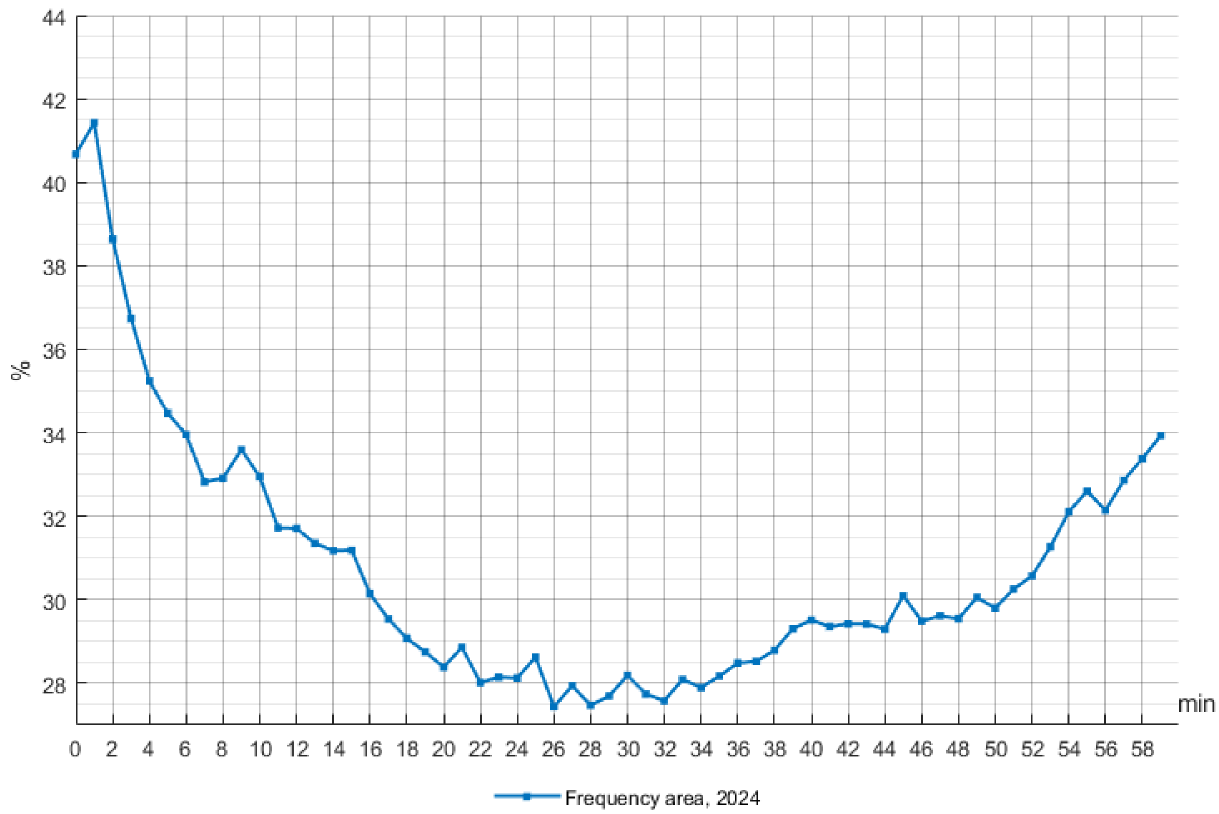


Figure 3.14 represents the frequency area within the hour. The frequency area has been smaller in the middle of the hour, while more deviation has occurred closer to the hour shift and especially in the first minutes of the hour.

***Figure 3.14**. The average frequency area for every minute within the hour in 2024*



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 2019 to 2024. All results are summed up in Figure 3.15.

***Table 3.3**. The 1st, 5th, 10th, 90th, 95th, and 99th percentiles for the year 2019*

	2019					
Month	**1st (Hz)**	**5th (Hz)**	**10th (Hz)**	**90th (Hz)**	**95th (Hz)**	**99th (Hz)**
Jan	49.901	49.930	49.945	50.056	50.071	50.101
Feb	49.895	49.925	49.940	50.061	50.077	50.109
Mar	49.893	49.925	49.941	50.060	50.076	50.107
Apr	49.897	49.927	49.943	50.059	50.076	50.111
May	49.889	49.923	49.940	50.059	50.075	50.106
Jun	49.888	49.922	49.939	50.060	50.077	50.110
Jul	49.905	49.932	49.947	50.053	50.069	50.099
Aug	49.900	49.930	49.946	50.055	50.072	50.104
Sep	49.896	49.929	49.945	50.055	50.071	50.104
Oct	49.895	49.927	49.943	50.056	50.073	50.106
Nov	49.902	49.932	49.947	50.054	50.070	50.102
Dec	49.895	49.927	49.944	50.056	50.072	50.108
Entire year	**49.896**	**49.928**	**49.943**	**50.057**	**50.073**	**50.106**

Table 3.4. 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 3.5. 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 3.6. The 1st, 5th, 10th, 90th, 95th, and 99th percentiles for 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**

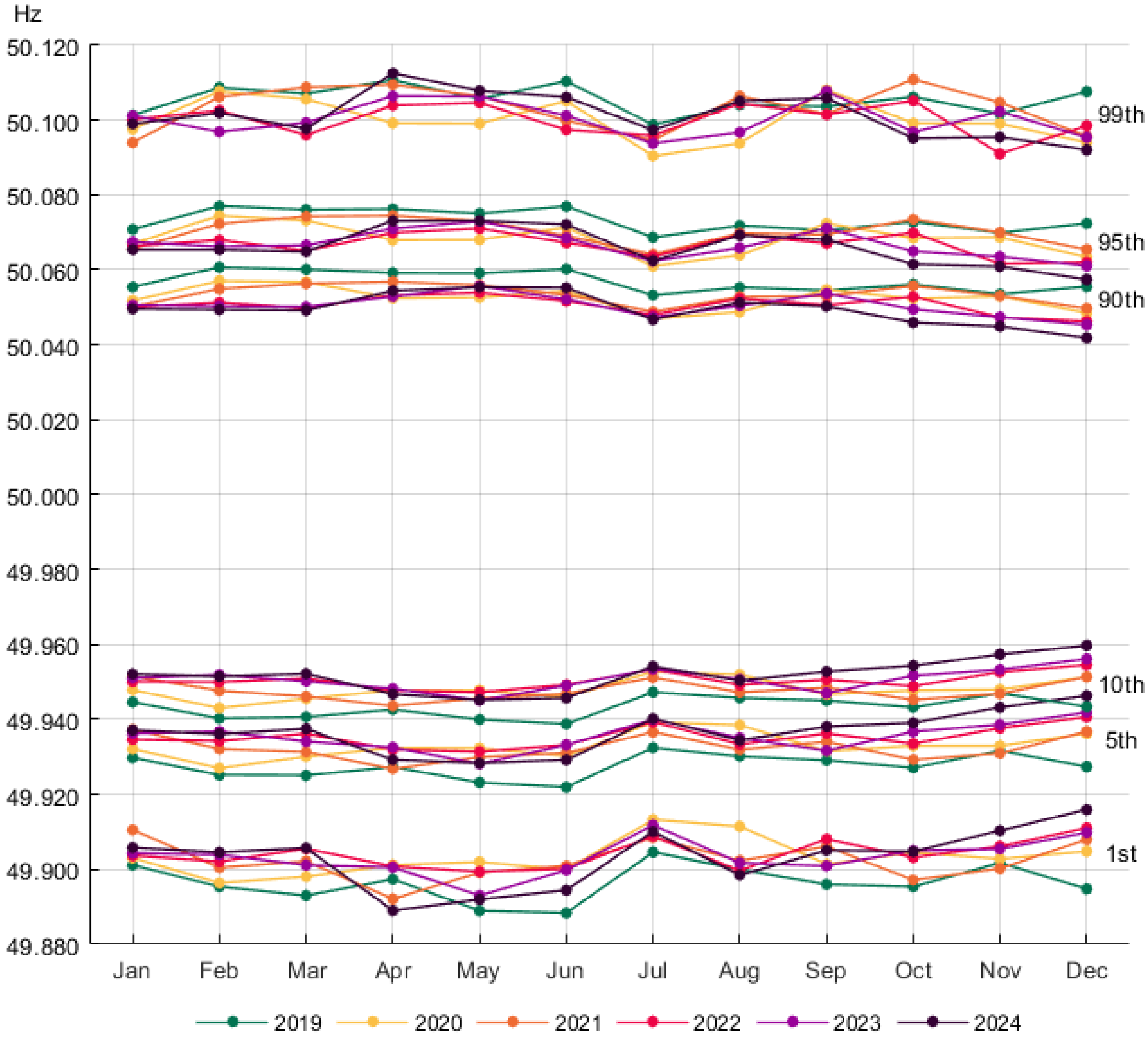
Table 3.7. The 1st, 5th, 10th, 90th, 95th, and 99th percentiles for the year 2023

	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 3.8. 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**

Figure 3.15. The 1st, 5th, 10th, 90th, 95th, and 99th percentiles for the years 2019-2024



More detailed results for the percentiles of 2024 are shown in the next figures. Figure 3.16 is a visual representation of the given percentiles for each month in 2024. The percentiles in April through June are the furthest away from 50 Hz, which indicates that the frequency values are spread around 50 Hz with a wide distribution. In 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, with 95th, 90th, 10th and 5th percentiles generally residing closer to the 50 Hz mark than during other years.

***Figure 3.16**. The 1st, 5th, 10th, 90th, 95th, and 99th percentile of the frequency for every month in 2024*

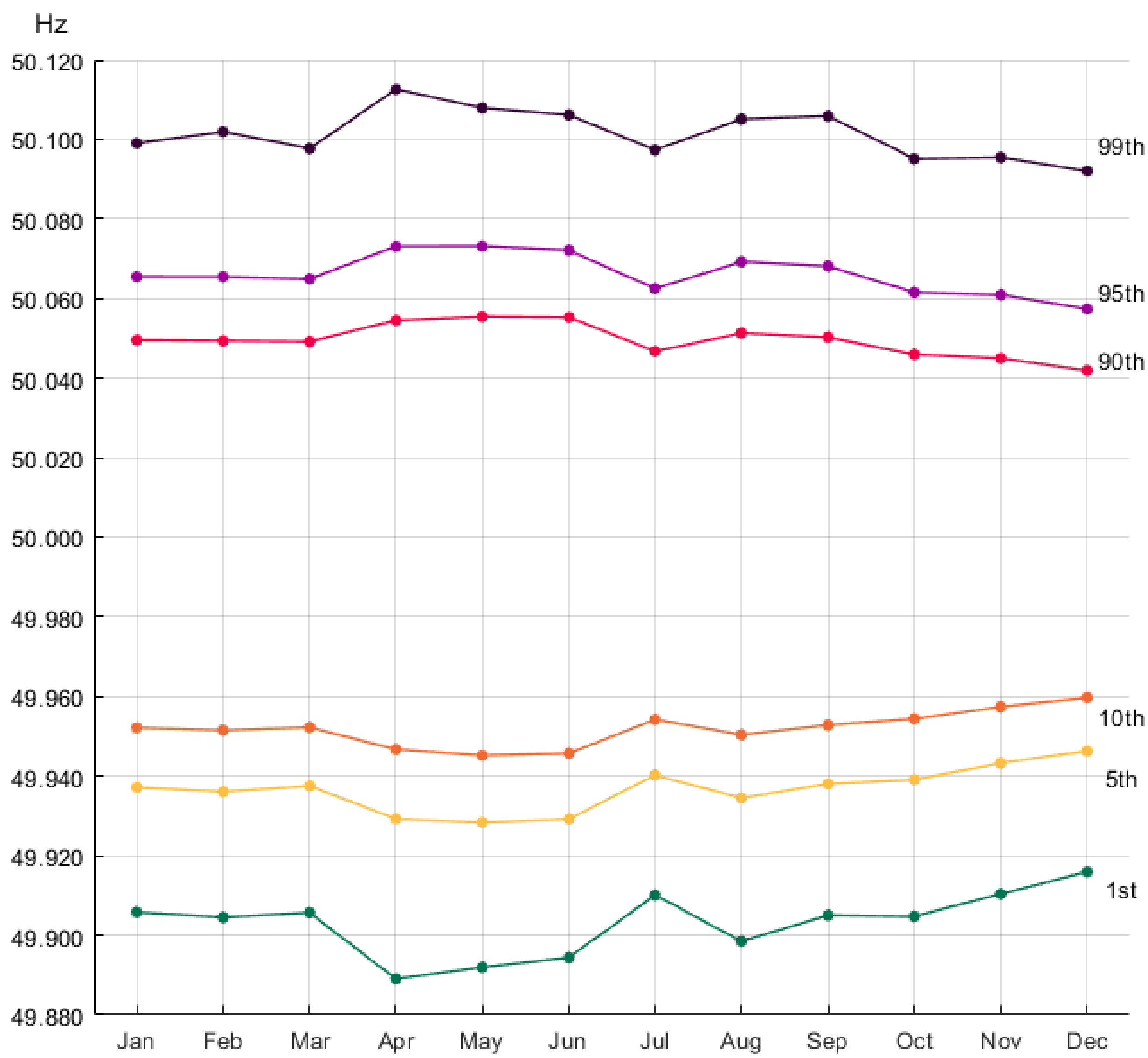


Figure 3.17 shows the percentiles for each day during the week. The percentiles stay approximately level through the week. The most notable exception to this trend is the 99th percentile, where Monday and Sunday are clearly furthest from 50 Hz, indicating wider frequency range during those days.

***Figure 3.17**. The 1st, 5th, 10th, 90th, 95th, and 99th percentile of the frequency for every day of the week in 2024*

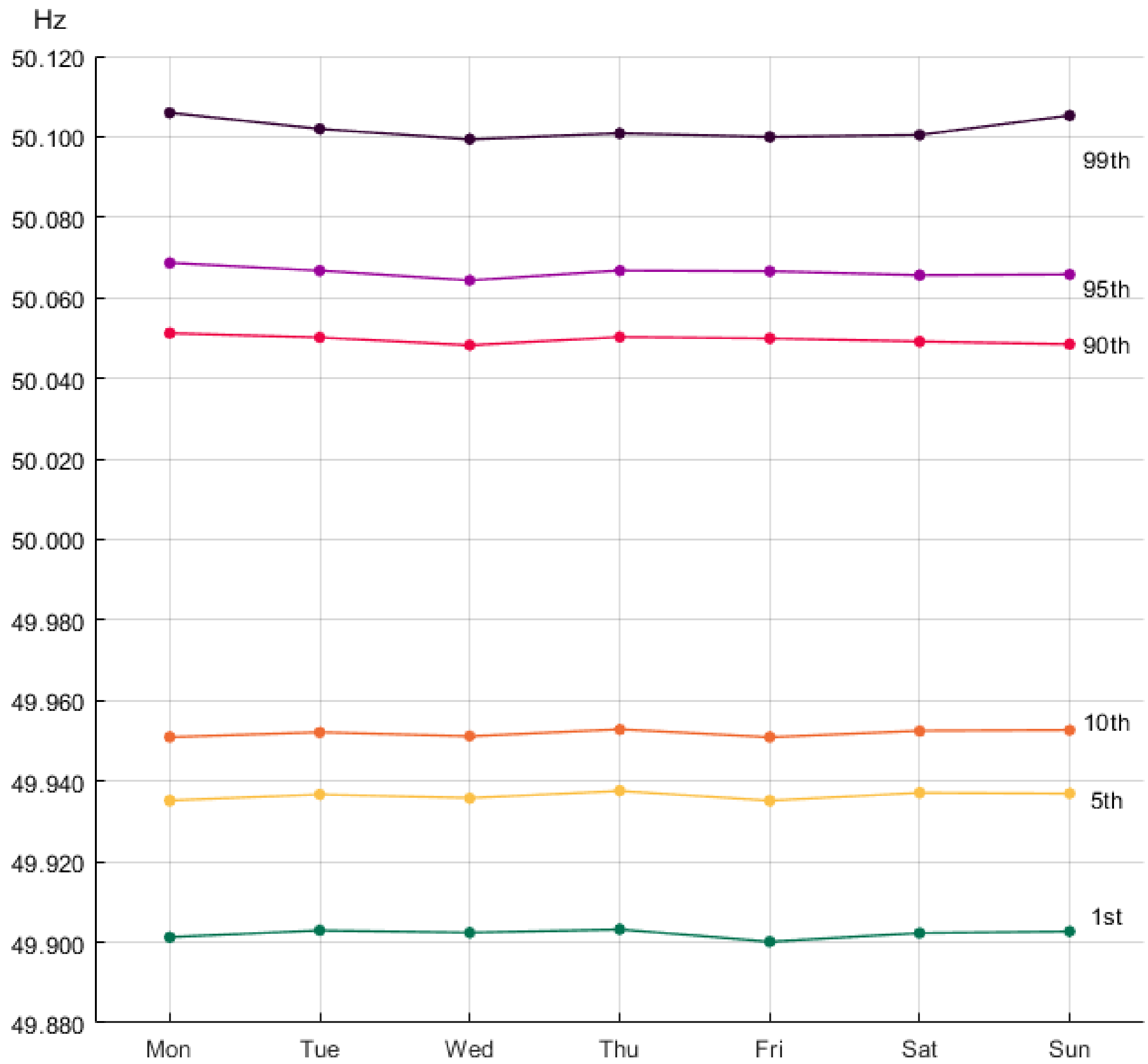


Figure 3.18 represents the percentiles within a day. All percentiles gain higher values at 9 pm, 11 pm and at midnight. This indicates that there have been more over frequencies and fewer under frequencies. Under frequencies are more typical at 1 am, 6 am, and at noon at around 2-4 pm.

***Figure 3.18**. The 1st, 5th, 10th, 90th, 95th, and 99th percentile of the frequency for every hour of the day in 2024*

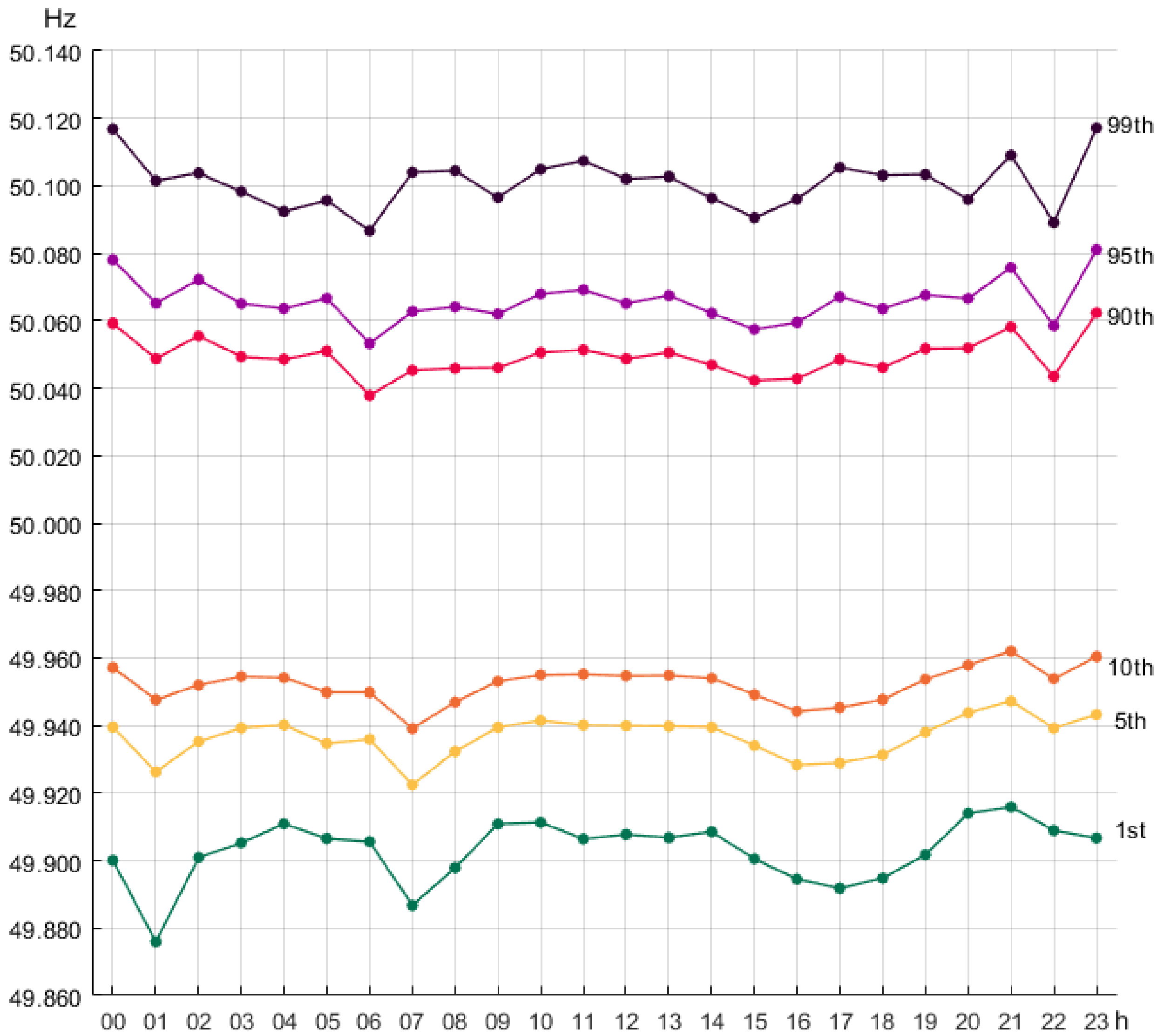
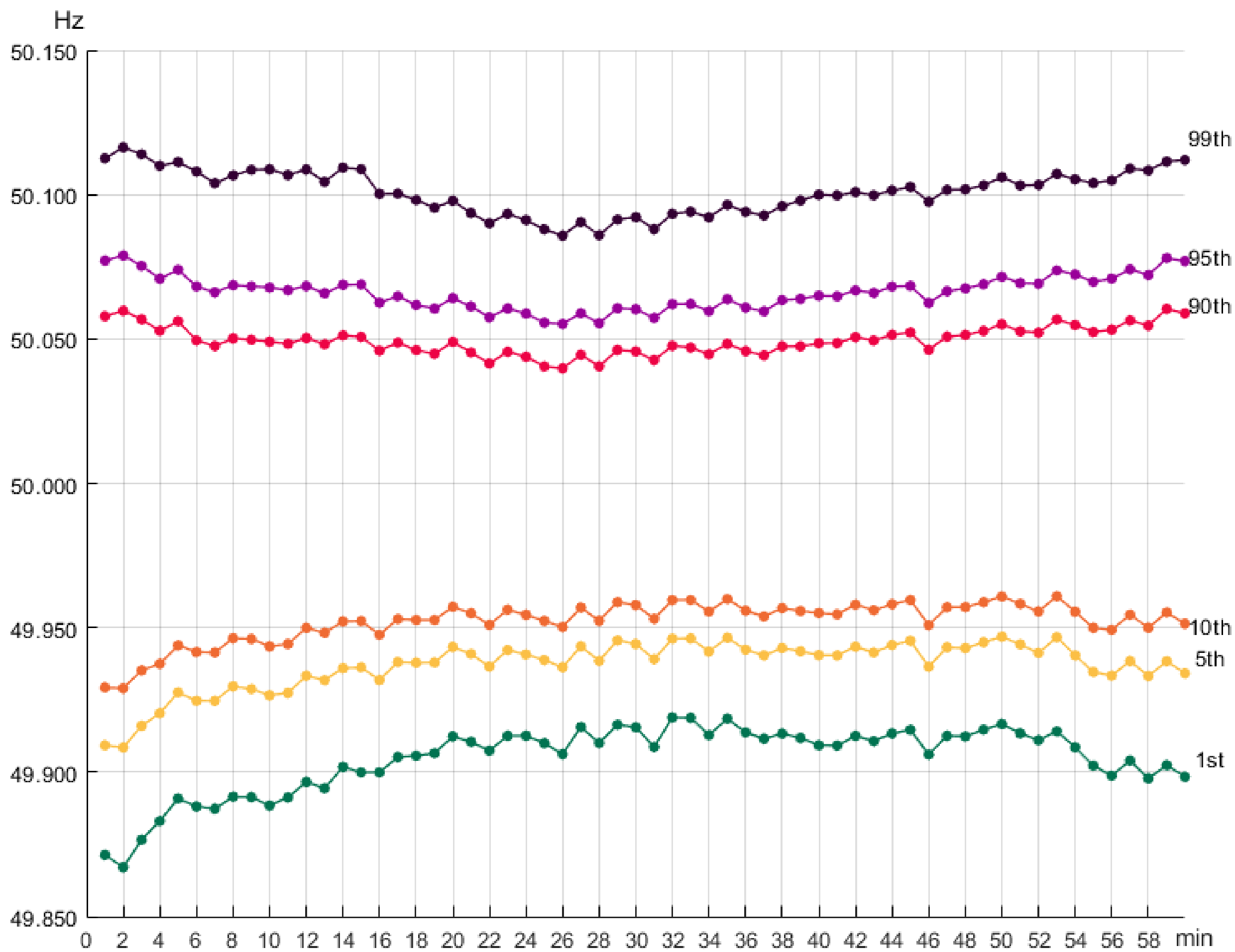


Figure 3.19 shows the percentiles within an hour. Overall, more frequency deviation has occurred close to the hour shift. The 90th, 95th, and 99th percentiles gain the highest values during a time interval of a few minutes at the hour shift. The 10th, 5th, and 1st percentiles gain the lowest values at 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 2024*



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 2024. The cumulative minutes outside the standard frequency range exceeded the Nordic target level of 10 000 minutes by approximately 500 minutes. The cumulative growth of minutes outside the standard frequency range is less steady compared to 2023 and especially compared to 2022. There are periods of fast growth in particular in April and August. Periods of slow and fast growth occur at similar points during the calendar year compared to 2023.

Figure 3.20. Cumulative minutes outside the standard frequency range in 2024

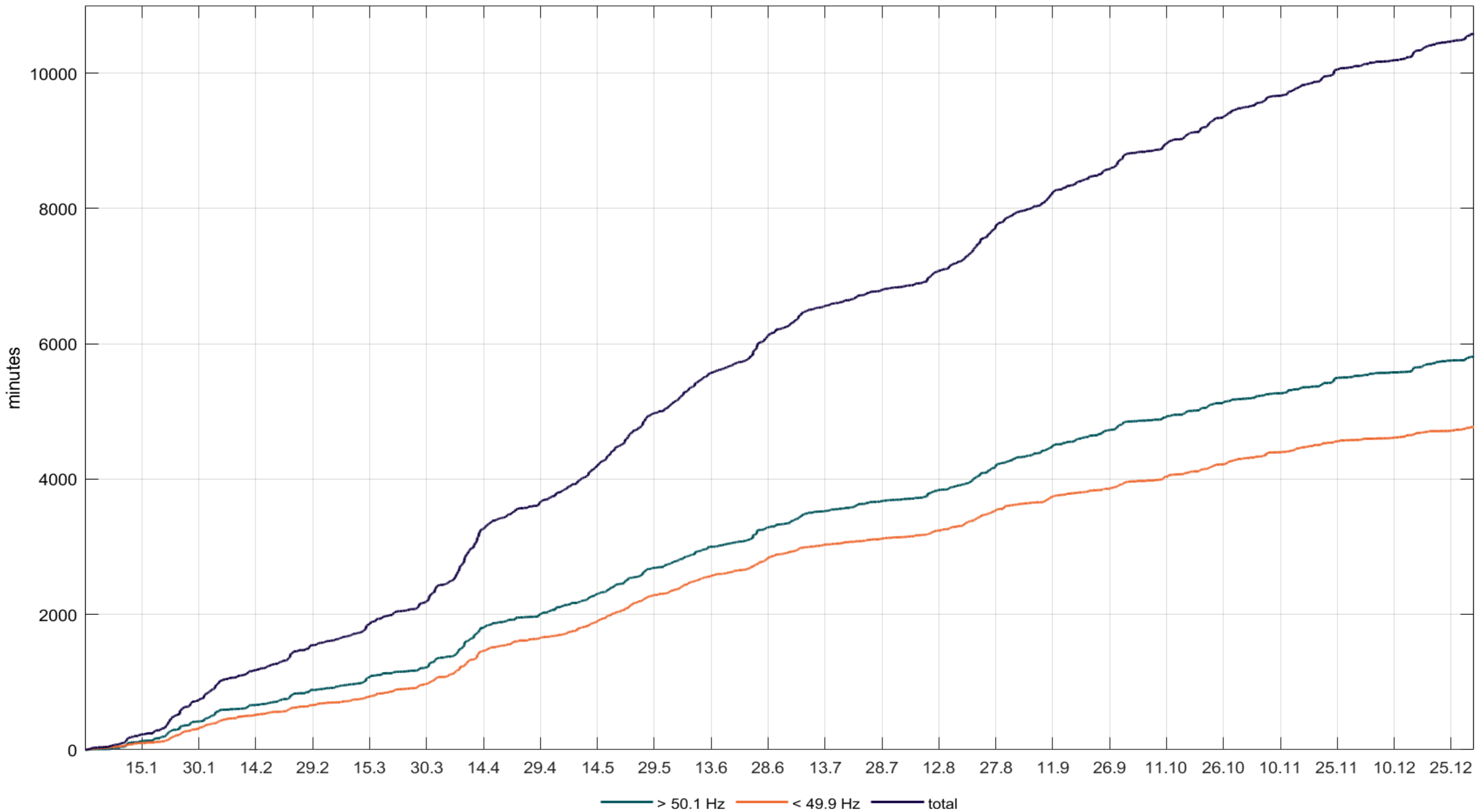
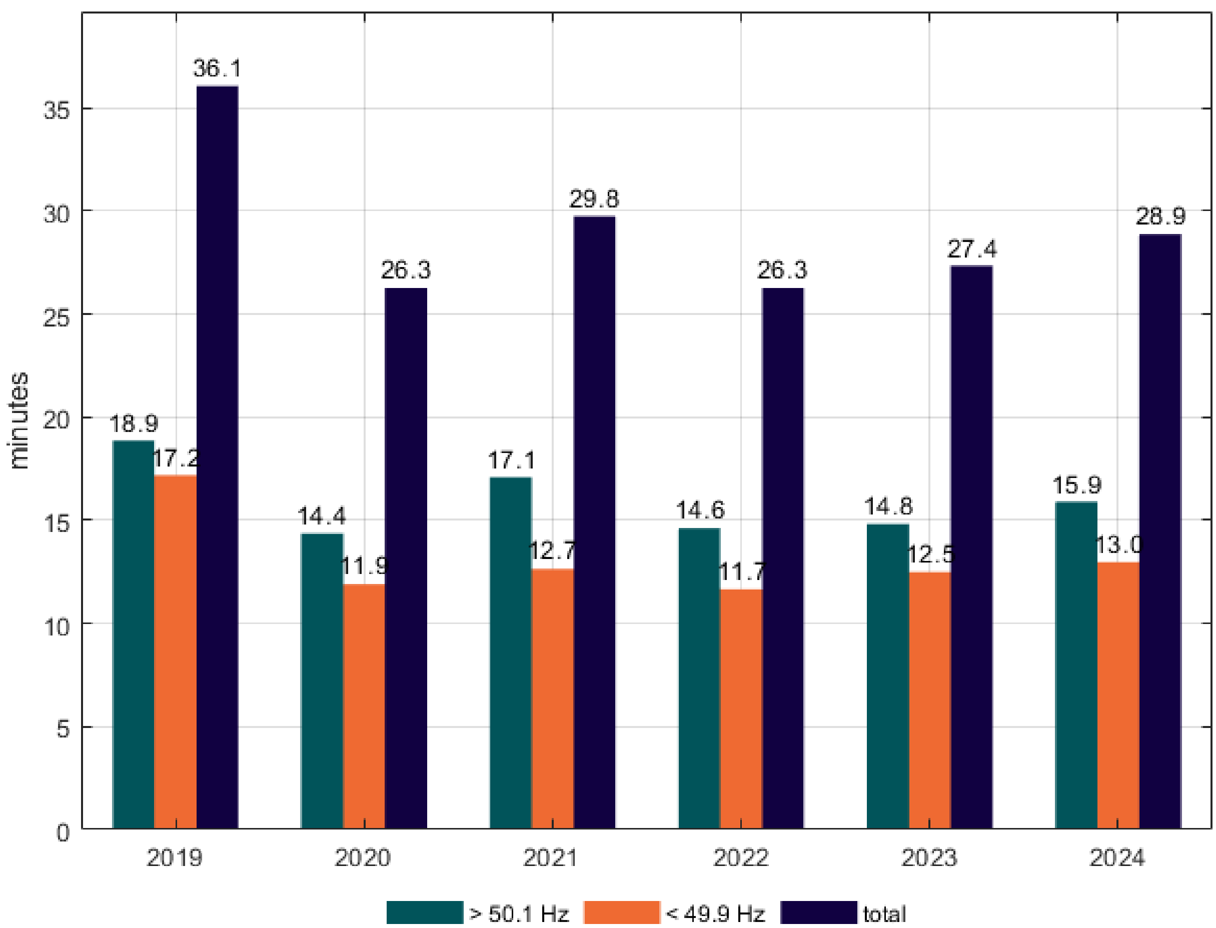


Figure 3.21 represents the daily average number of minutes for which the frequency was outside the standard frequency range in 2024. The number of minutes outside the standard frequency range has slightly increased since 2023. Every year, there have been more over frequencies than under frequencies.

***Figure 3.21**. Daily average number of minutes per year that the frequency was outside the standard frequency range in 2019-2024*



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
2019	1.33 %	1.21 %	97.46 %
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 %

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)
2019	6997	6377	13374
2020	5375	4456	9831
2021	6247	4621	10868
2022	5357	4273	9630
2023	5438	4586	10025
2024	5822	4749	10571

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 2019-2024. 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 2019-2021

	2019		**2020**		**2021**	
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	478	414	385	375	299	199
February	632	519	619	506	547	393
March	650	628	598	489	687	390
April	709	501	411	405	682	620
May	507	633	422	399	618	466
June	719	766	563	430	428	407
July	413	332	251	179	322	262
August	552	444	259	179	589	386
September	515	526	614	390	471	295
October	606	568	420	333	717	516
November	471	387	397	359	537	425
December	637	584	320	352	346	275
Entire year	**6890**	**6302**	**5258**	**4396**	**6242**	**4631**

Table 3.12. Total time for which the frequency was outside the 49.9-50.1 Hz band in years 2022-2024

	2022		**2023**		**2024**	
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	449	363	474	356	424	335
February	454	361	332	334	461	327
March	339	315	428	420	394	337
April	524	413	600	420	749	669
May	568	460	629	621	673	638
June	373	428	459	436	603	572
July	357	285	305	211	389	259
August	555	453	365	407	583	478
September	464	267	617	408	569	337
October	574	374	370	342	342	355
November	255	306	478	334	339	273
December	420	233	359	278	293	191
Entire year	**5334**	**4260**	**5416**	**4568**	**5819**	**4770**

Figure 3.22. Total time for which the frequency was outside the 49.9-50.1 band in years 2019-2024

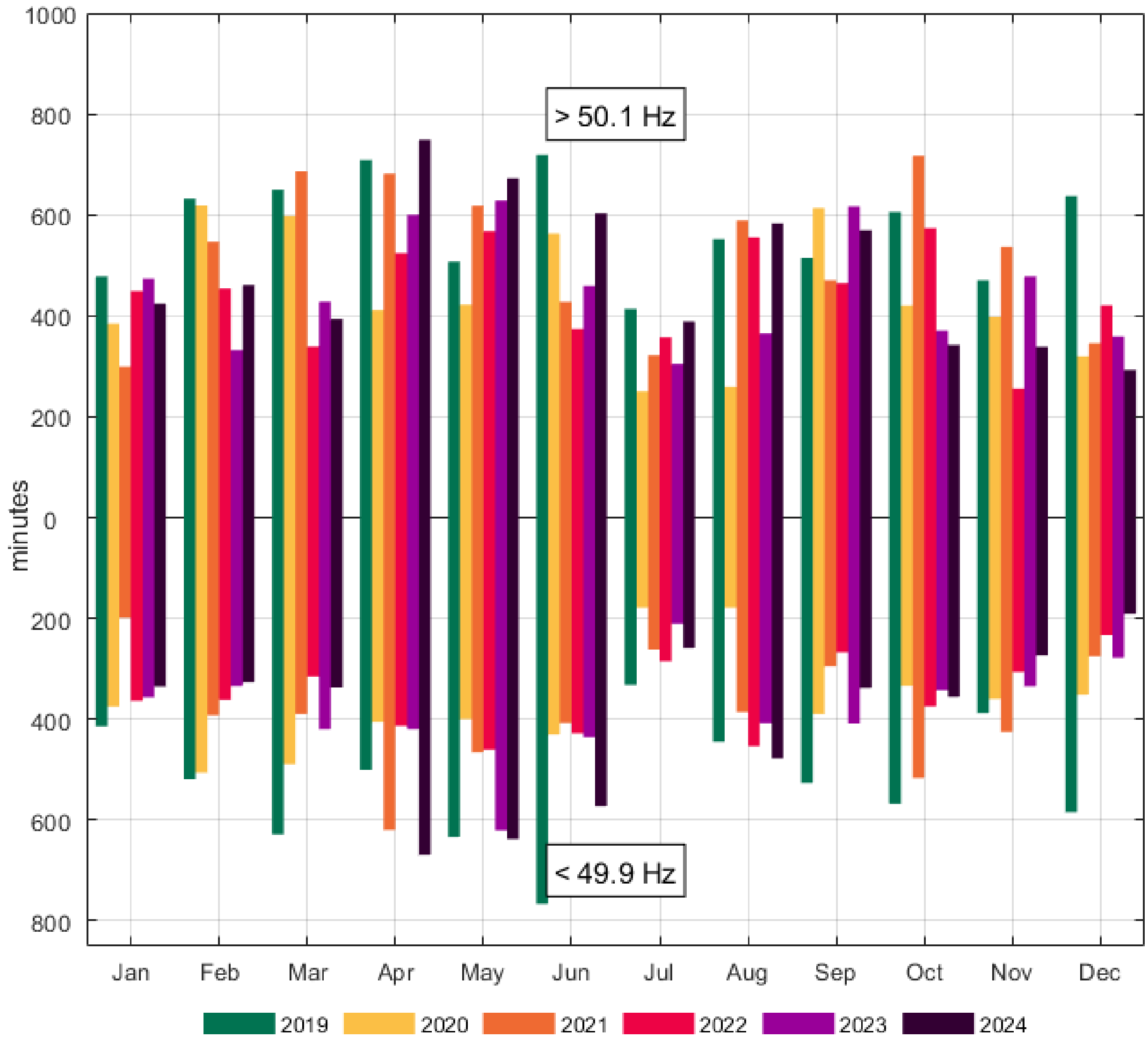


Figure 3.23 shows the daily average in minutes, month by month, for which the frequency has been outside the standard frequency range in the years 2019-2024. In 2024, April had the longest time outside the standard frequency range, while December had the best frequency in this comparison.

***Figure 3.23**. Daily average time for which the frequency was outside the standard frequency range month by month for years 2019-2024*

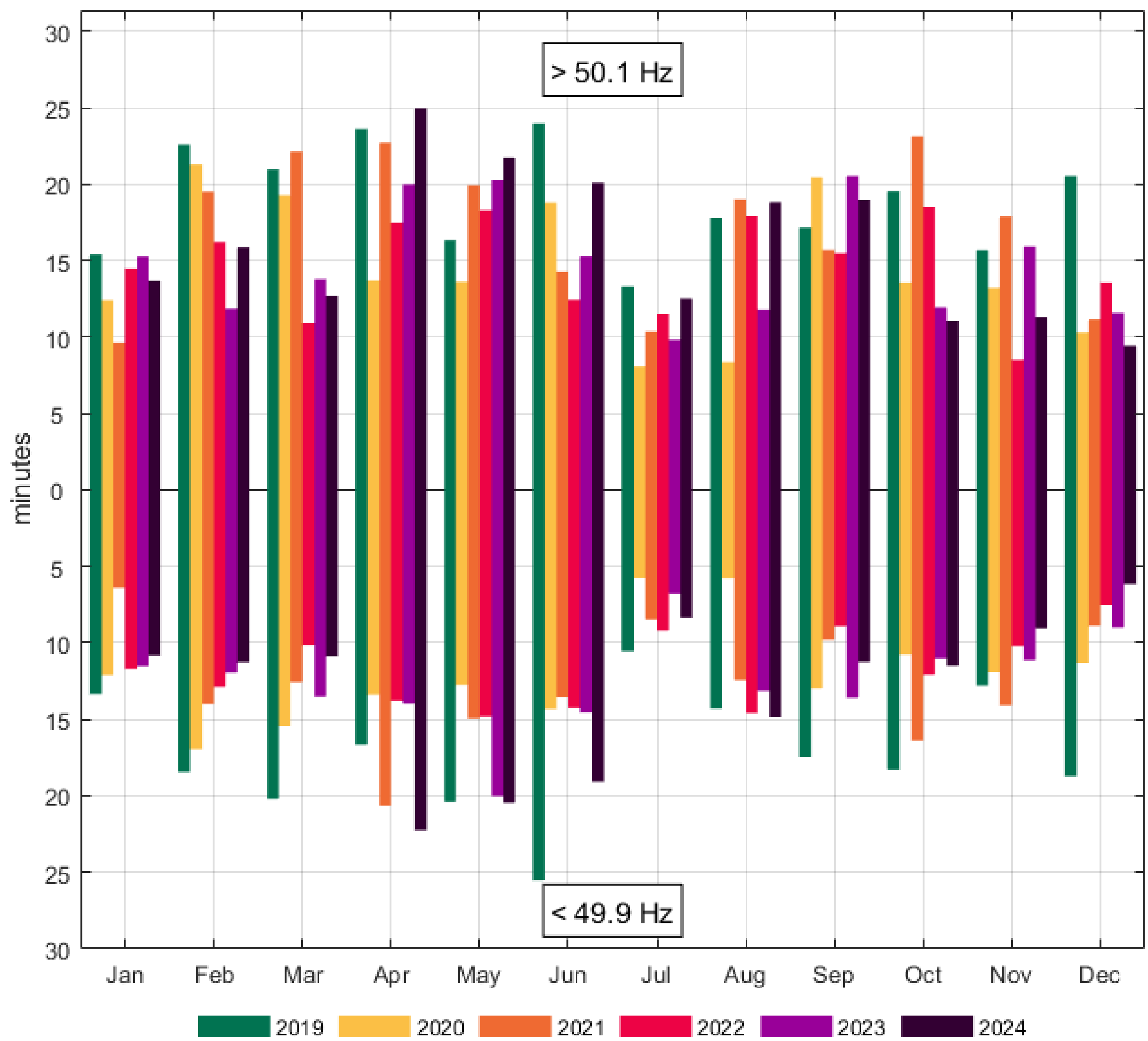


Figure 3.24 represents the daily average time for which the frequency has been outside the standard frequency range during each day of the week. In 2024, the frequency has been outside the standard frequency range the most on Monday and Sunday, and least on Wednesday and Friday.

***Figure 3.24**. Daily average time that the frequency was outside the standard frequency range during each day of the week for years 2019-2024*

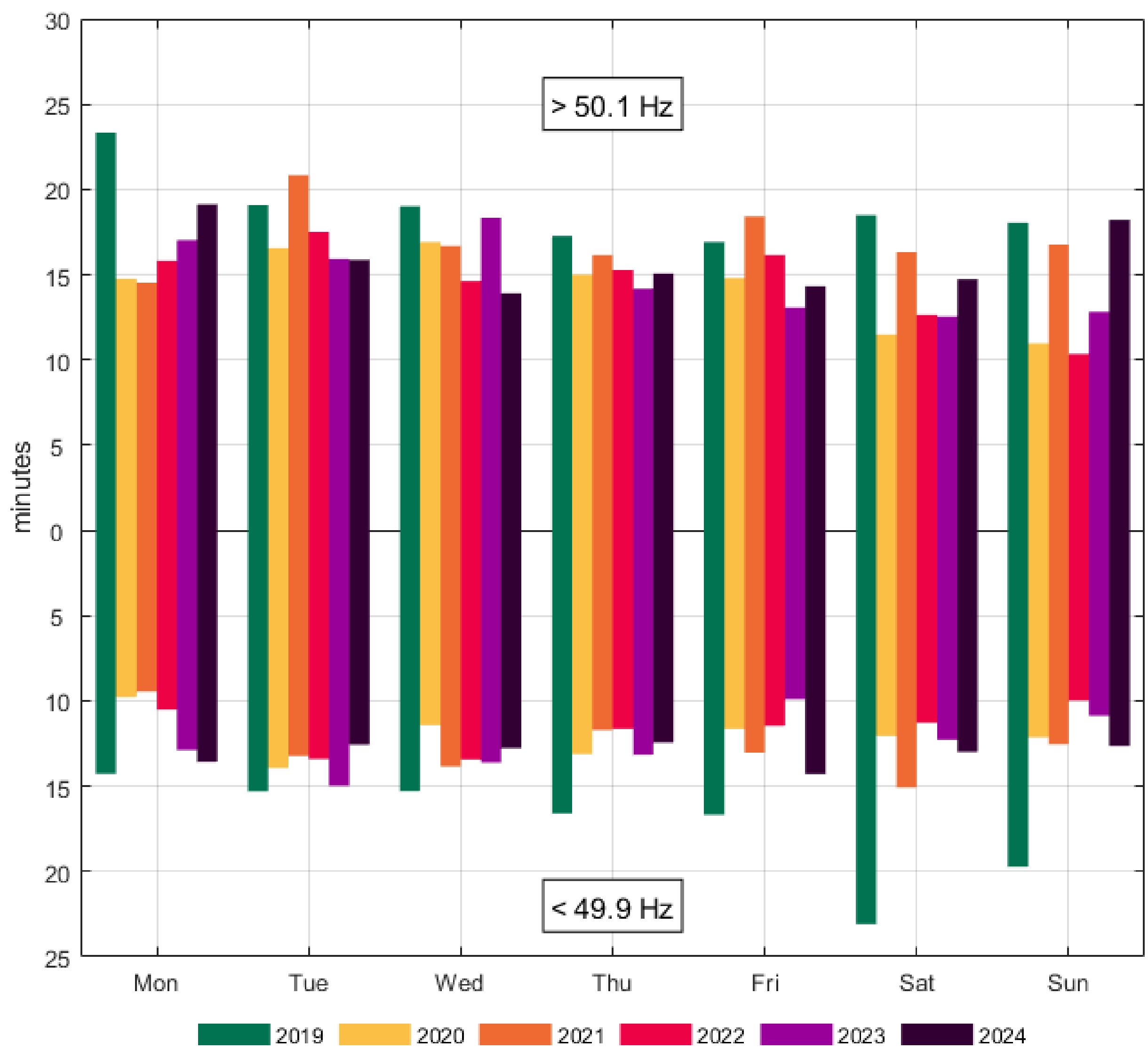


Figure 3.25 represents the daily average time that the frequency was outside the standard frequency range for each hour within a day. In 2024, the frequency went above 50.1 Hz the most at midnight and at 9 and 11 pm. Frequencies under 49.9 Hz were the most common at 1 am, 7 am, and 5 pm. The frequency was most consistently within the standard frequency range between 9 am and 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 2019-2024*

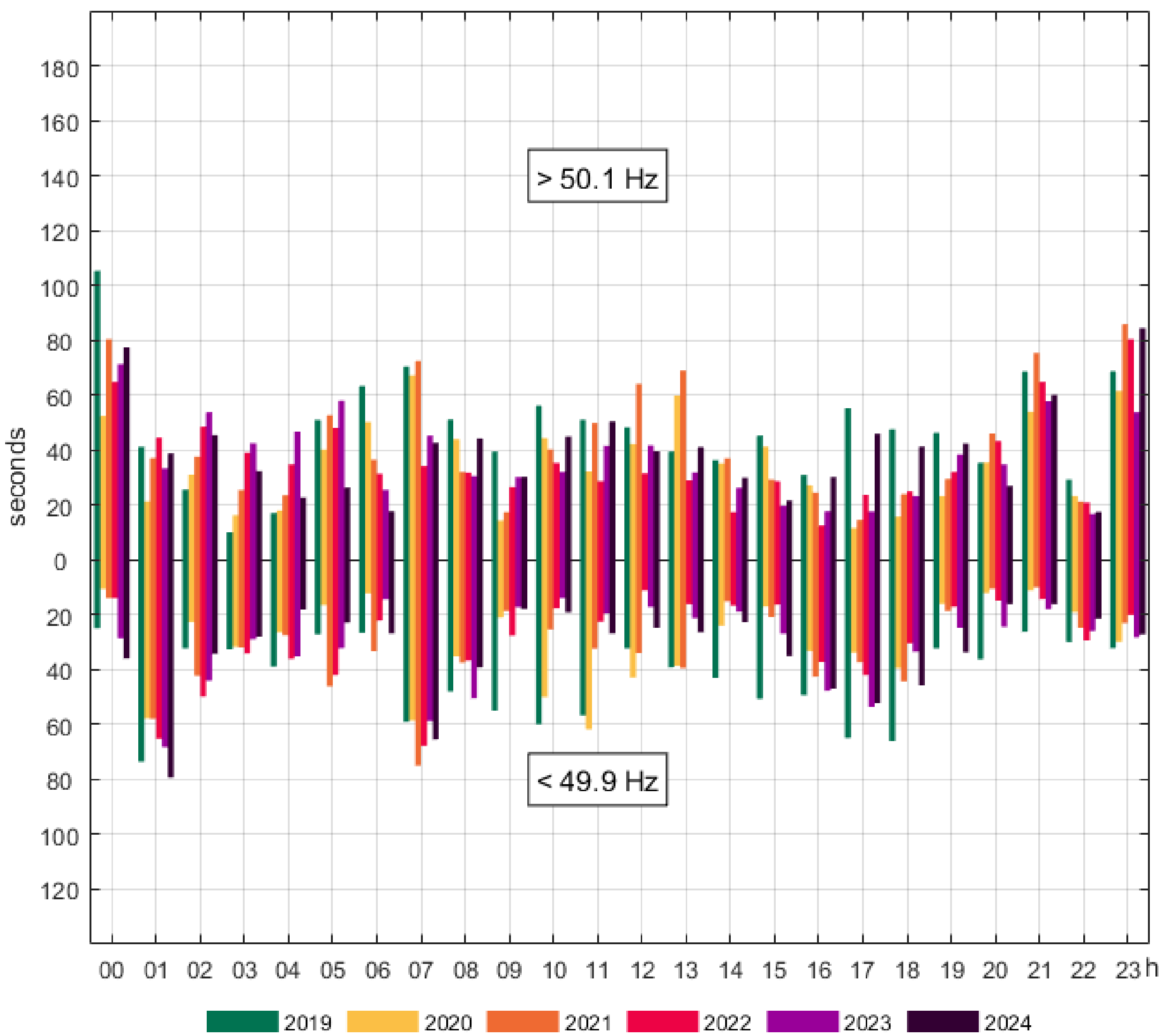


Figure 3.26 shows the daily average time outside the standard frequency range per hour and the absolute value of Nordic consumption and production differences. Also, the transmission difference of HVDC links connecting the Nordic power system to the rest of Europe is presented.

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 ENTSO-E Transparency platform 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 production difference is around 1500 MWh, and for consumption difference, the peak is around 2200 MWh. At midnight, for both the production and consumption difference, the peak is slightly below 1500 MWh. The peaks of the production difference have dropped significantly in comparison to 2023, while the peaks of the consumption difference have increased slightly. The peaks in HVDC transmission differences are comparable to those in 2023, and the peak at 6 pm has remained at approximately 700 MWh.

***Figure 3.26**. Seconds per hour outside the standard frequency range and the absolute values of Nordic consumption, production and HVDC transmission differences in 2024*

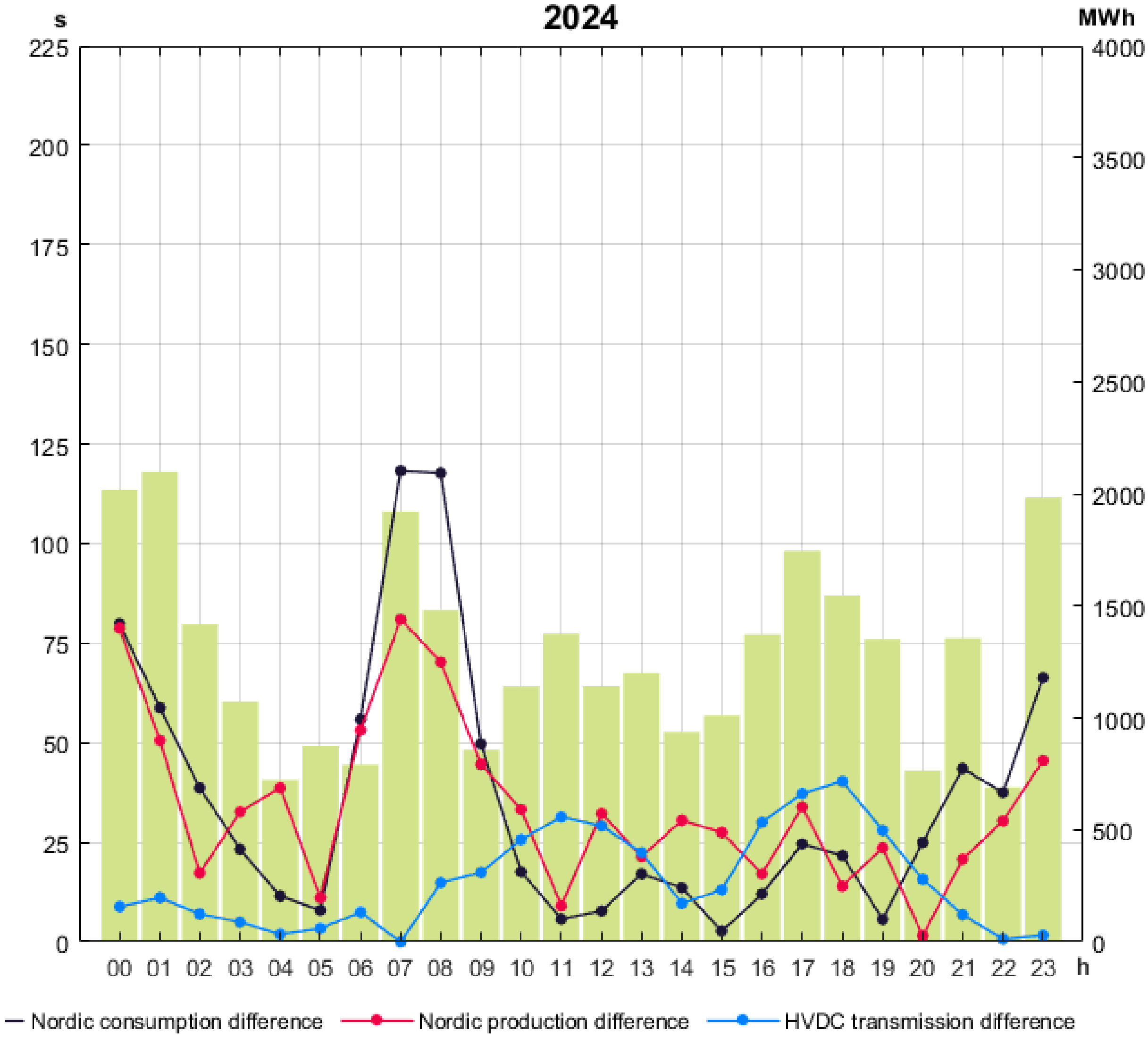


Figure 3.27 illustrates an average hour divided into 60 minutes. For each minute of the average hour, there is a value in seconds per hour indicating how long the frequency has been above or below the standard frequency range. In the years 2019-2024, the frequency has been outside the standard frequency range most often at the beginning of the hour. The frequency has stayed the best inside the standard frequency range in the middle of the hour. The time above the standard frequency range has increased again towards the end of the hour. In 2024, there have been more under frequencies at the beginning of the hour compared to previous years. Otherwise, the performance has been comparable or better than in the previous years.

***Figure 3.27**. Number of seconds per hour outside the standard frequency range in 2019-2024 for each minute of an average hour*

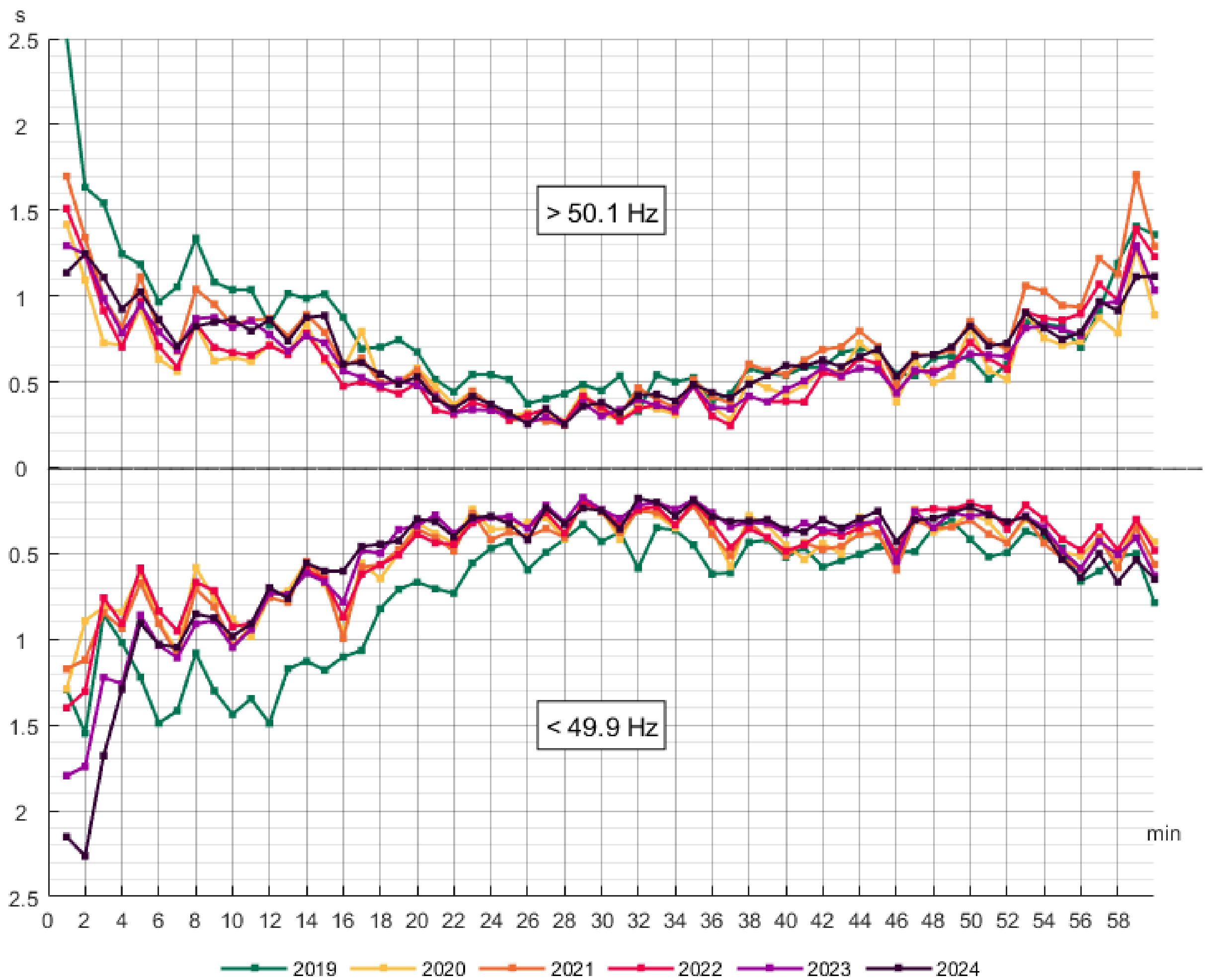
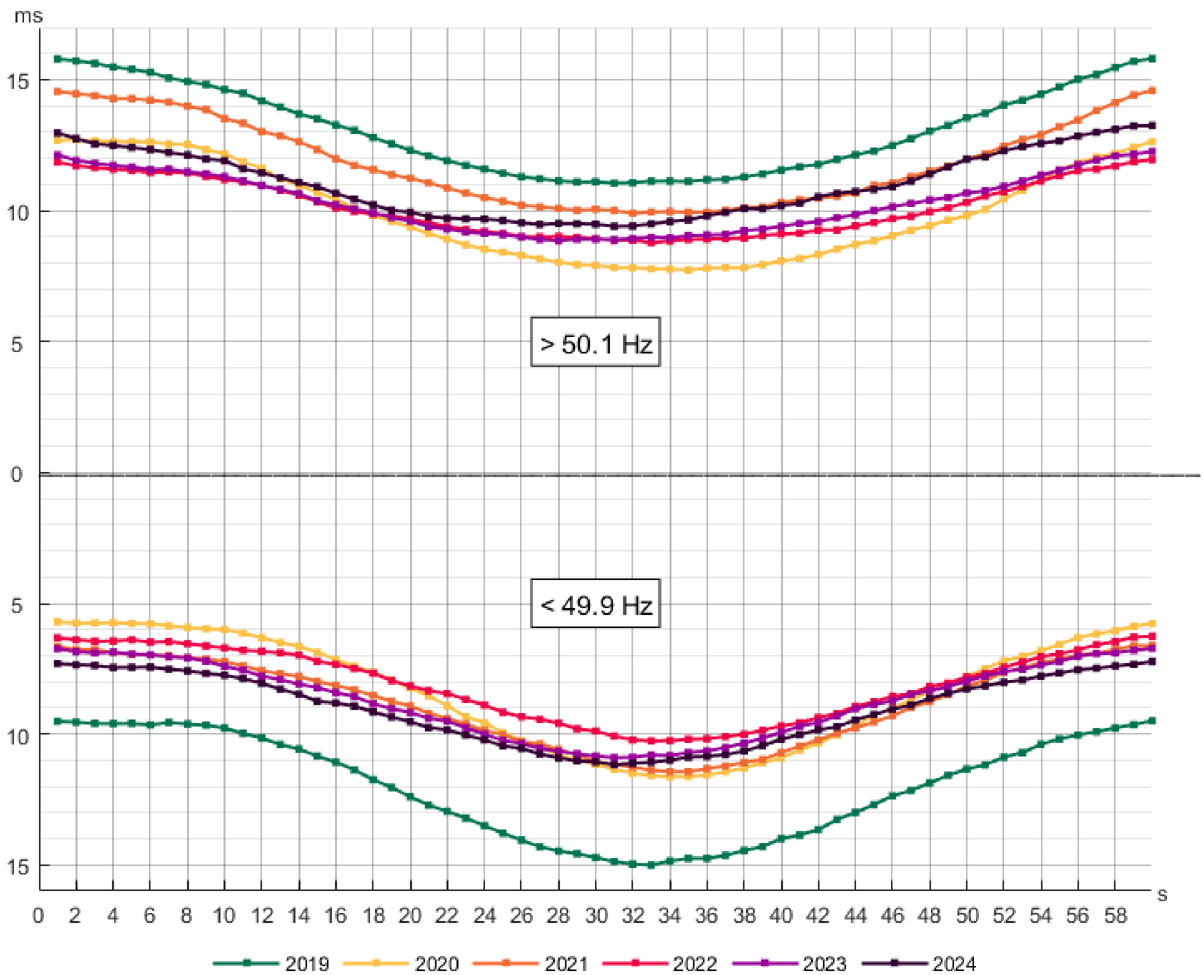


Figure 3.28 illustrates an average minute divided into 60 seconds. For each second of the average minute, there is a value in milliseconds per minute indicating the time that the frequency has been above or below the standard frequency range. There have been more over frequencies at the beginning and at the end of the average minute. Under frequencies have occurred more frequently in the middle of the minute. Both under and over frequencies have been more common through the minute in 2024 when compared to 2023.

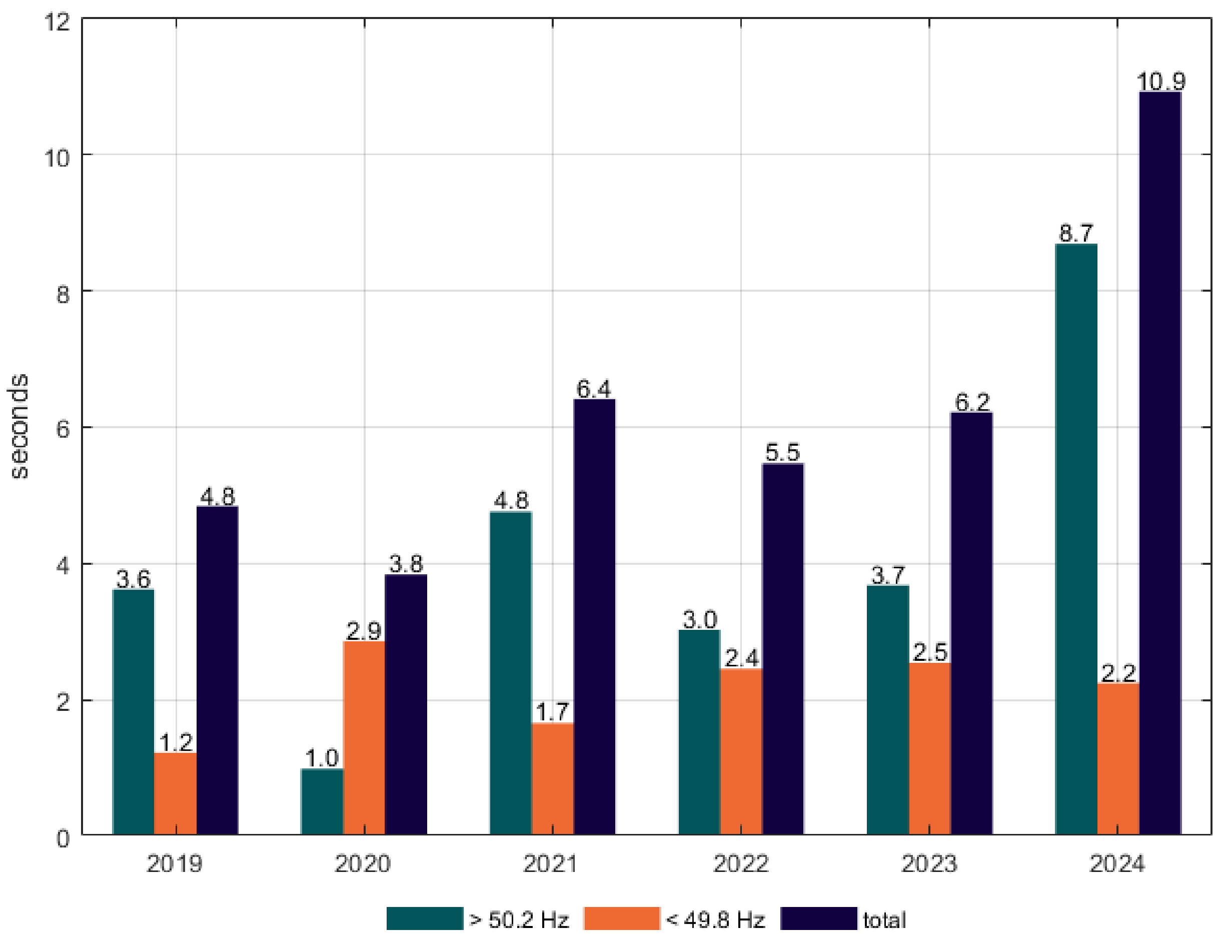
***Figure 3.28**. Number of milliseconds per minute outside the standard frequency range in 2019-2024 for each second of an average minute*



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 49.8-50.2 Hz was higher in 2024 compared to 2023. In 2024, over frequencies exceeding 200 mHz have been more common than under frequencies, which is in line with the trend of the previous years excluding 2020. While examining the years 2019 to 2024, the year 2024 had the clearly the largest total time outside 49.8-50.2 Hz.

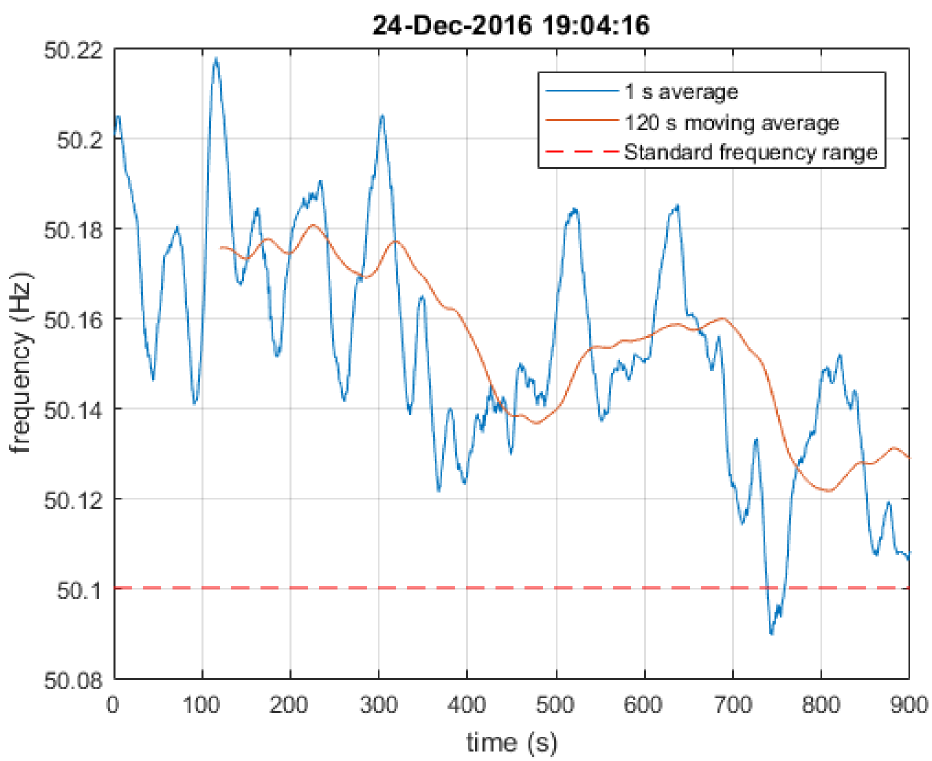
***Figure 3.29**. Average number of seconds per day that the frequency was outside the 49.8-50.2 Hz band for years 2019-2024*



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).
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 2019-2024 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.

	2019		**2020**		**2021**		**2022**		**2023**		**2024**	
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	0	0	1	0	0	0	0	0	1	0
March	0	0	0	0	1	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	0	0	1	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	0	0	1	0	2	0	0	0	0	0	**1**	**0**

Table 3.14 shows the number of events in 2019-2024 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.*

	2019		**2020**		**2021**		**2022**		**2023**		**2024**	
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	1	0
February	1	0	0	0	2	0	0	0	0	0	1	0
March	0	0	0	0	1	0	0	0	0	0	0	0
April	1	0	0	0	0	0	0	0	0	0	0	1
May	0	0	0	0	1	0	0	0	0	0	0	1
June	0	1	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	1	0	0
September	0	0	1	0	1	0	0	0	2	0	0	0
October	1	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	1	0	0	0	1	0	0	0
December	1	0	0	0	0	0	1	0	0	0	0	0
Entire year	4	1	1	0	6	0	1	0	3	1	**2**	**2**
Sum	**5**		**1**		**6**		**1**		**4**		**4**	

3.4.3 Time outside 49.0-51.0 Hz

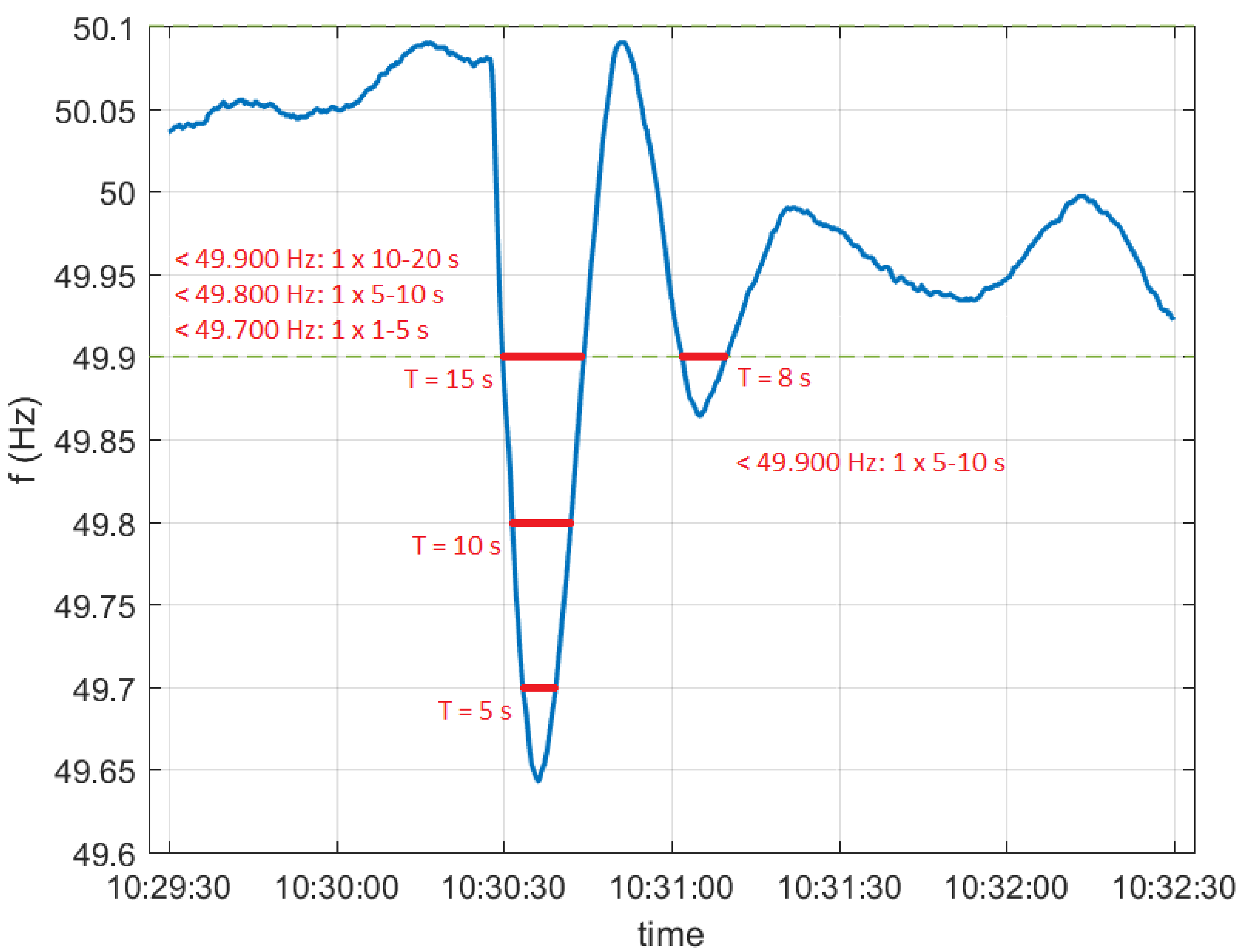
Time outside 49.0 Hz and 51.0 Hz is calculated by counting the number of samples that are below 49.0 Hz or above 51.0 Hz and multiplying the number by the time duration of the sample. The criteria are also defined in SO GL Article 131(1)(a) (v). The resolution of the data used was 1 second.

There were no instances in 2019-2024 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 2019 to 2024. 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 2019

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	17123	5604	3945	6279	4075	933	682	132	38773	833.60	10.43
> 50.2	59	23	30	36	14	3	1	0	166	62.70	8.24
> 50.3	1	2	0	0	0	0	0	0	3	4.10	2.87
< 49.9	15996	5903	3903	5897	3776	858	634	110	37077	731.40	9.90
< 49.8	57	33	21	12	2	0	0	0	125	23.80	3.78
< 49.7	0	2	2	0	0	0	0	0	4	9.00	6.53
< 49.6	0	1	0	0	0	0	0	0	1	1.60	1.60
< 49.5	0	0	0	0	0	0	0	0	0	0.00	0.00

Table 3.16. 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 3.17. 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 3.18. 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 3.19. 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 3.20. 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

Figure 3.32 is a visual representation of the data in Tables 3.15-3.20. The number of deviations is now given as a daily average instead of a total number per year. The year 2020 has had the smallest number of deviations in the observation period. The number of frequency deviations of 0-1 seconds in 2024 has been higher than in previous years, while the number of longer deviations is comparable to previous years.

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

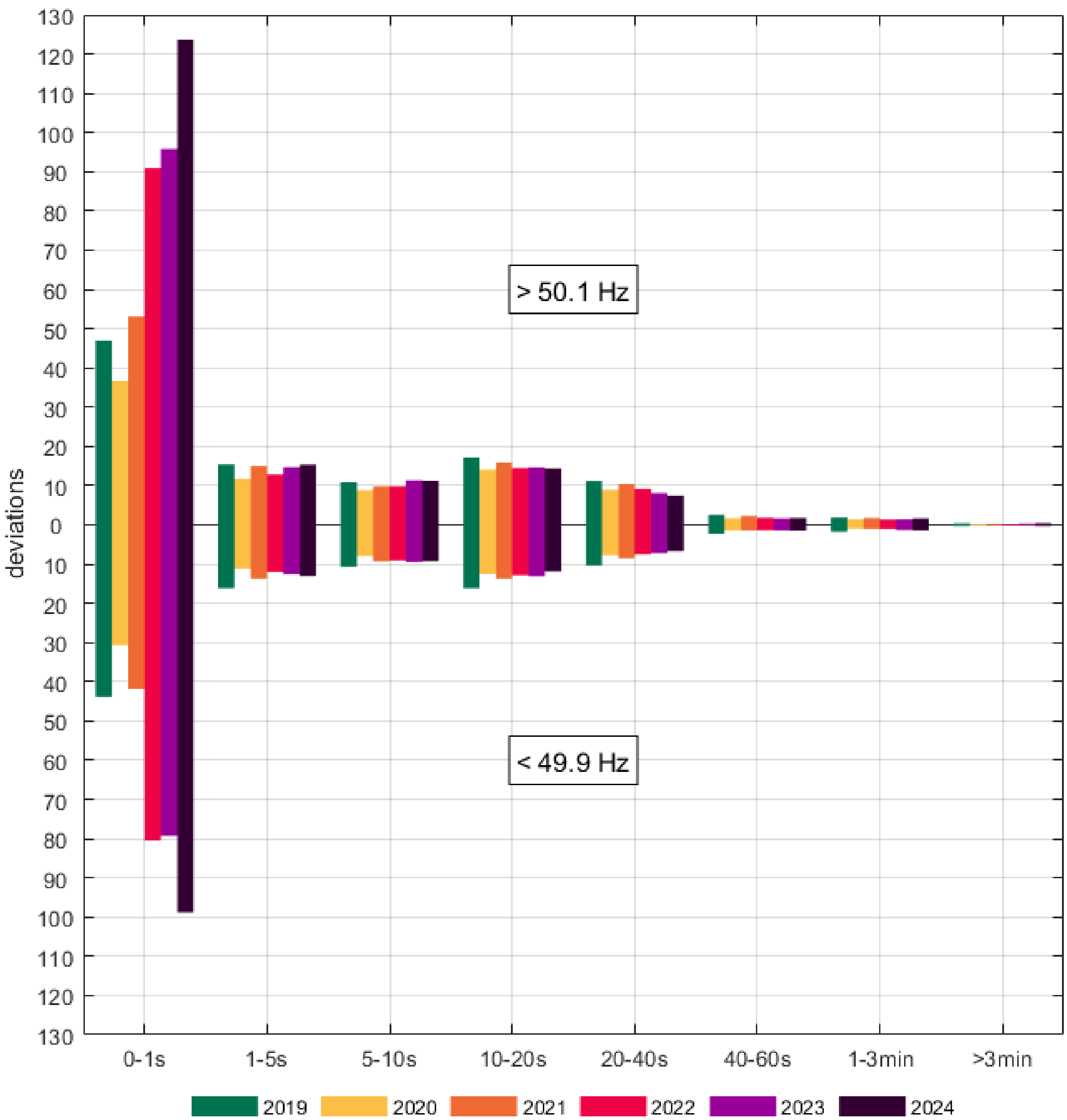
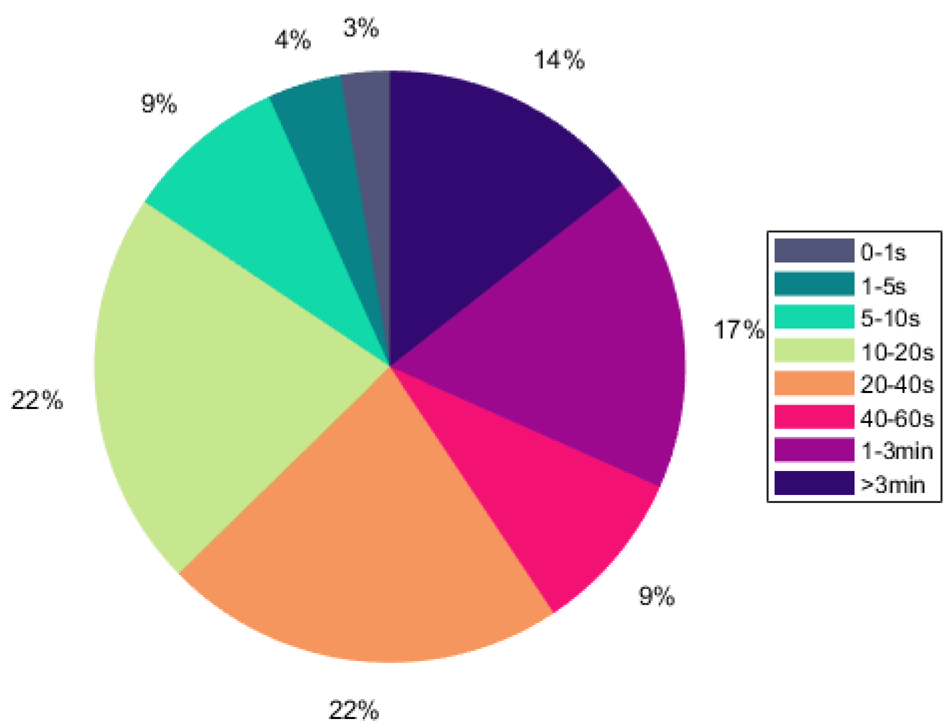


Table 3.21 shows how deviations of different durations affected the total time outside the standard frequency range in 2024. The times are given in minutes. Figure 3.33 shows in percentages how the total time outside the standard frequency range was divided between deviations of different durations. Deviations with a duration of 10-20 s and 20-40 s made up 44 % of the total time outside the standard frequency range. The share of over 3-minute deviations has increased by four percentage points from the previous year.

***Table 3.21*. Total minutes in 2024 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	159	230	514	1255	1232	518	960	955	5822
< 49.9 Hz	125	195	425	1039	1097	433	860	569	4744
total	284	425	939	2294	2329	951	1820	1524	10566

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



The following figures go into more detail on the deviations in 2024. Figure 3.34 represents the total number of deviations per duration for each month in 2024. Most of the deviations have lasted less than 1 second. Deviations occurred most commonly in May, June and September, while January and December had the smallest number of deviations.

***Figure 3.34**. Total number of frequency deviations per duration for each month in 2024*

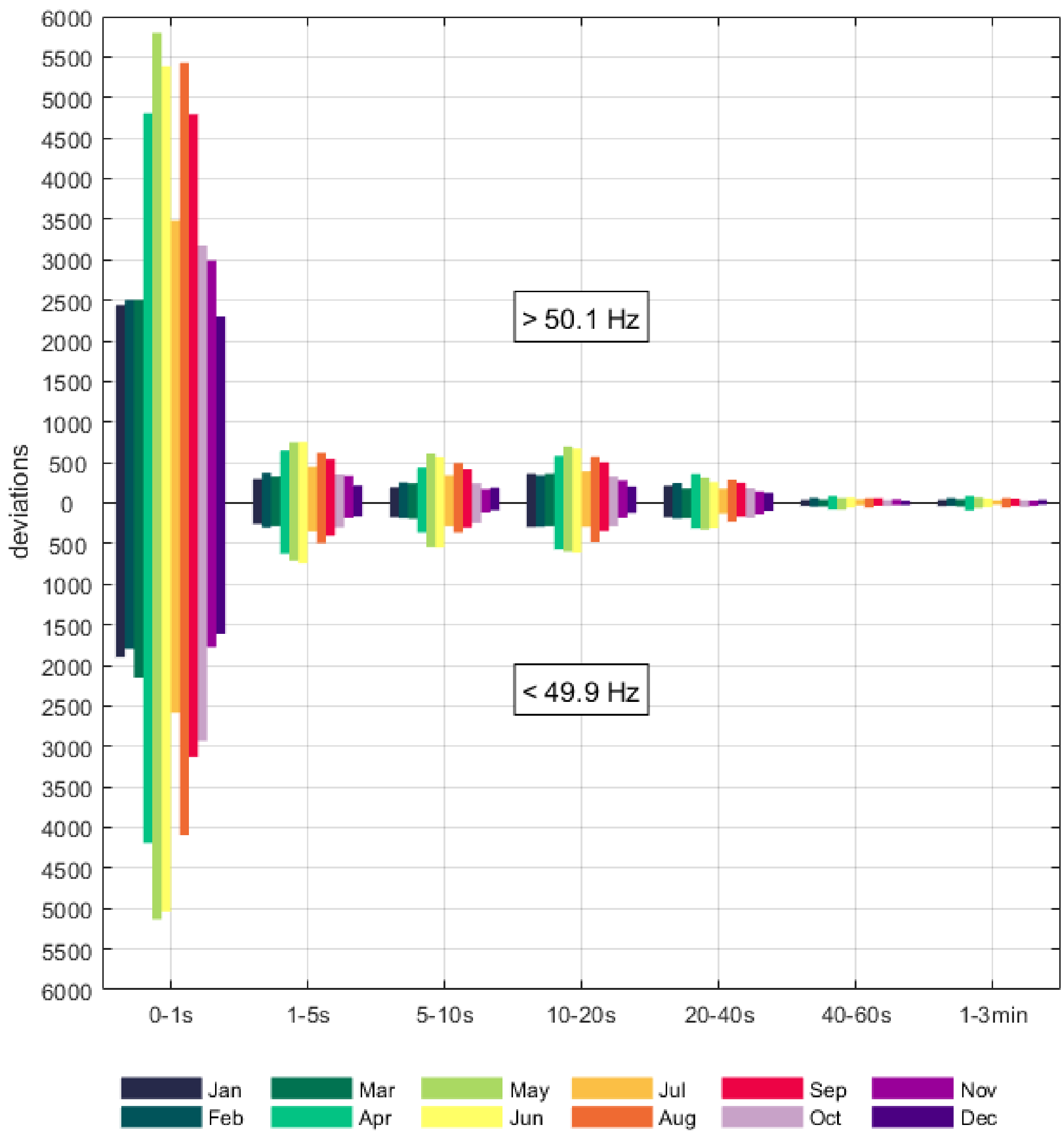
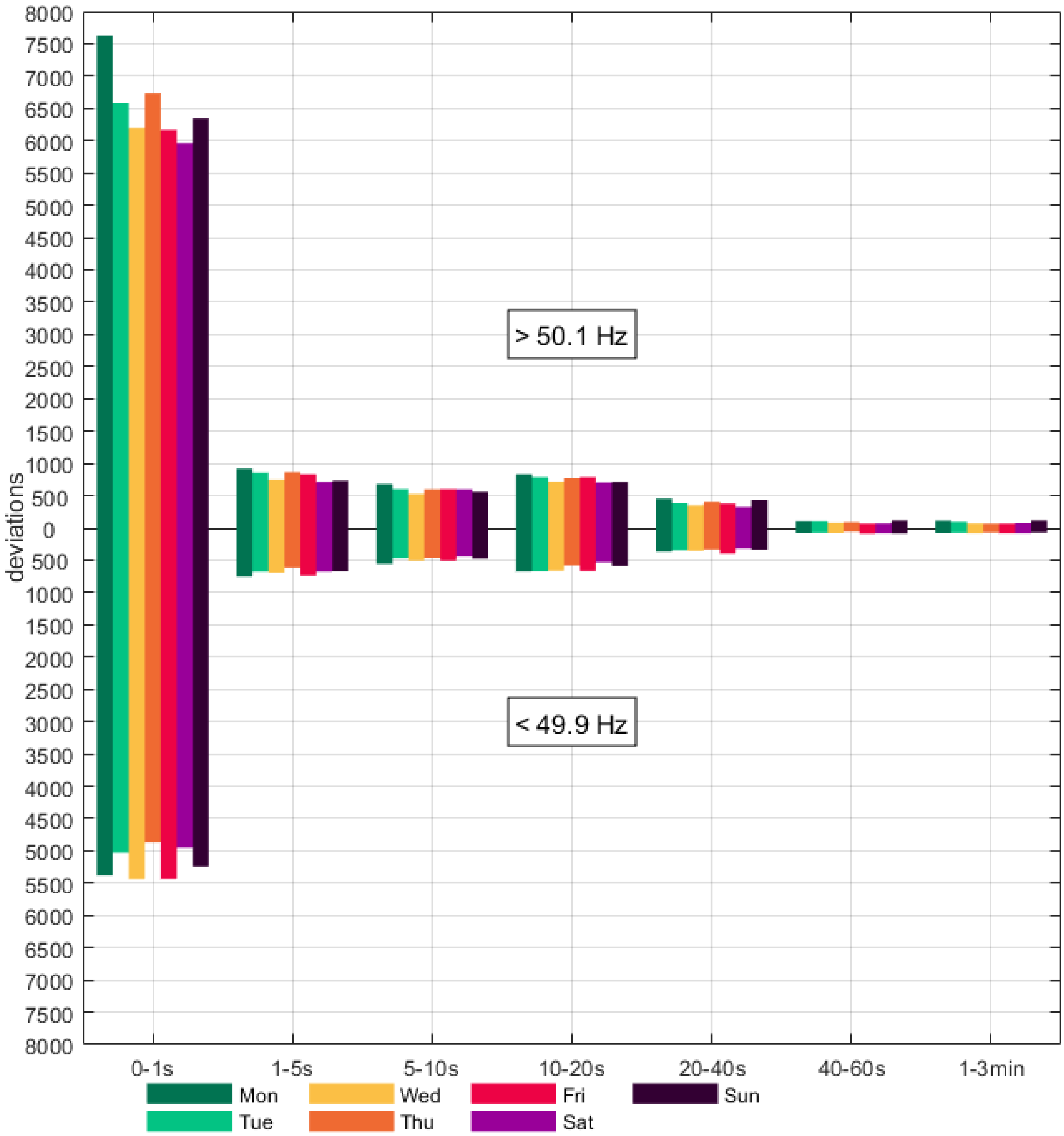


Figure 3.35 shows the number of deviations for every day of the week. Mondays experienced the highest number of deviations, while Saturdays had the fewest deviations. The deviations are slightly more evenly distributed across the week compared to 2023.

***Figure 3.35**. Total number of frequency deviations per duration for each day of the week in 2024*



Figures 3.36 and 3.37 illustrate the number of deviations per duration within the day. Figure 3.36 includes hours 0-11 and Figure 3.37 includes hours 12-23. Most deviations over the standard frequency range occurred at midnight, 9 pm, and 11 pm. With under frequencies, the most deviations happened at 2 am and 7 am. It is noteworthy that the number of over frequency deviations at 11 pm was considerably higher than the number of any other deviations in 2024 or 2023.

***Figure 3.36**. Total number of frequency deviations per duration for hours 0-11 in 2024*

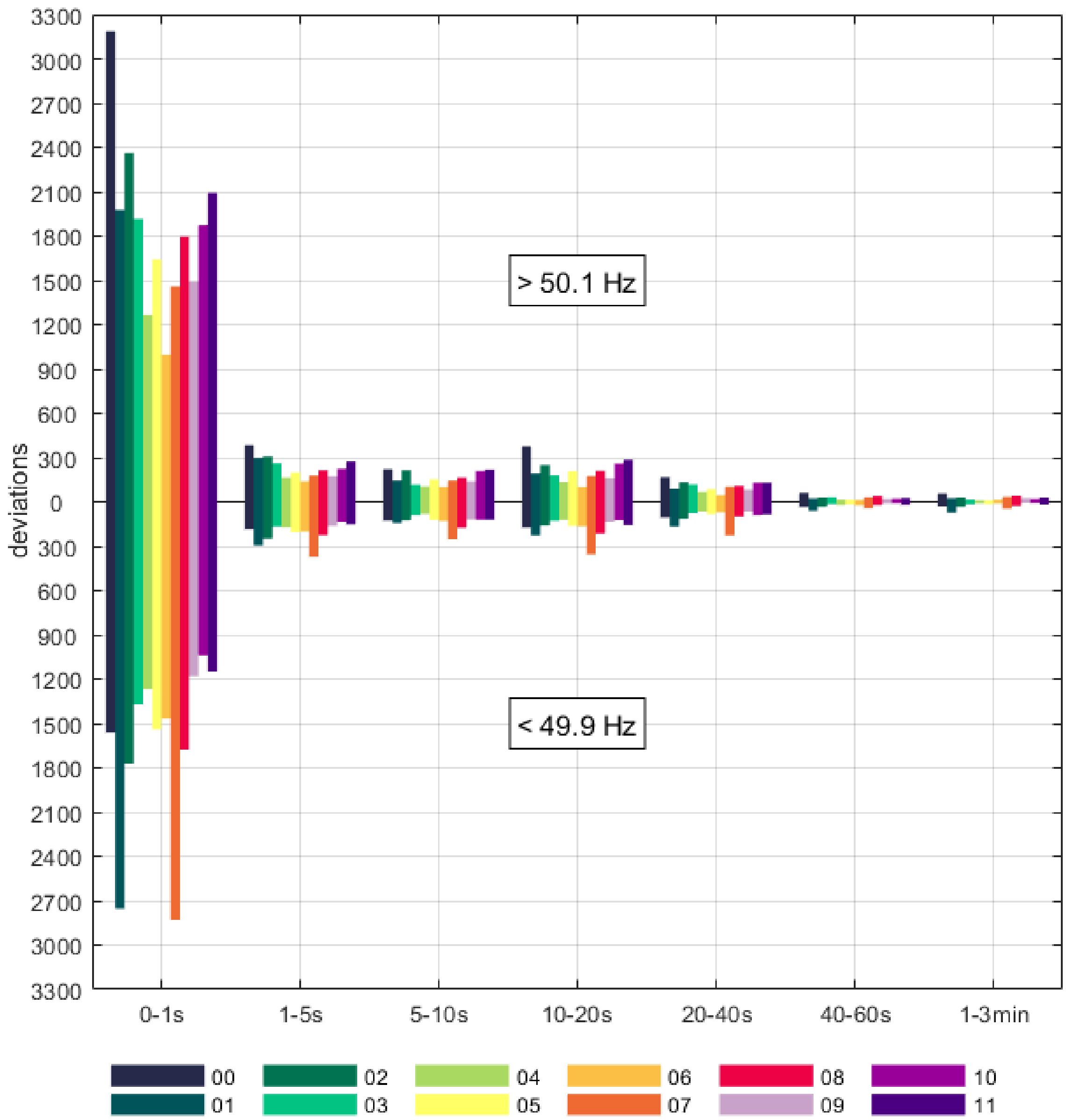


***Figure 3.37**. Total number of frequency deviations per duration for hours 12-23 in 2024*

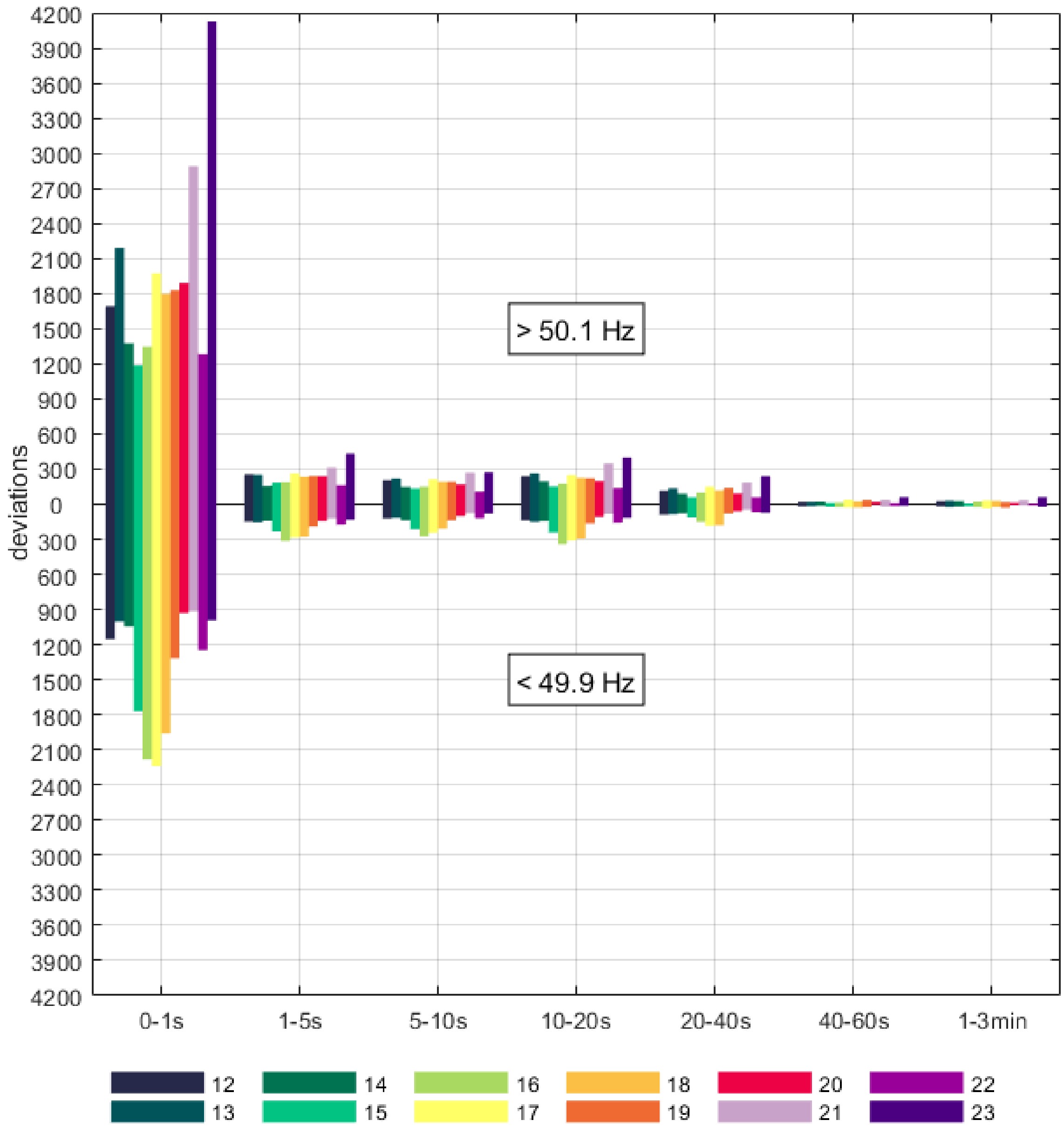
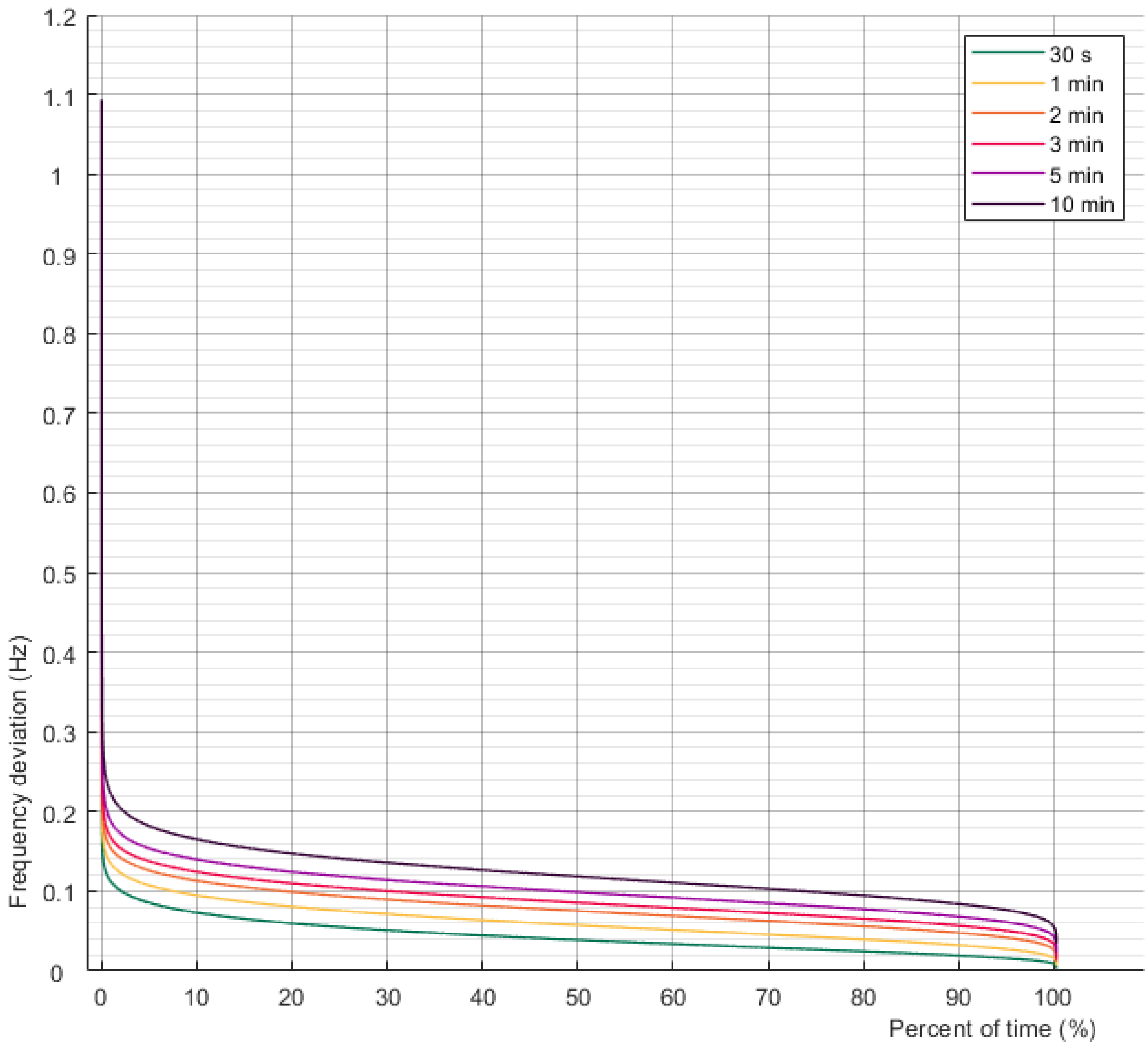


Figure 3.38 represents the duration curve of maximum frequency deviation within different time windows in 2024. The resolution of the frequency data used is 1 second. The studied time windows can be found in the legend of Figure 3.38. There have been some frequency disturbances of over 0.3 Hz, which can be seen here as a peak near 0% permanence. Chapter 4 will go through these in detail.

***Figure 3.38*. Duration curve of maximum frequency deviation within different time windows in 2024**



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 2019 and 2024. The number of over and under frequency deviations increased from the previous year in all duration categories except in the case of 1-3 minute deviations, where only under frequencies increased. The change was the most significant in 10-15 minute deviations. There was a clear increase also in the 3-5 minute category.

***Figure 3.39**. Total number of longer frequency deviations per duration between 2019-2024*

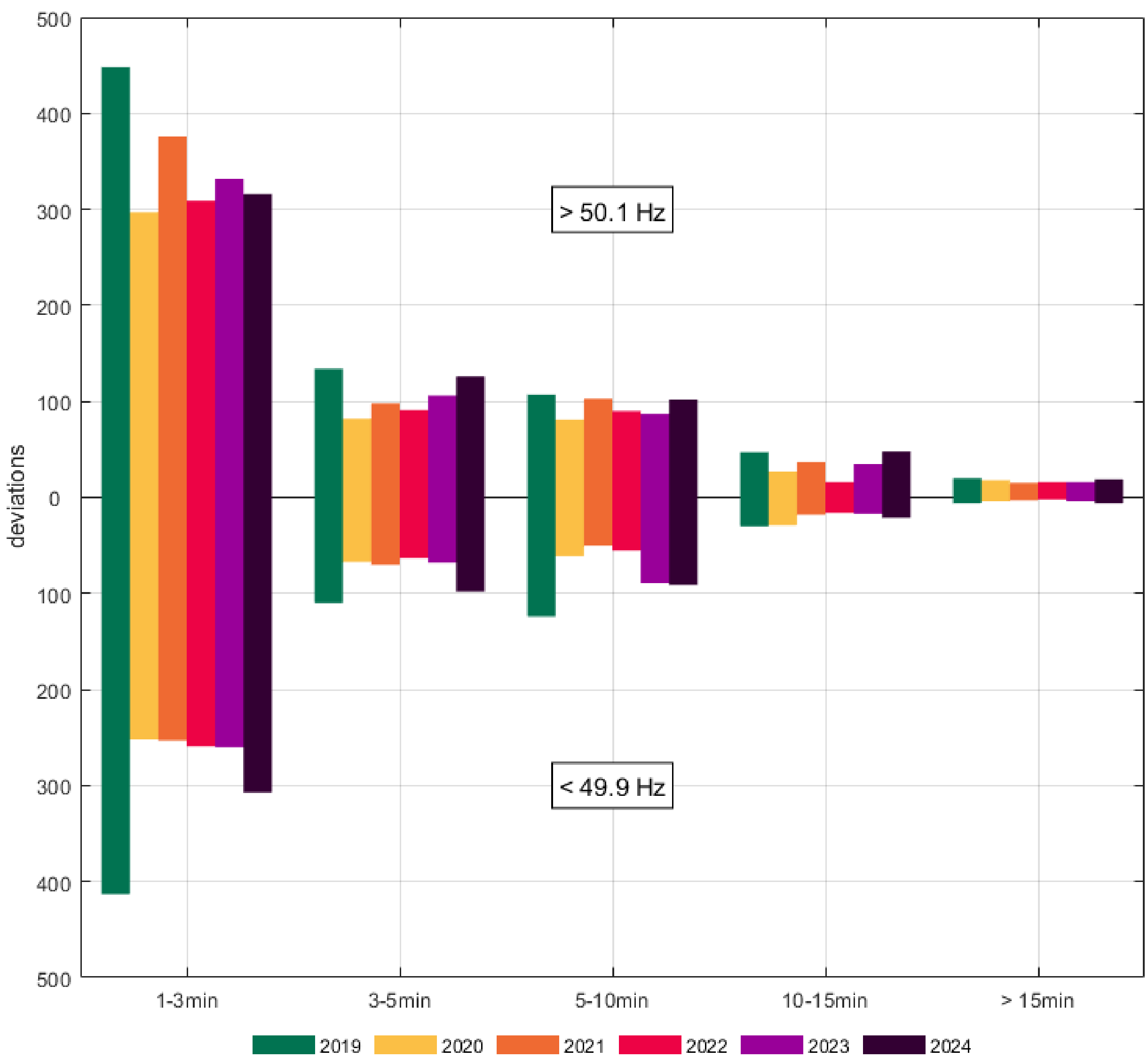


Figure 3.40 shows the total number of longer deviations exceeding the standard frequency range for each month in 2024. April, May, and September had the most over frequency deviations. The trend is less obvious for under frequency deviations, but these also occurred commonly in April and May.

***Figure 3.40**. Total number of longer frequency deviations per duration for each month in 2024*

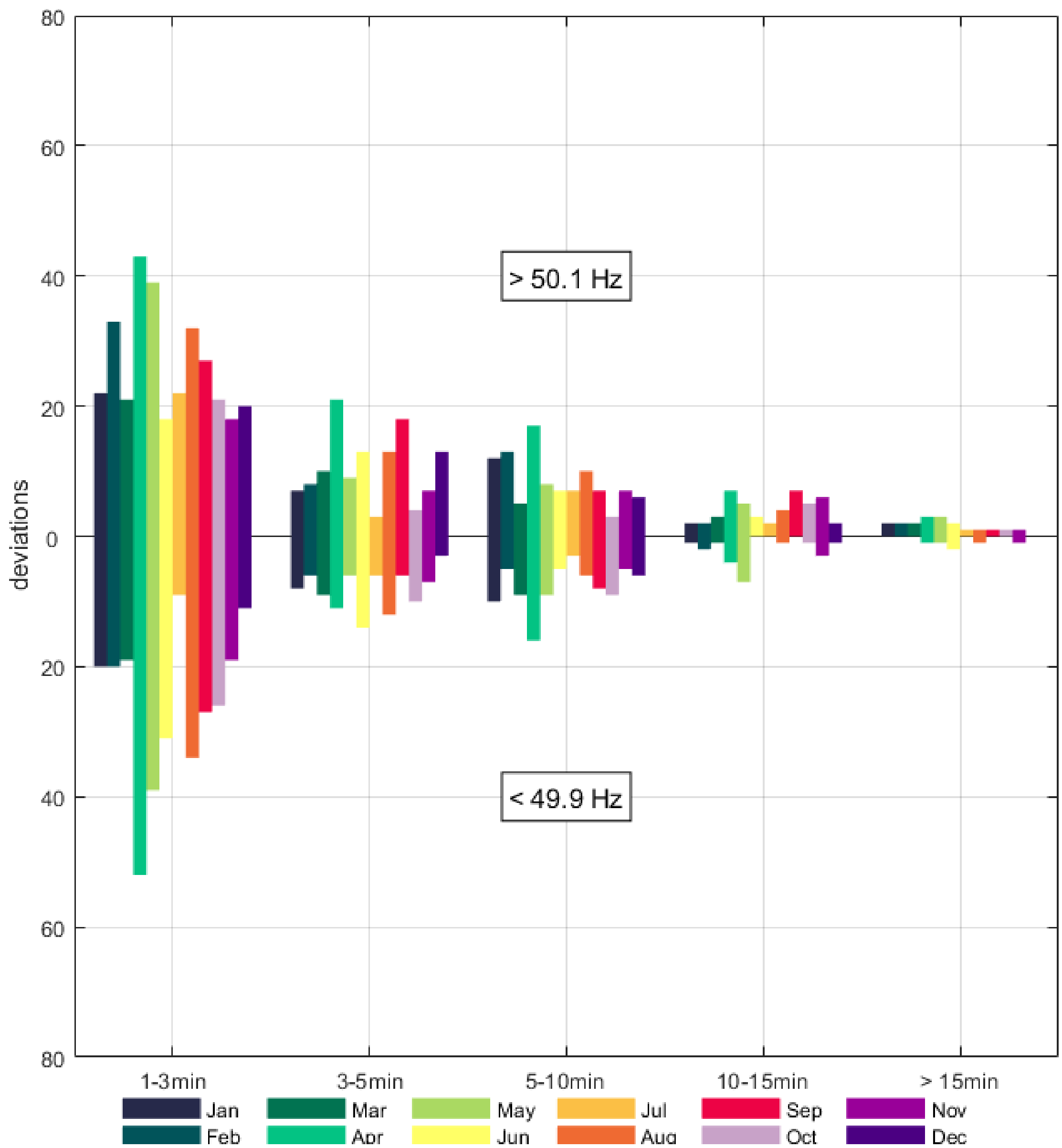
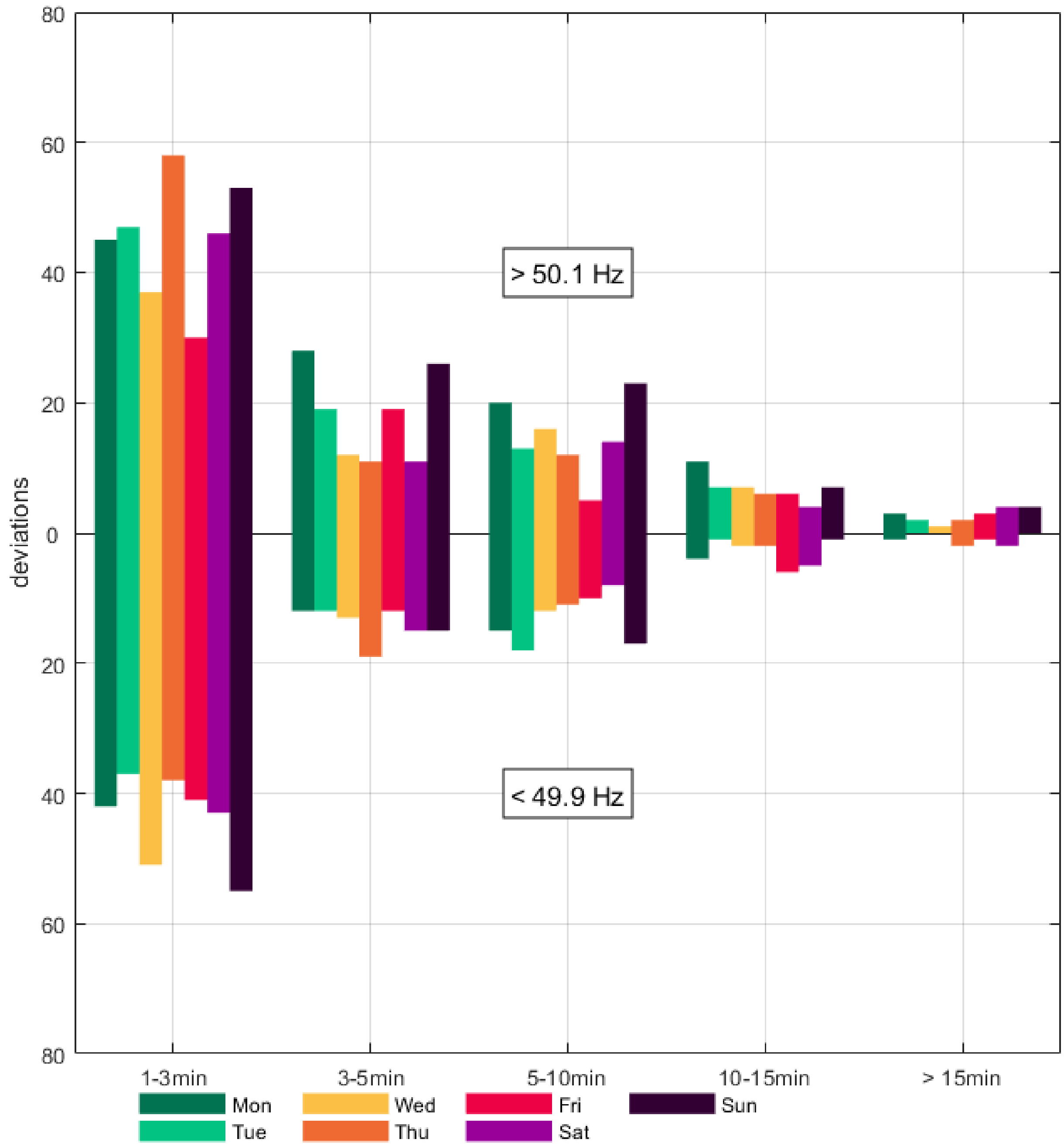


Figure 3.41 represents the number of deviations with different durations during every day of the week in 2024. Most 1-3 minute deviations happened onThursday and Sunday. In the remaining categories, deviations occurred commonly on Monday and Sunday.

***Figure 3.41**. Total number of longer frequency deviations per duration for each day of the week in 2024*



Figures 3.42 and 3.43 illustrate longer frequency deviations within the day. Over frequency deviations were common between 11 pm to 12 am while under frequency deviations were often experienced at 2 am.

***Figure 3.42**. Total number of longer frequency deviations per duration for hours 0-11 in 2024*

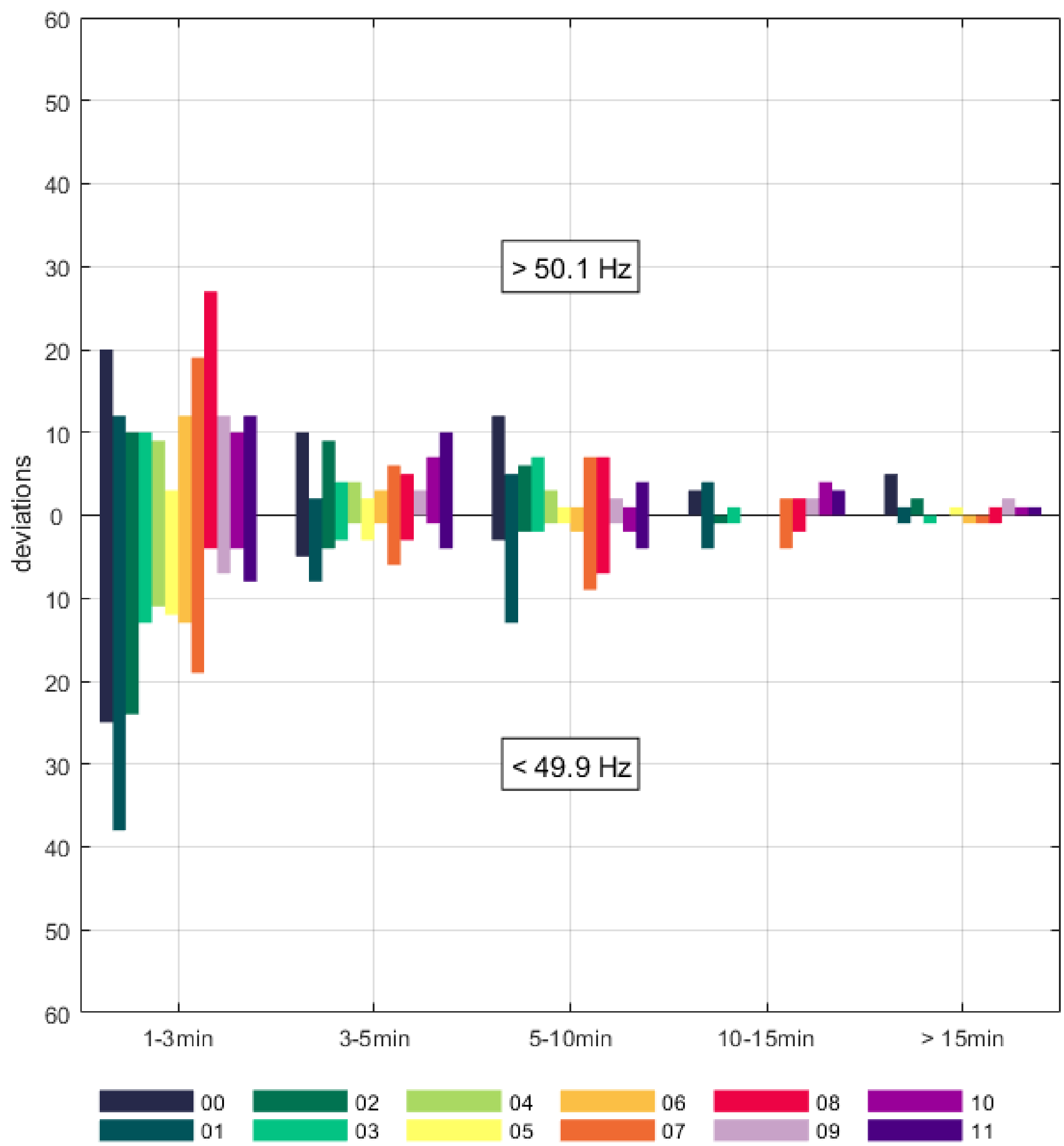
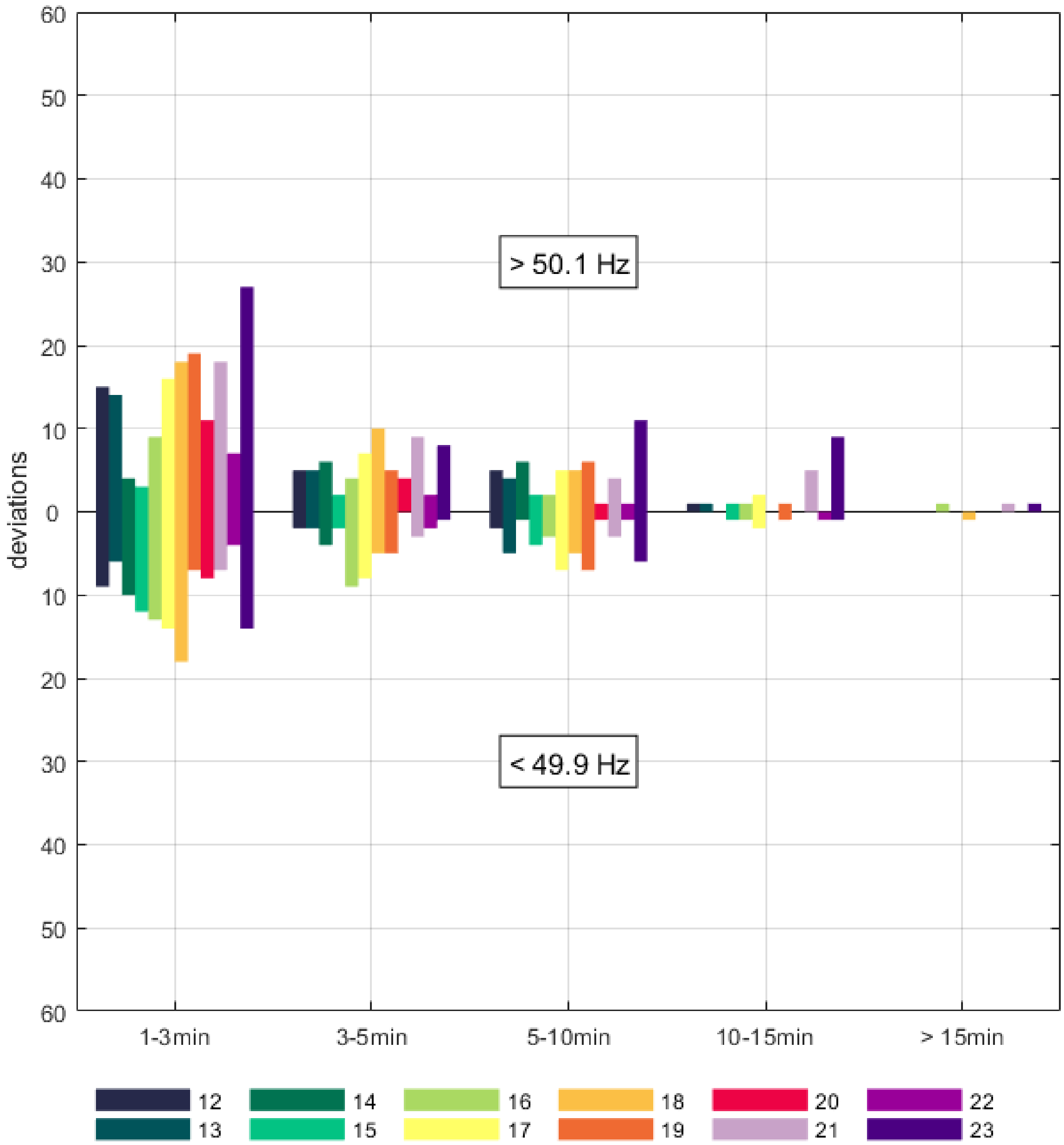


***Figure 3.43**. Total number of longer frequency deviations per duration for hours 12-23 in 2024*



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 2019 to 2024. There were slightly less both over 50.1 Hz and under 49.9 Hz threshold crossings in 2024 compared to 2023. Every year, there have been more threshold crossings over 50.1 Hz than under 49.9 Hz.

***Figure 3.44**. Daily average number of threshold crossings for the years 2019-2024*

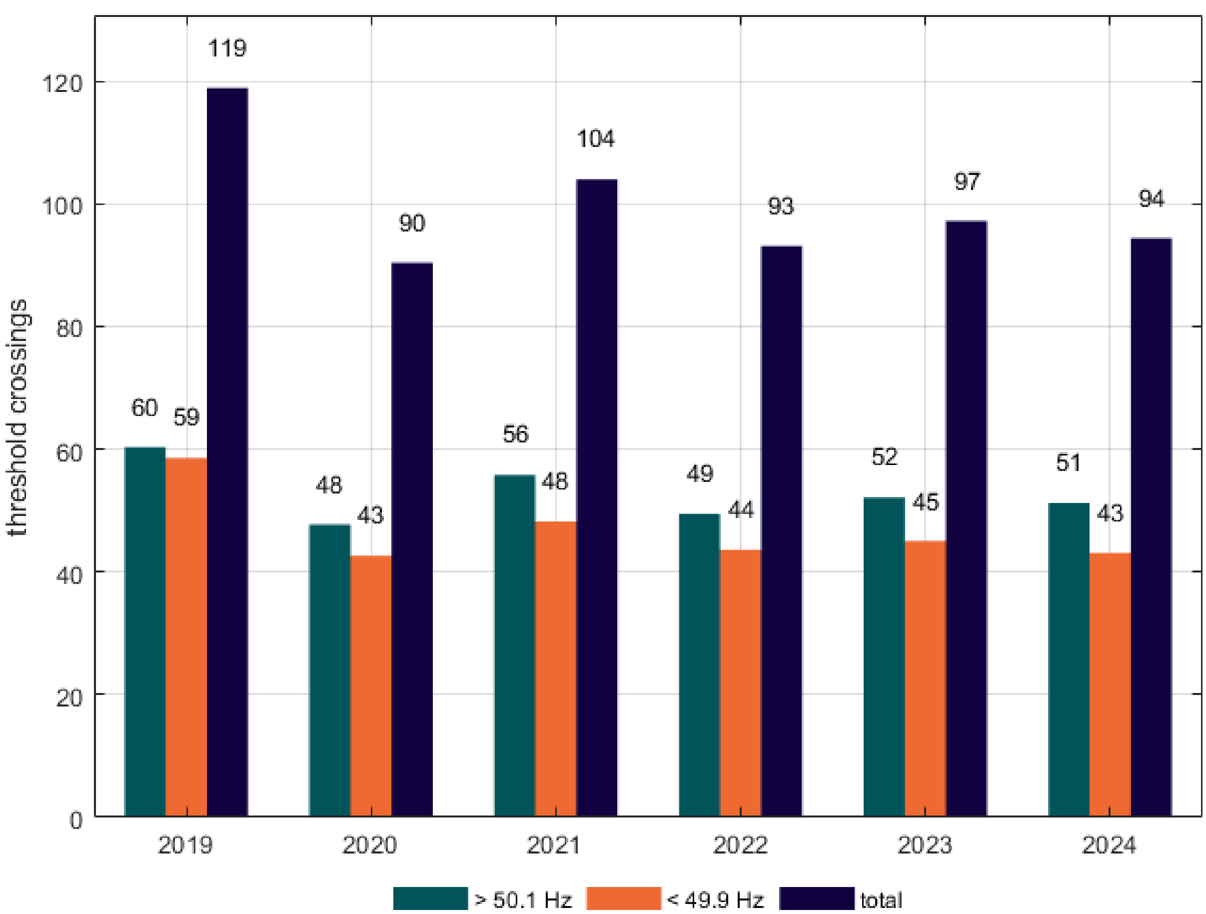


Figure 3.45 represents the daily average number of threshold crossings for each month in 2024. The frequency crossed the threshold most often in May and June. Months from November to January had the smallest number of threshold crossings.

***Figure 3.45**. Daily average number of threshold crossings for every month in 2024*

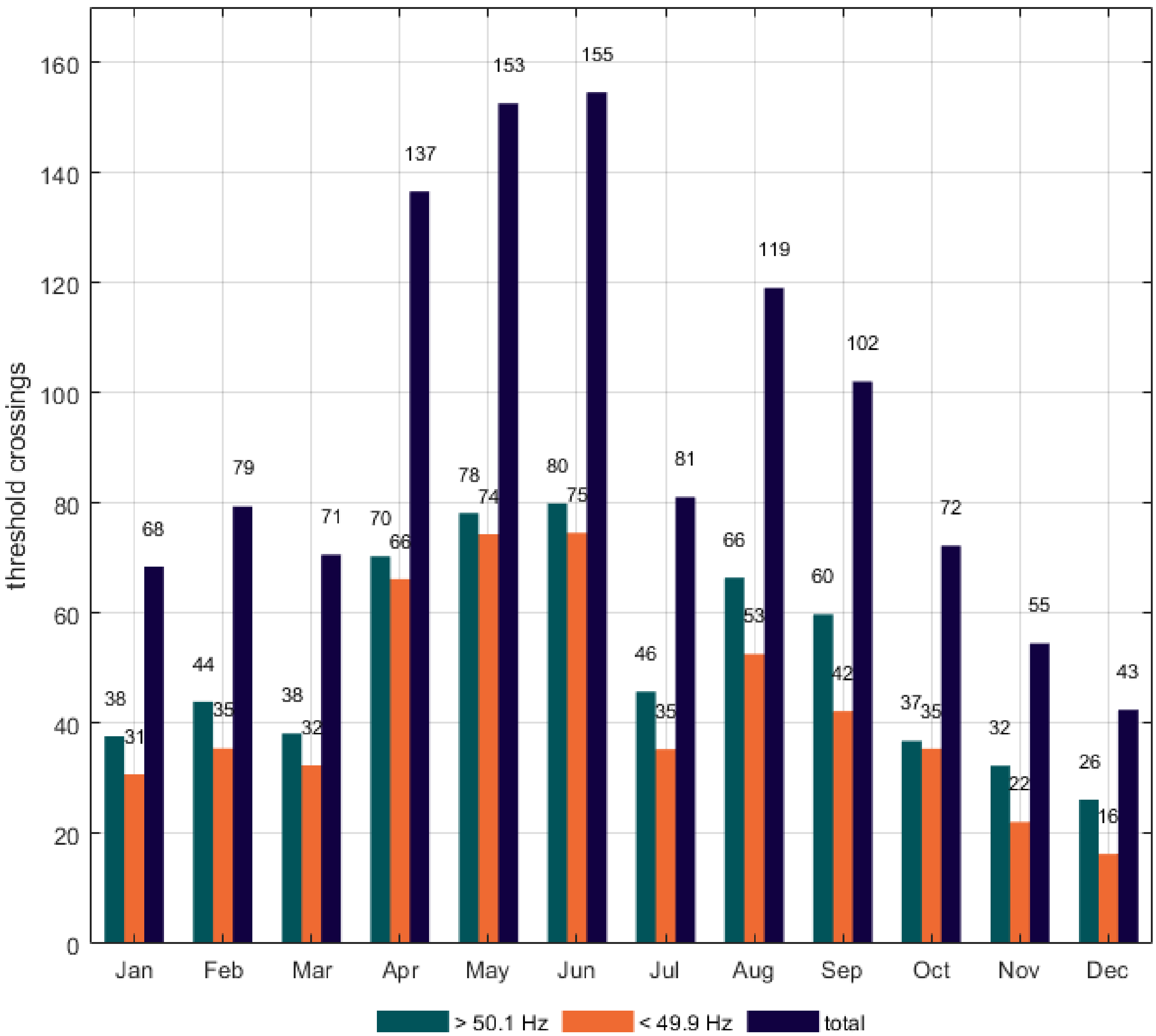
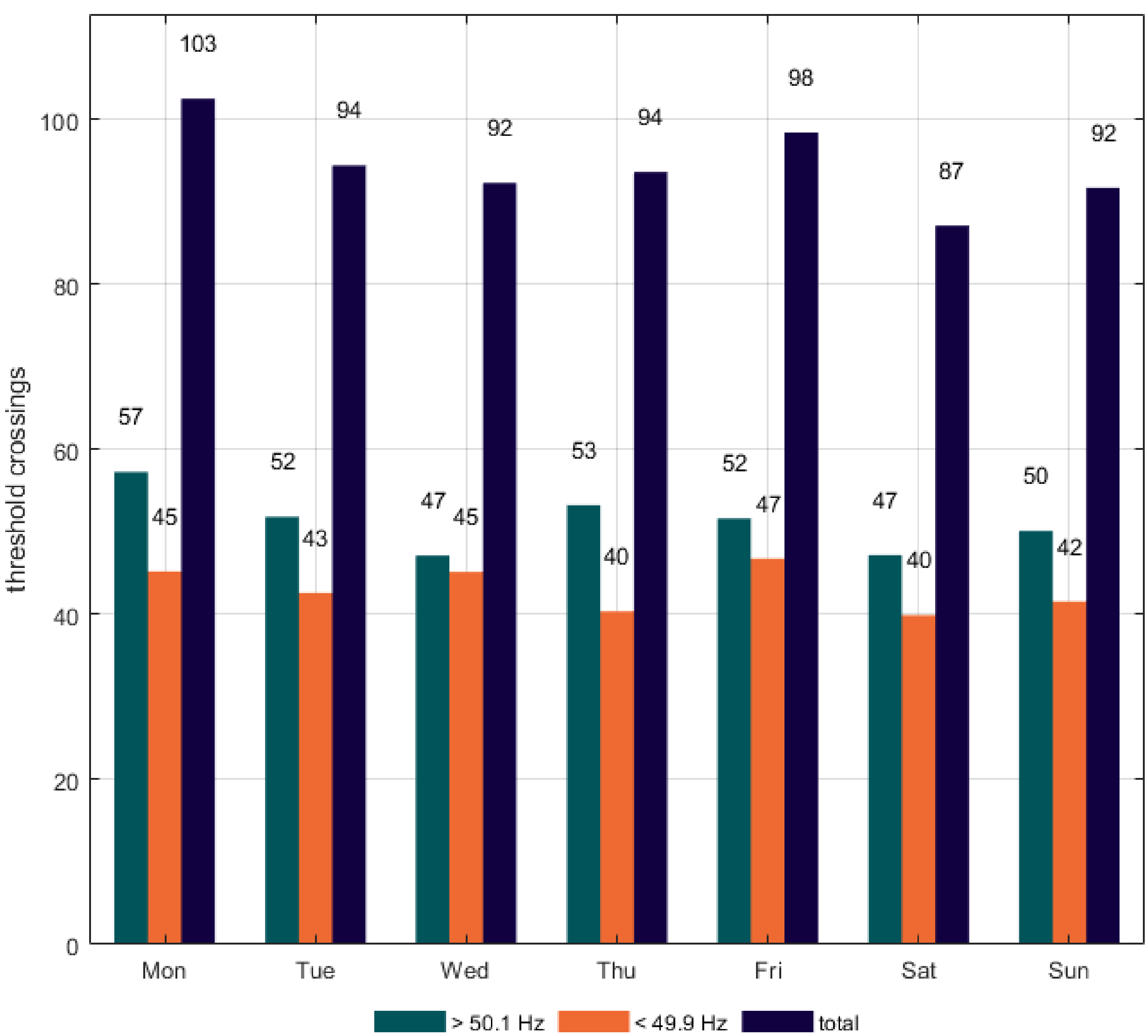


Figure 3.46 shows the number of threshold crossings for each day of the week in 2024. The number of crossings has been higher on Monday and Friday, and lower on Wednesday and on the weekend.

***Figure 3.46**. Daily average number of threshold crossings for every day of the week in 2024*



The hourly number of threshold crossings within an average day is presented in Figure 3.47. The most crossings in 2024 happened at 5 pm, 7 am and 11 pm. The smallest number of threshold crossings occurred at 4 am, 6 am and 10 pm. The trend is somewhat similar to the previous year, but the average number of threshold during the early morning hours has decreased.

***Figure 3.47**. Average number of threshold crossings for every hour of the day in 2024*

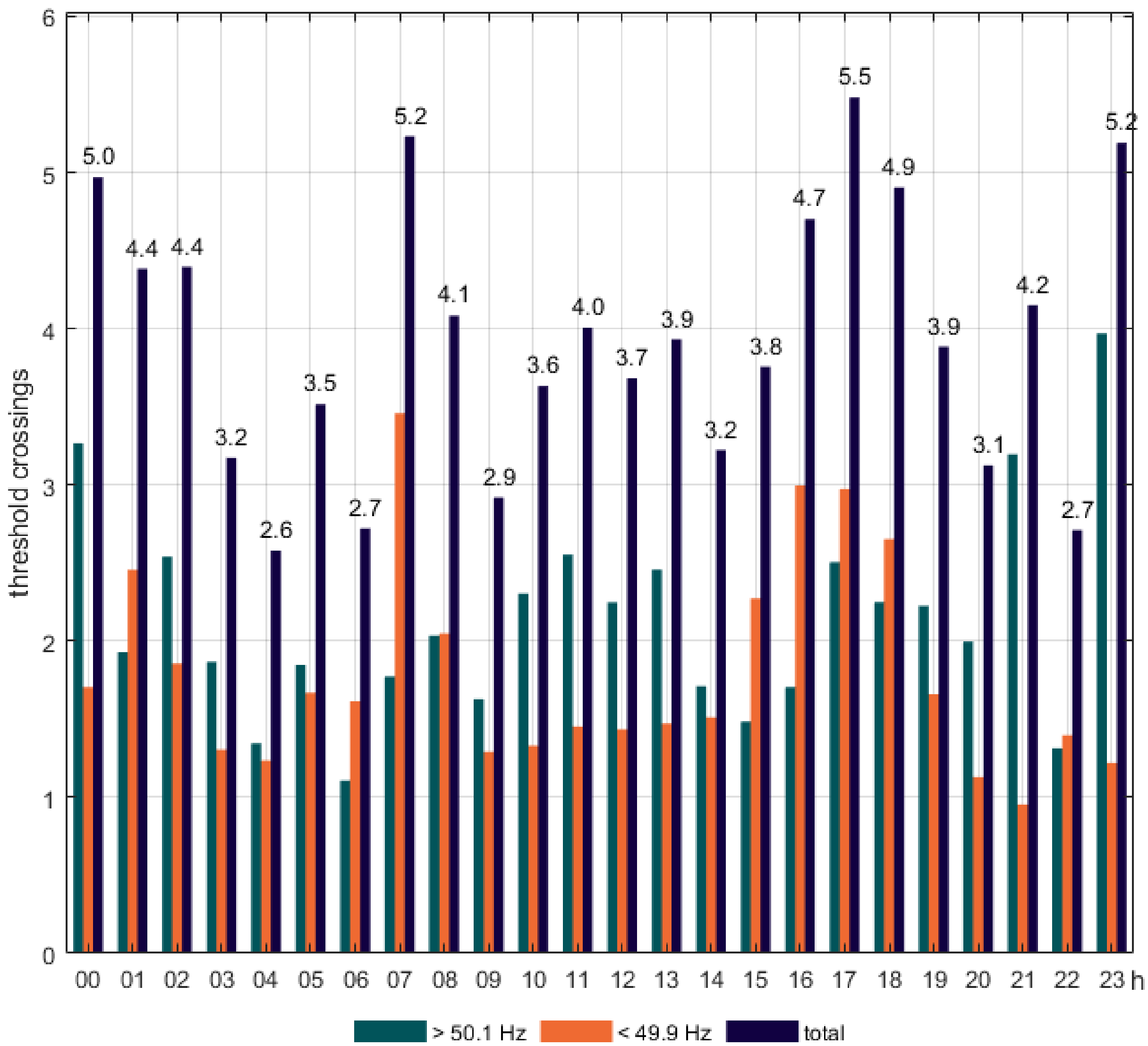
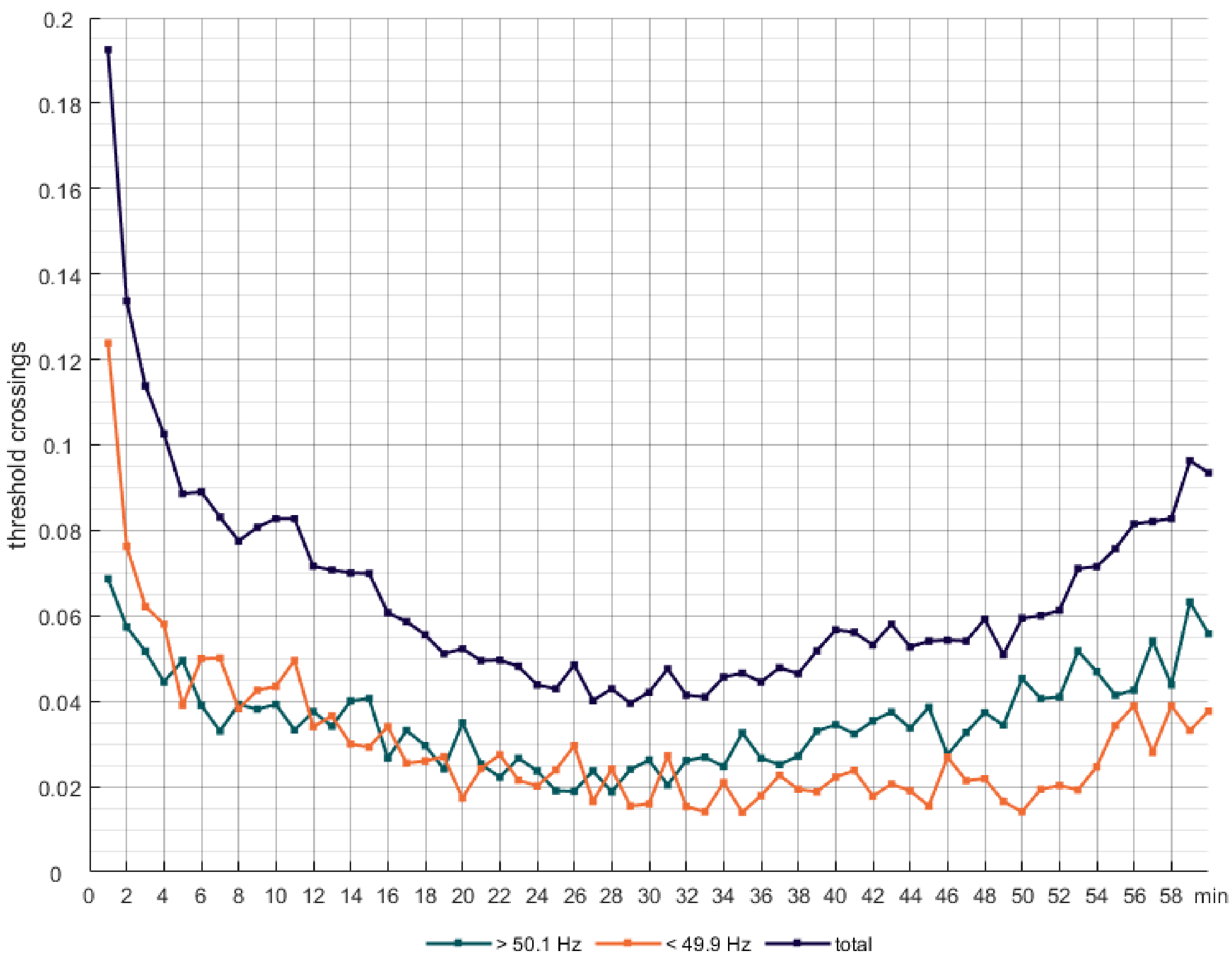


Figure 3.48 represents the average number of threshold crossings for every minute within the hour. Most crossings in 2024 occurred in the first few minutes of the hour. The crossings were least common in the middle of an hour. During the first 30 minutes of the hour, the frequency crossed 49.9 Hz more often, whereas more crossings of 50.1 Hz took place in the latter part of the hour. The trend is very similar to 2023.

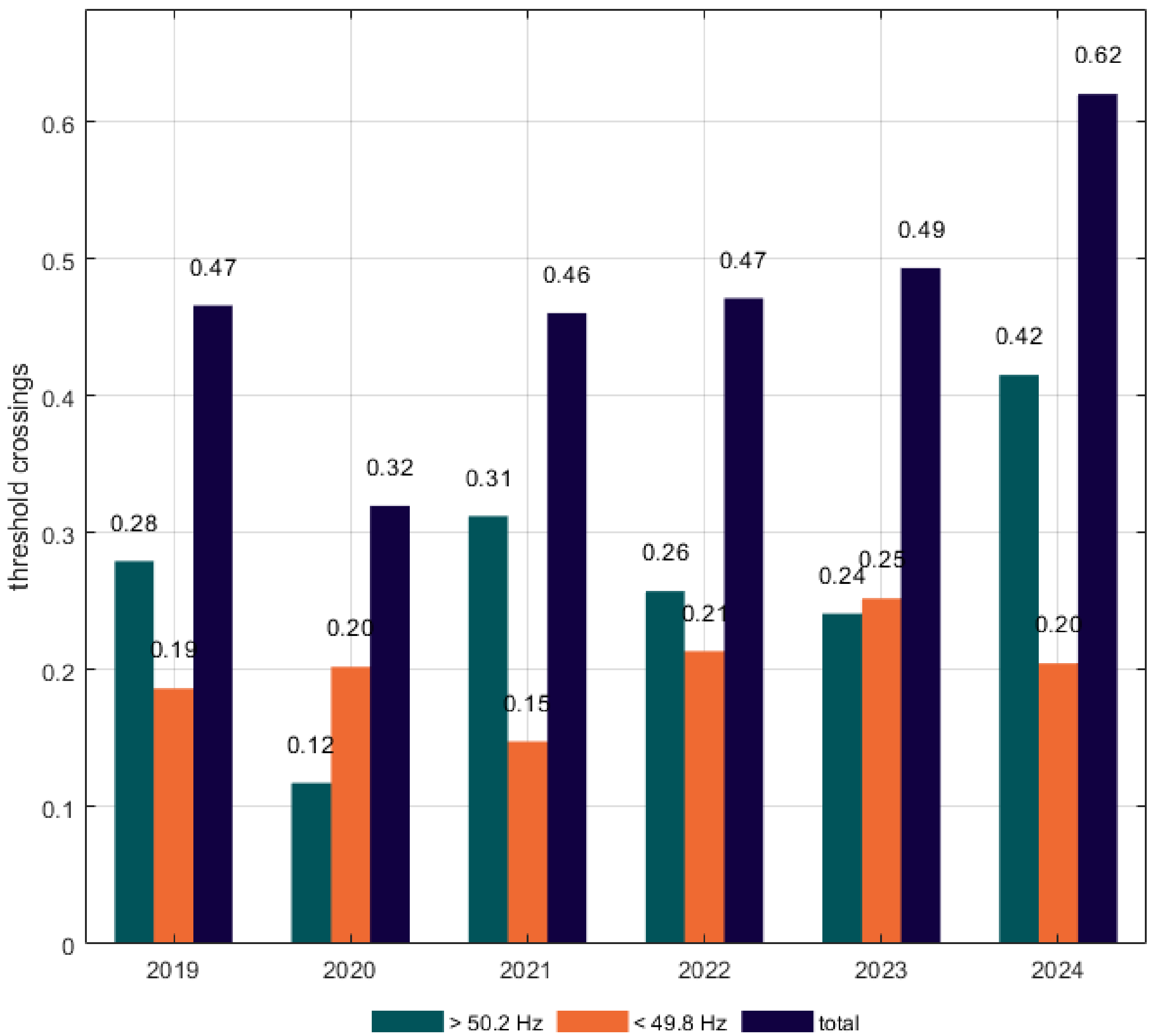
***Figure 3.48**. Average number of threshold crossings for every minute of the hour in 2024*



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 2024. The total number of crossings was noticeably higher than in any of the previous years.

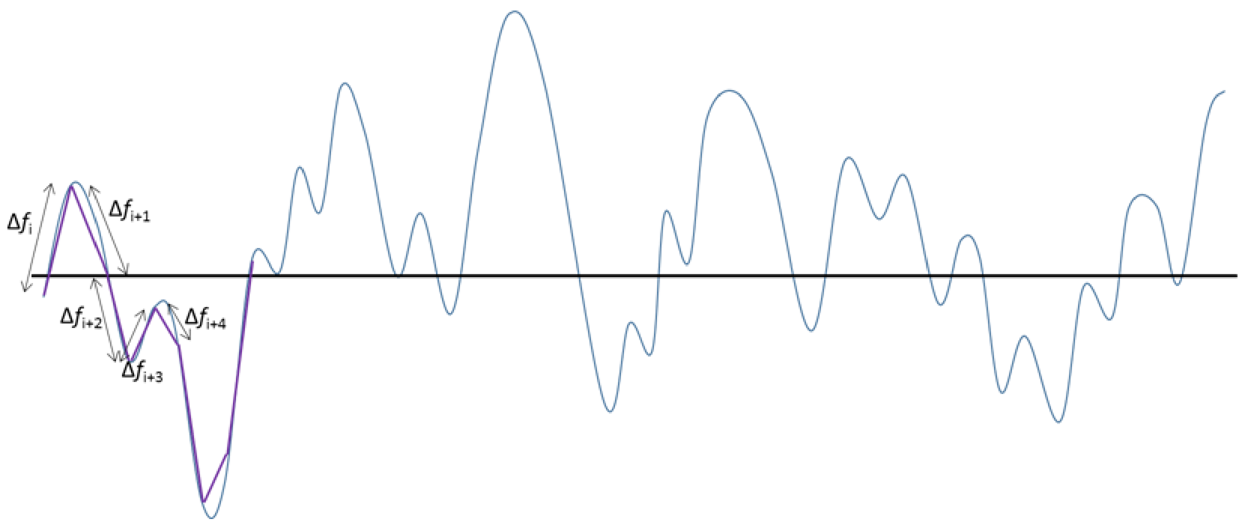
***Figure 3.49**. Daily average number of threshold crossings larger than ±200 mHz for years 2019-2024*



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).

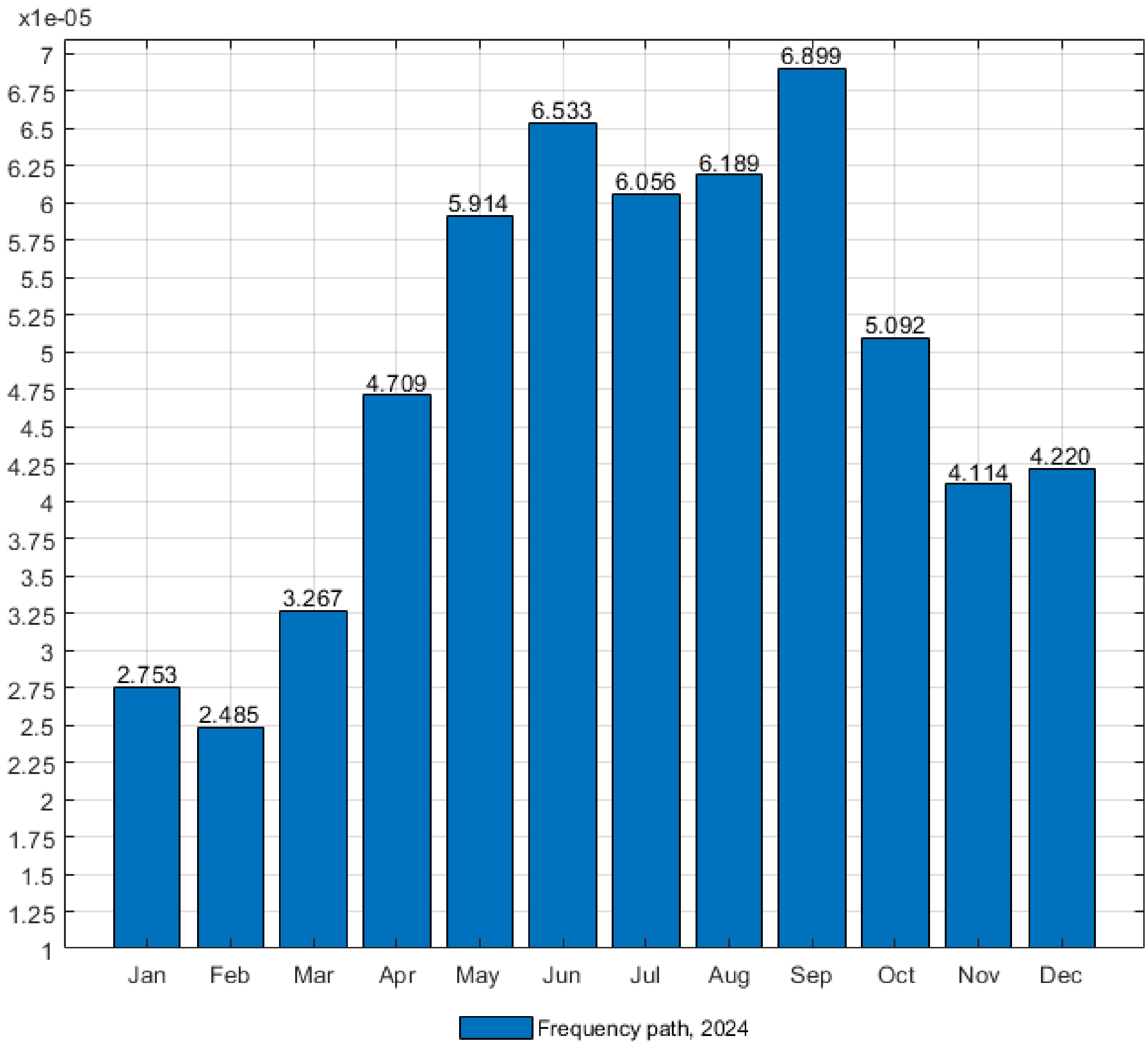
***Figure 3.50**. Frequency quality index: Length of the frequency path [7]*



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

Figure 3.51 represents the frequency path for each month in 2024. The highest values of the frequency path occurred from May until September. January and February had the lowest values. While there is a slight decrease in the length of the frequency path in January and February, the path length has noticeably increased for all remaining months in comparison to the previous year. The peak path length has experienced roughly a 40 % increase.

***Figure 3.51**. Length of the frequency path month by month in 2024*



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 2024

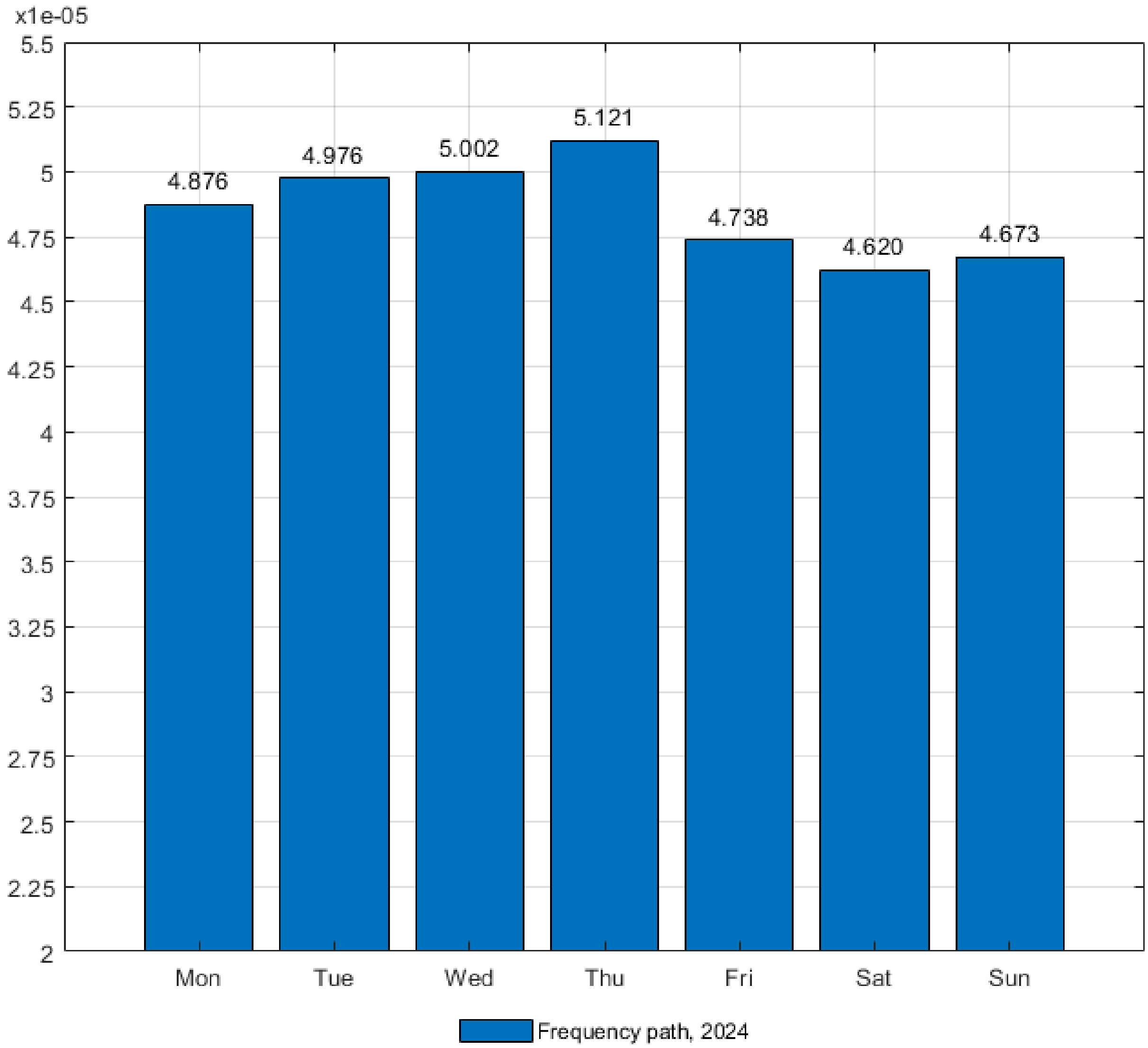


Figure 3.53 shows the frequency path for each hour within a day. The distribution of the frequency path values between different hours, compared to 2023, is less even. In particular, the peaks at 1-2 am and 1-2 pm were not present in 2023, but were, to a lesser extent, present in 2022. Lowest values are attained from 8 to 12 am, similar to the year before.

***Figure 3.53**. Length of the frequency path for every hour of the day in 2024*

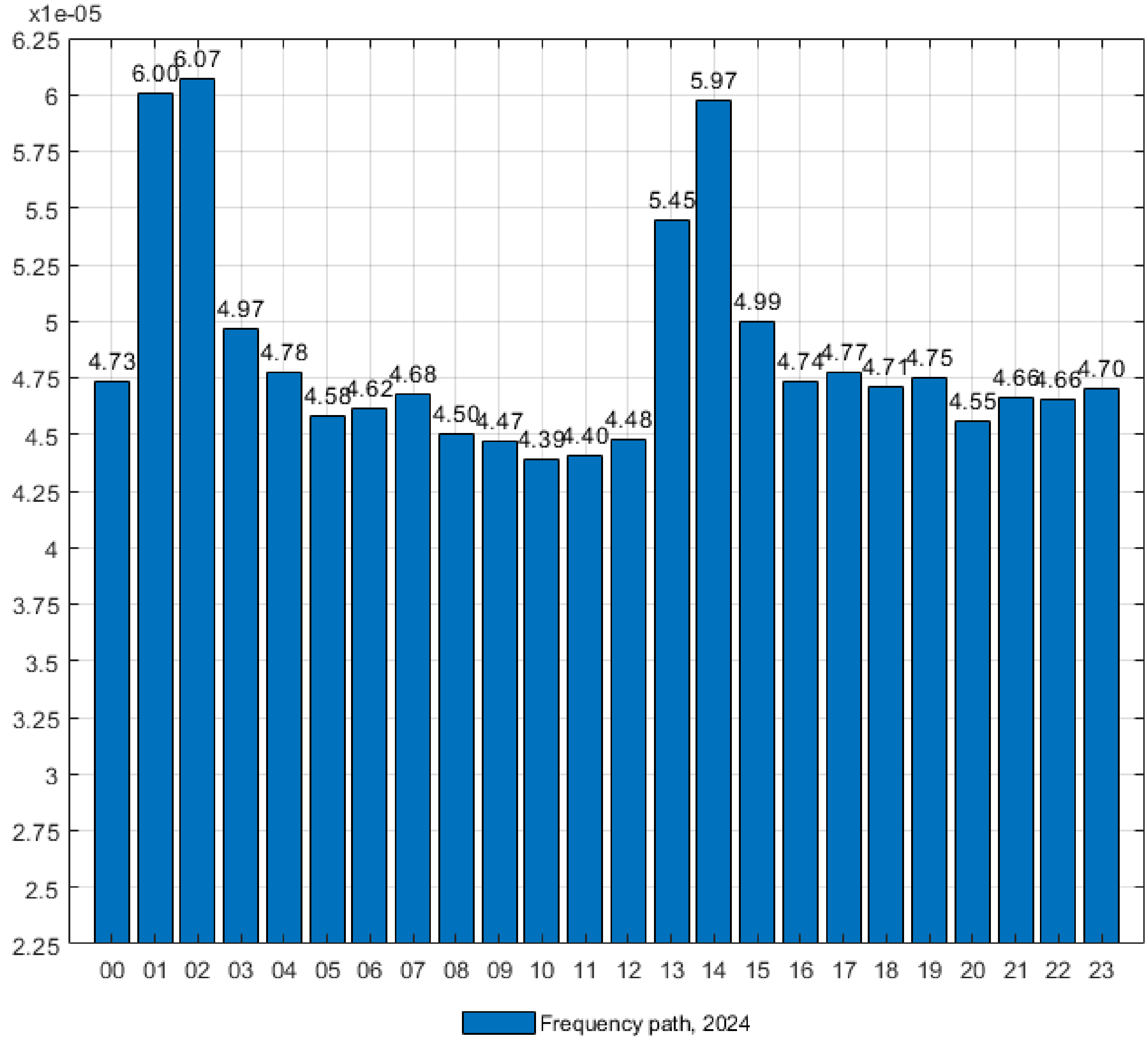
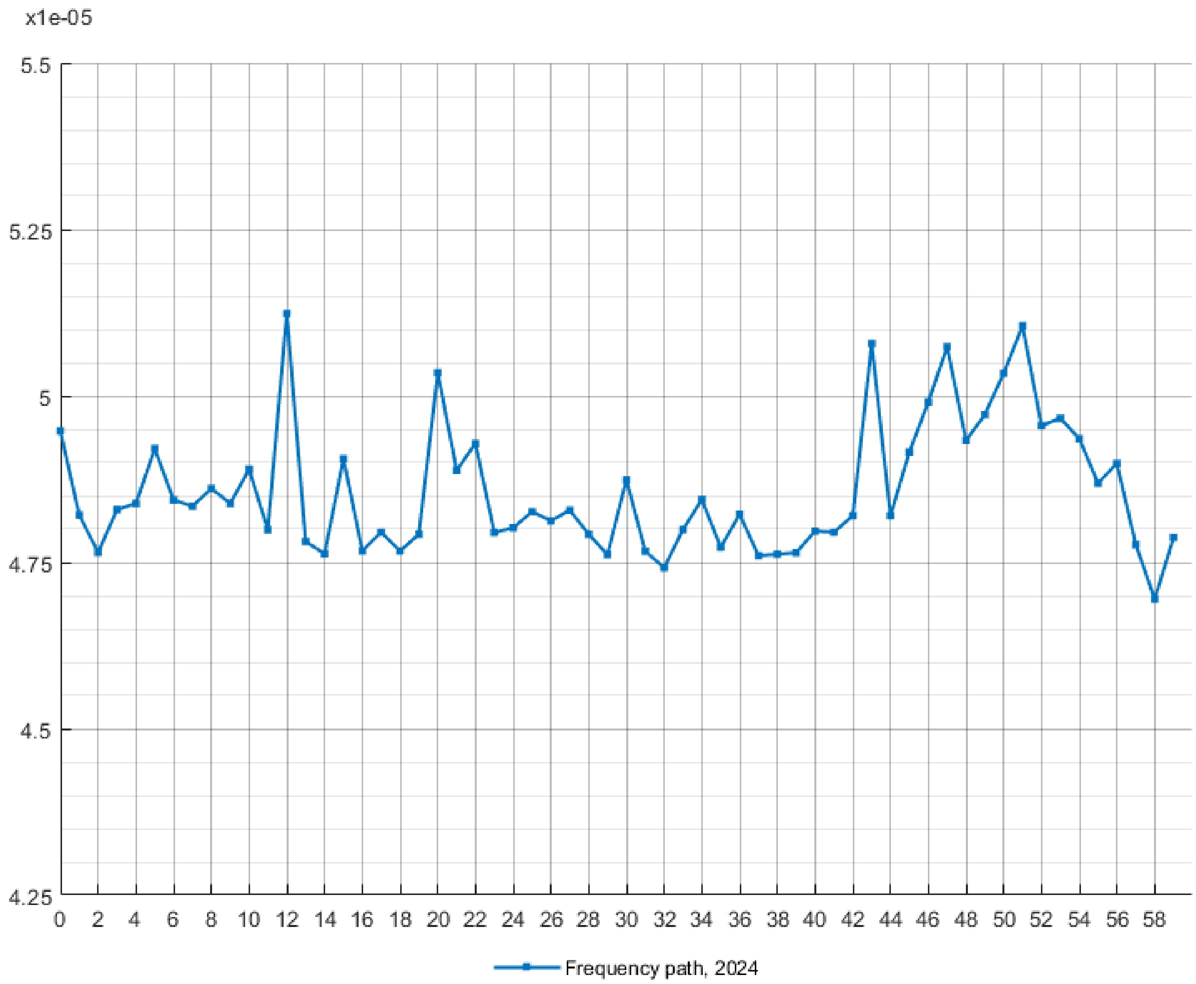


Figure 3.54 represents the average frequency path for every minute within an hour in 2024. The amount of variation in this graph has increased every year since 2020. The highest peak occurs at minute ten. The path length attains several large values also between minutes 43 and 55. This type of cluster of larger values is not present in the previous year's graph.

Figure 3.54. Length of the frequency path for every minute of the hour in 2024



3.8 Amount of frequency oscillation

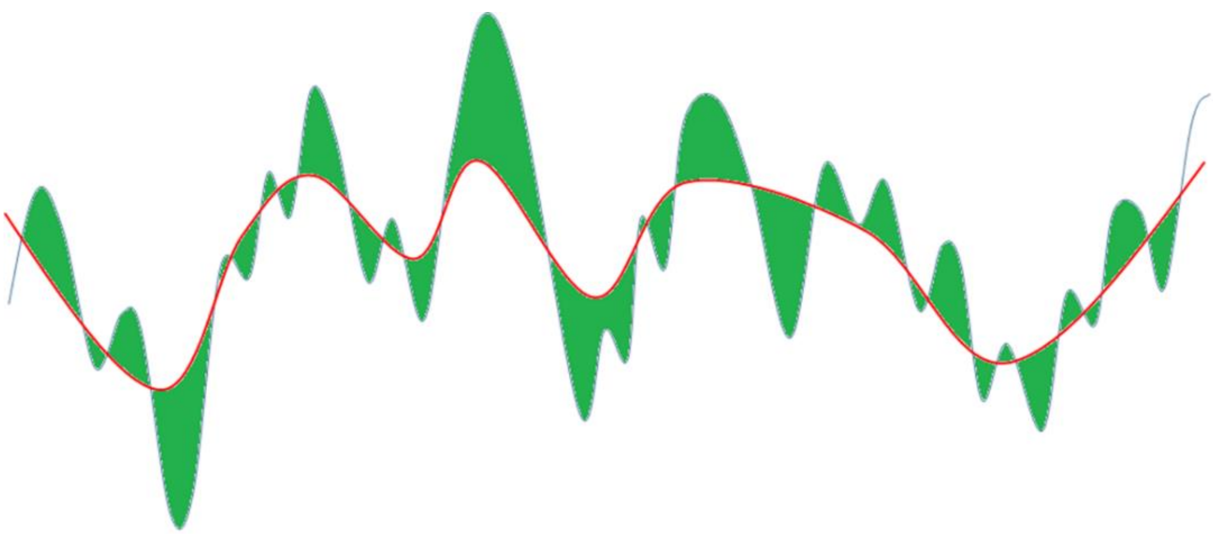
The frequency of the Nordic synchronous system oscillates constantly. The time period of the oscillation is approximately 40 to 90 seconds. This behavior is a natural characteristic of the system, but it can be influenced through adequate settings of system reserves. Oscillation has an increasing effect 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]

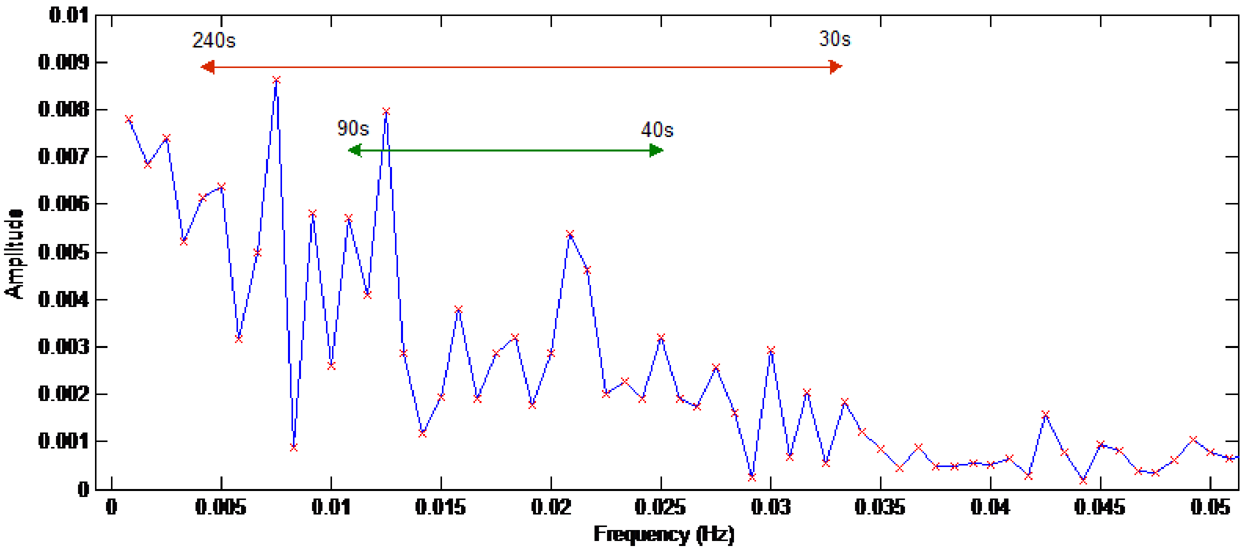
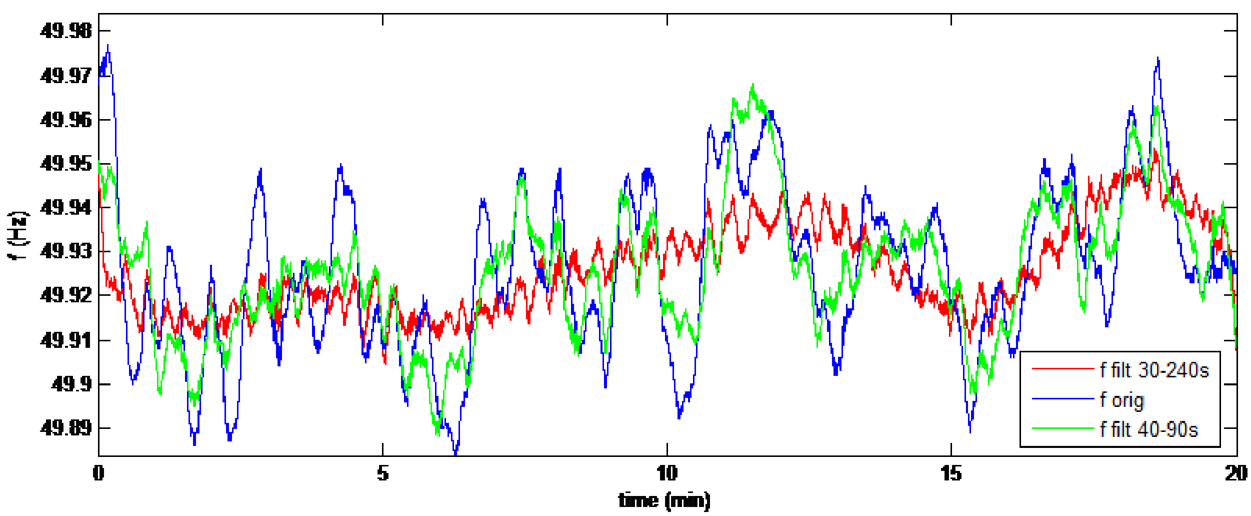


Figure 3.57. Original frequency (blue), frequency with 40-90 s band filtered (green), and frequency with 30-240 s band filtered (red). The first 20 minutes of December 2012 are shown (UTC+2). [8]



3.8.2 Amount of oscillation

Figure 3.58 shows hourly values and 24-hour moving averages for the amount of oscillation in 2024. 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 had the highest values between May and June. Compared to 2023, the bottom values were more concentrated towards the beginning and end of the year. Moreover, in 2023, in addition to May, peak values were also obtained in September, whereas in 2024, this trend is significantly weaker and peak values are heavily concentrated between May and June. Figures 3.59 and 3.60 contain the previously mentioned 24-hour moving averages for years 2019-2021 and 2022-2024, respectively.

Figure 3.58. Amount of oscillation in 2024

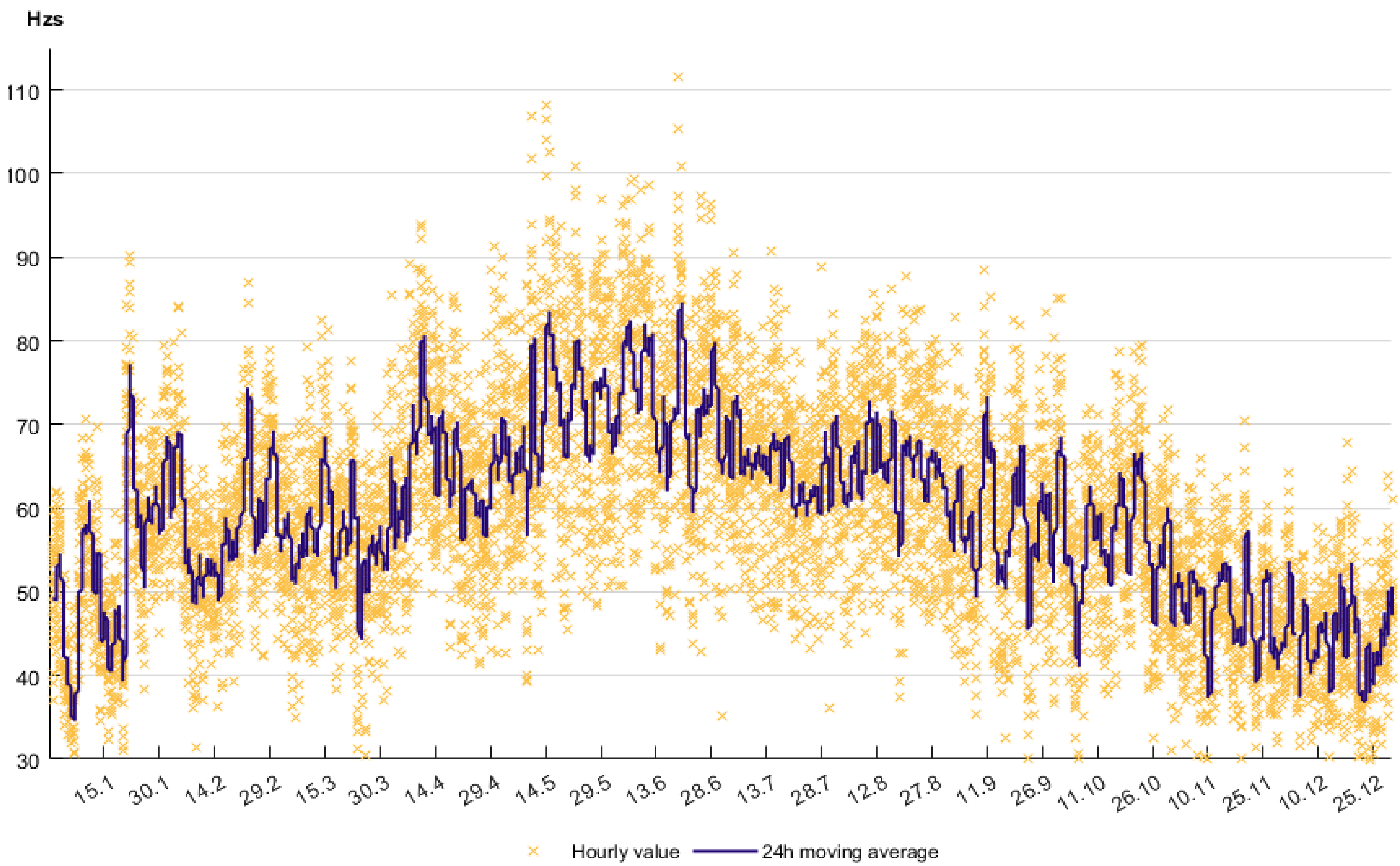


Figure 3.59. Amount of oscillation in 2019-2021

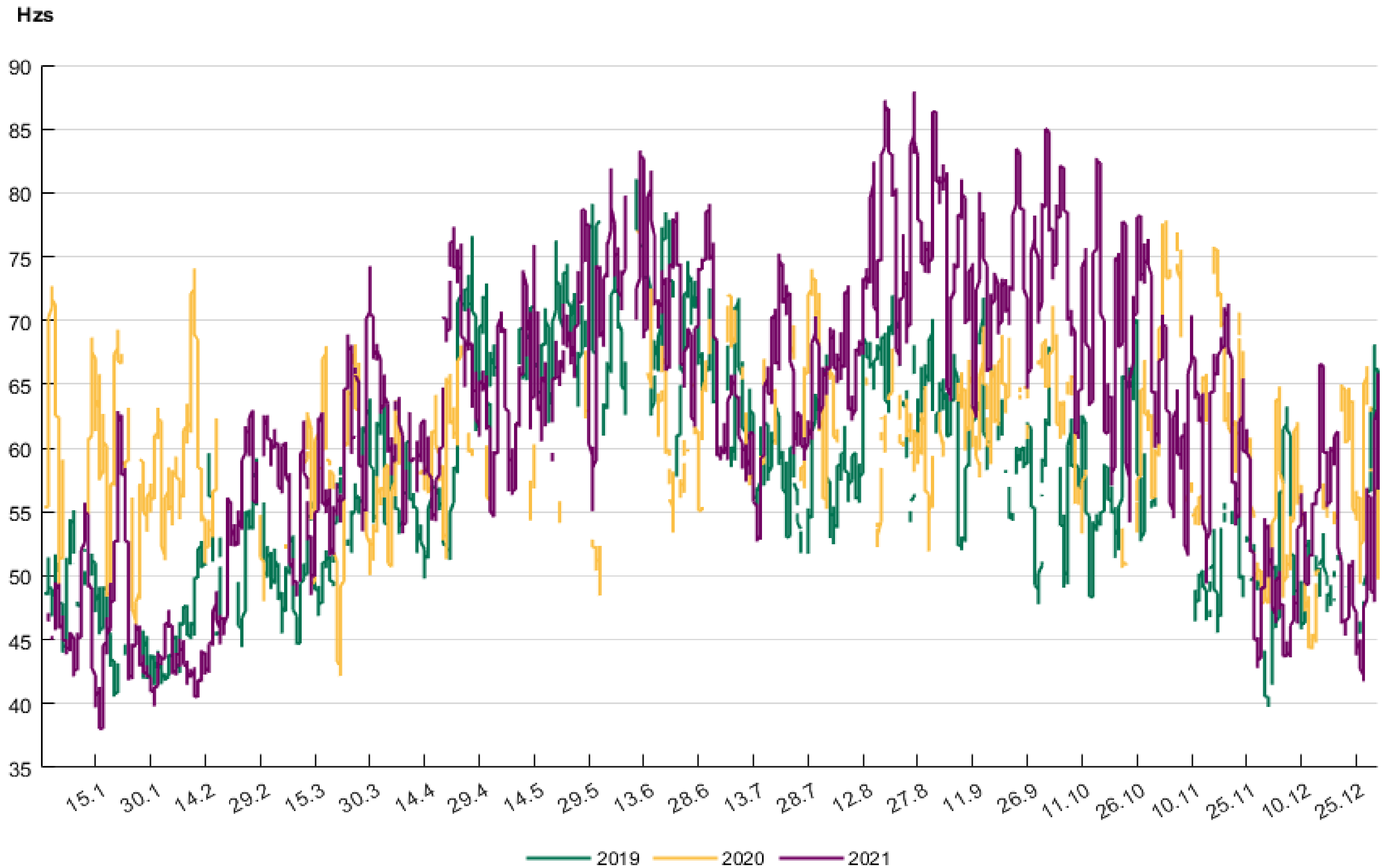
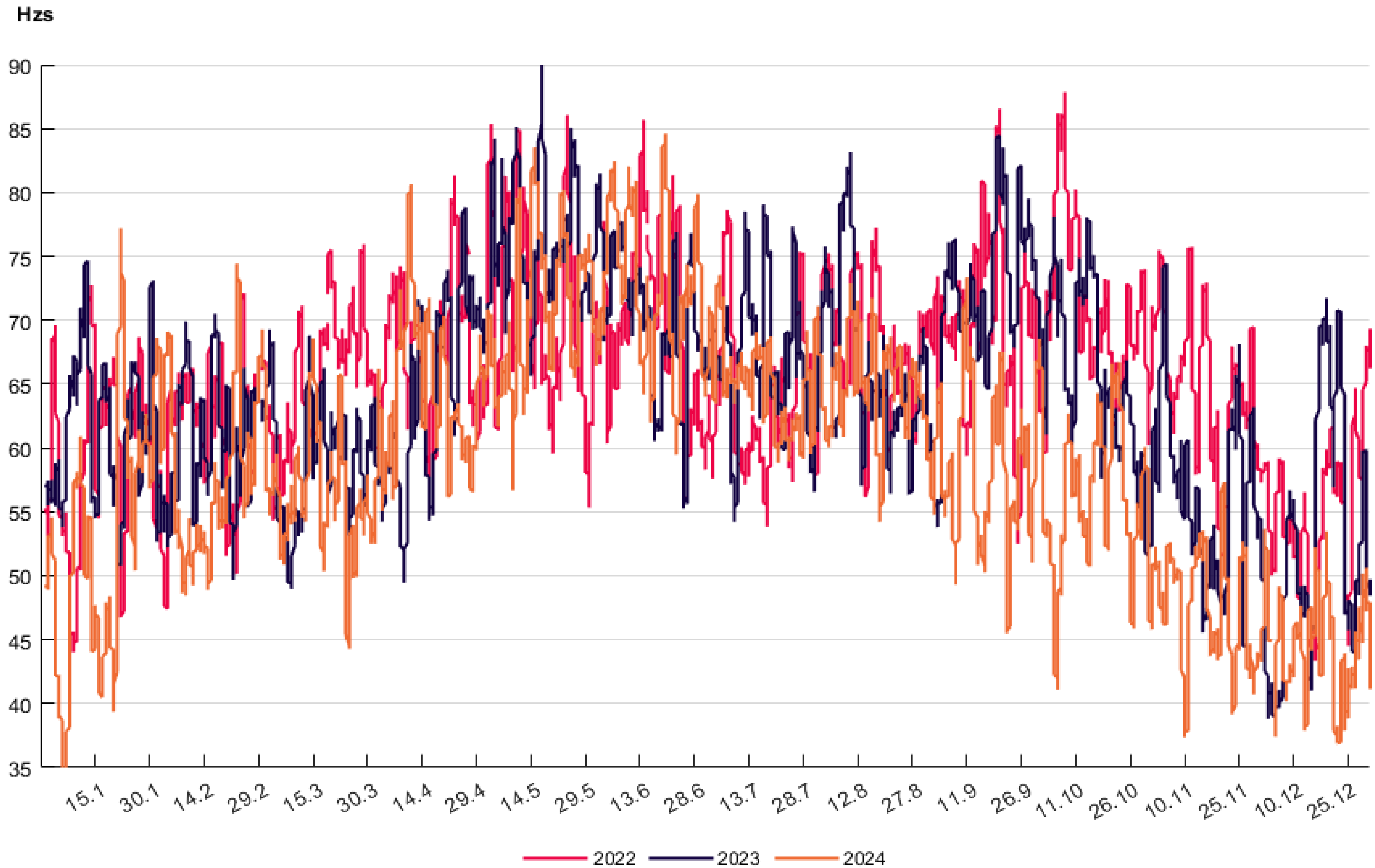


Figure 3.60. Amount of oscillation in 2022-2024



The mean value and standard deviation of the oscillation for each month from 2019 to 2024 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 June. The mean amount of oscillation is smaller than in 2023, and the second lowest within the observation period, the mean oscillation value being smaller only in 2019.

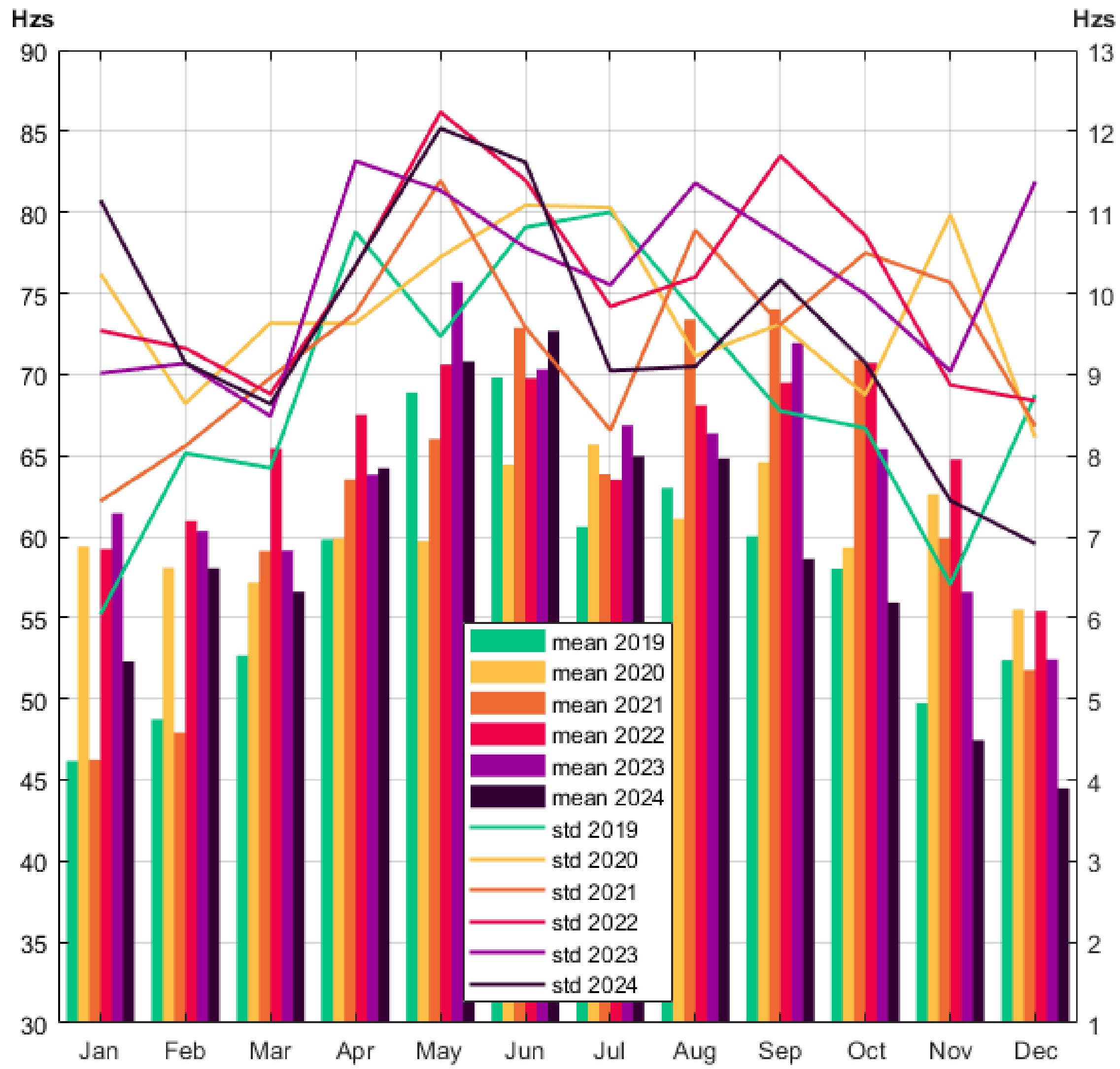
Table 3.22. Mean values and standard deviations for oscillation in years 2019-2021

	Mean value (Hzs)			**Standard deviation (Hzs)**		
Month	**2019**	**2020**	**2021**	**2019**	**2020**	**2021**
January	46.2	59.4	46.2	6.0	10.2	7.4
February	48.7	58.1	47.9	8.0	8.6	8.1
March	52.7	57.2	59.1	7.8	9.6	9.0
April	59.8	59.9	63.5	10.8	9.6	9.8
May	68.9	59.7	66.0	9.5	10.4	11.4
June	69.8	64.4	72.9	10.8	11.1	9.6
July	60.6	65.7	63.9	11.0	11.1	8.3
August	63.0	61.1	73.4	9.8	9.2	10.8
September	60.0	64.6	74.0	8.5	9.6	9.6
October	58.0	59.3	70.9	8.3	8.7	10.5
November	49.7	62.6	59.9	6.4	11.0	10.1
December	52.4	55.5	51.8	8.7	8.2	8.4
Entire year	**57.5**	**60.6**	**62.5**	**8.8**	**9.8**	**9.4**

Table 3.23. Mean values and standard deviations for oscillation in years 2022-2024

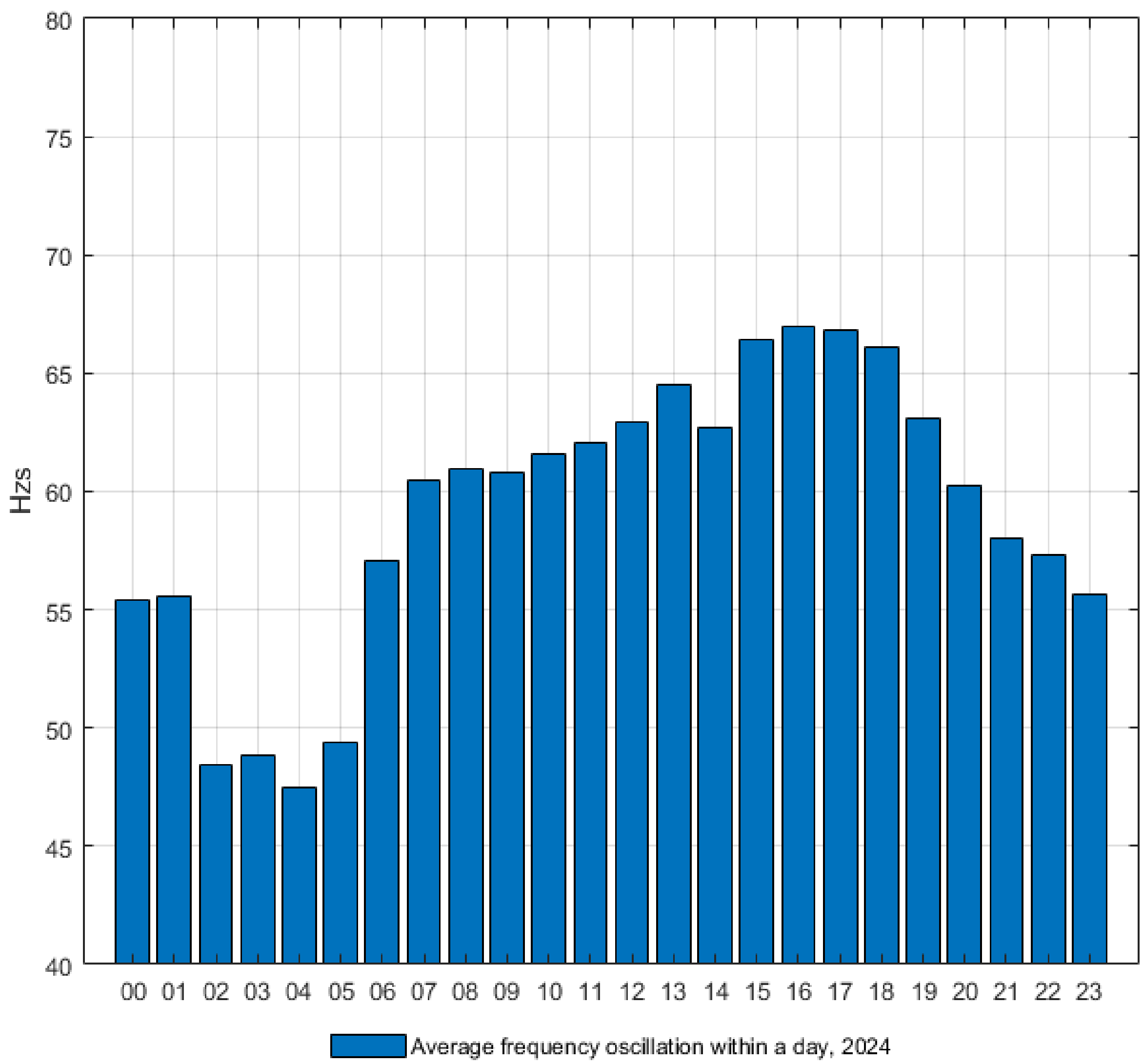
	Mean value (Hzs)			**Standard deviation (Hzs)**		
Month	**2022**	**2023**	**2024**	**2022**	**2023**	**2024**
January	59.2	61.4	52.3	9.5	9.0	11.1
February	61.0	60.3	58.1	9.3	9.1	9.1
March	65.4	59.2	56.6	8.8	8.5	8.6
April	67.5	63.8	64.2	10.3	11.6	10.3
May	70.6	75.7	70.8	12.2	11.3	12.0
June	69.8	70.3	72.7	11.4	10.6	11.6
July	63.5	66.9	65.0	9.8	10.1	9.0
August	68.1	66.4	64.8	10.2	11.4	9.1
September	69.5	71.9	58.6	11.7	10.7	10.2
October	70.7	65.4	55.9	10.7	10.0	9.1
November	64.8	56.6	47.5	8.9	9.0	7.4
December	55.4	52.4	44.5	8.7	11.4	6.9
Entire year	**65.5**	**64.2**	**59.2**	**10.1**	**10.2**	**9.6**

***Figure 3.61**. Mean values (left y-axis) and standard deviations (right y-axis) for oscillation in years 2019-2024*



The average oscillation within a day in 2024 can be seen in figure 3.62. The amount of oscillation peaked in the late afternoon and early evening. The lowest values of oscillation are at night, from 2 am to 5 am. The amount of oscillation was at its highest between 3 pm and 6 pm. The trend is very similar to previous years.

Figure 3.62. Average frequency oscillation within a day in 2024

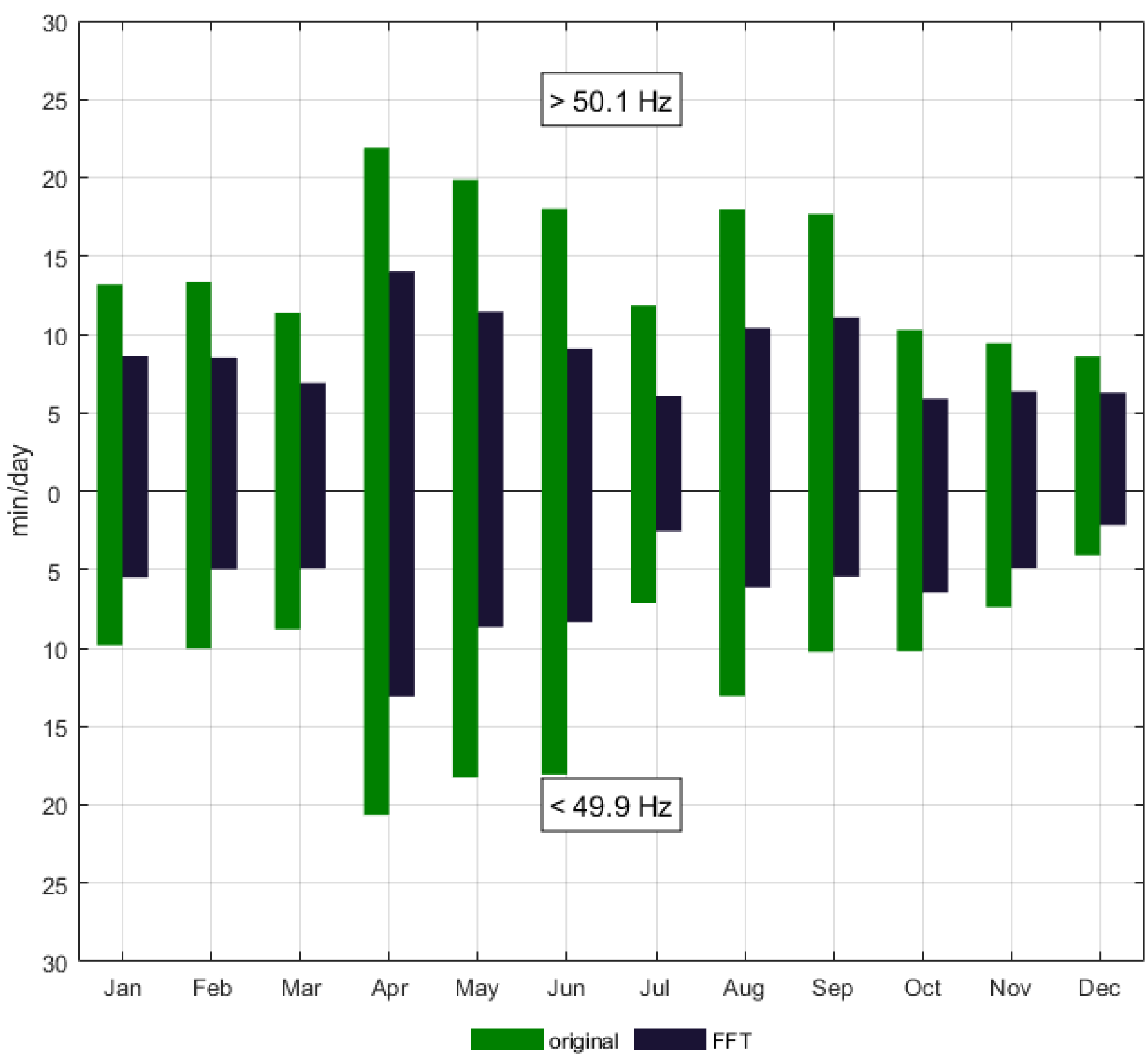


3.8.3 Influence of oscillation on frequency variations

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 2024 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 2024



In Figure 3.64, the reduction of time outside the standard frequency range in 2024 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 July and smallest in November and December. The values are slightly lower compared to 2023.

***Figure 3.64**. Reduction in time per month outside the standard frequency range after filtering in 2024*

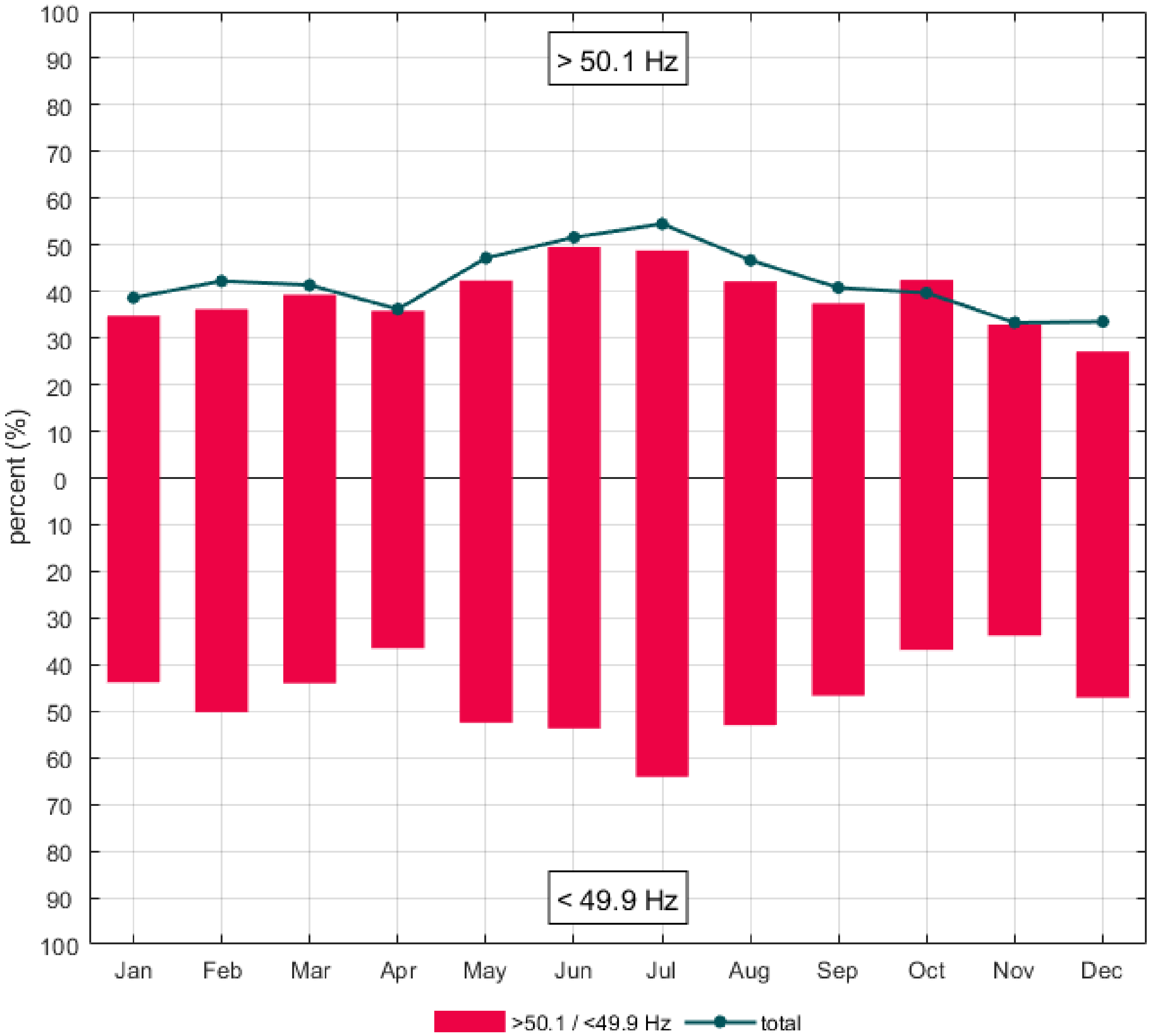
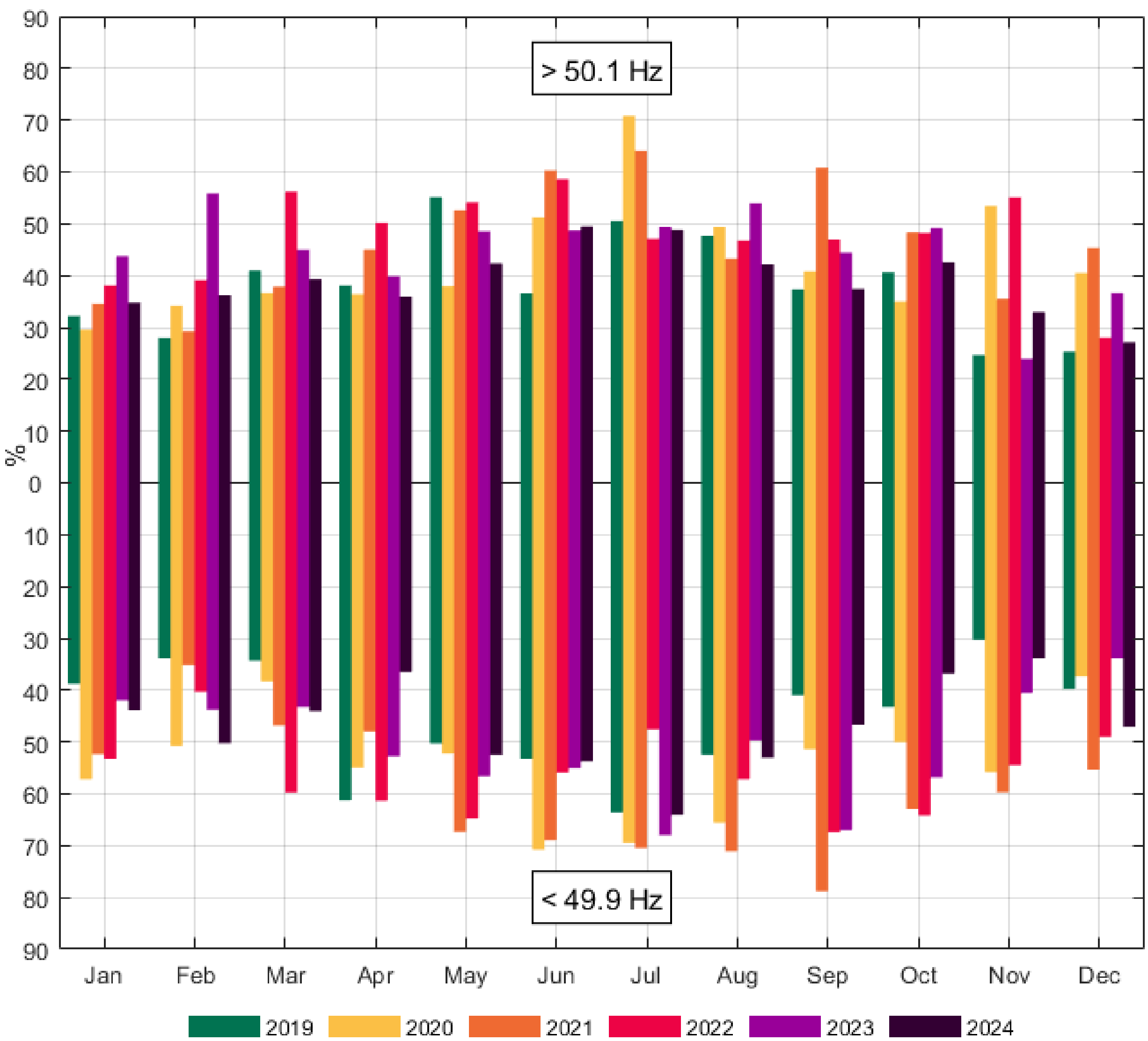


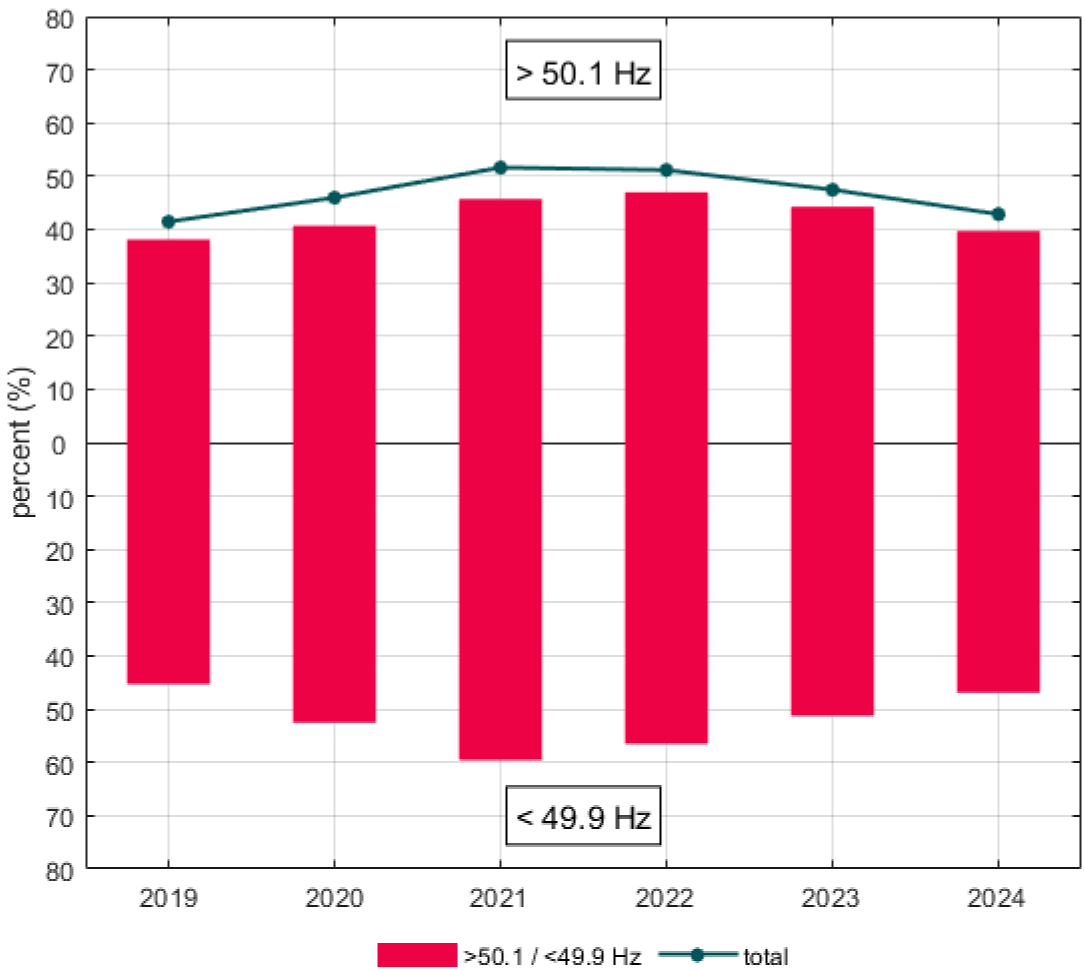
Figure 3.65 represents the reduction in time outside the standard frequency range in percentages month by month for years 2019 to 2024.

***Figure 3.65**. Reduction in time per month outside the standard frequency range after filtering in years 2019-2024*



In addition to the monthly values presented in the previous figure, results for the entire year in 2019-2024 are shown below in Figure 3.66. Filtering the oscillation reduces the duration of frequency deviations by a bit less than 50% in 2024. Slight yearly growth in reduction can be seen from 2019 up to 2021, after which the values have decreased in 2022 to 2024. Time below 49.9 Hz is affected more by the oscillation since the reduction values are higher with under frequencies.

Figure 3.66**. **Reduction in time outside the standard frequency range after filtering for years 2019-2024



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 2024. 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]*

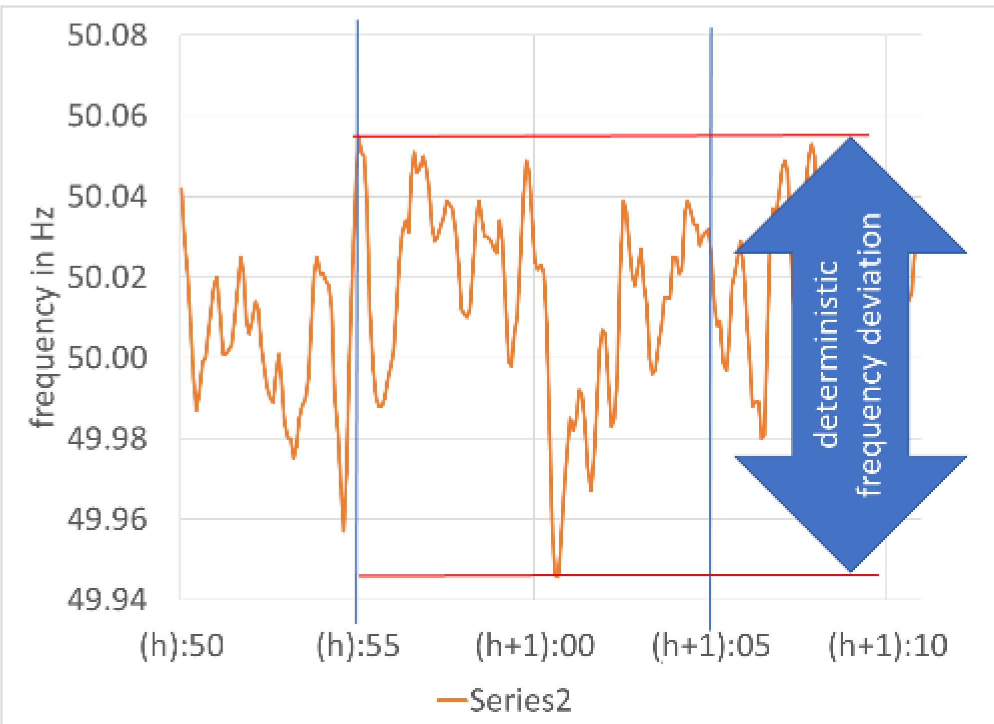


Figure 3.68 represents the deterministic frequency deviation per month in 2024. The 50th percentile stays below zero for the entire year, which indicates that the highest frequency took place before the lowest in more than half of the hour shifts. The percentiles are the furthest away from zero in April. The values are similar to 2023, albeit slightly further from zero in the 1st and 99th percentile.

***Figure 3.68**. The 1st, 5th, 10th, 50th, 90th, 95th, and 99th percentiles of deterministic frequency deviation for every month in 2024*

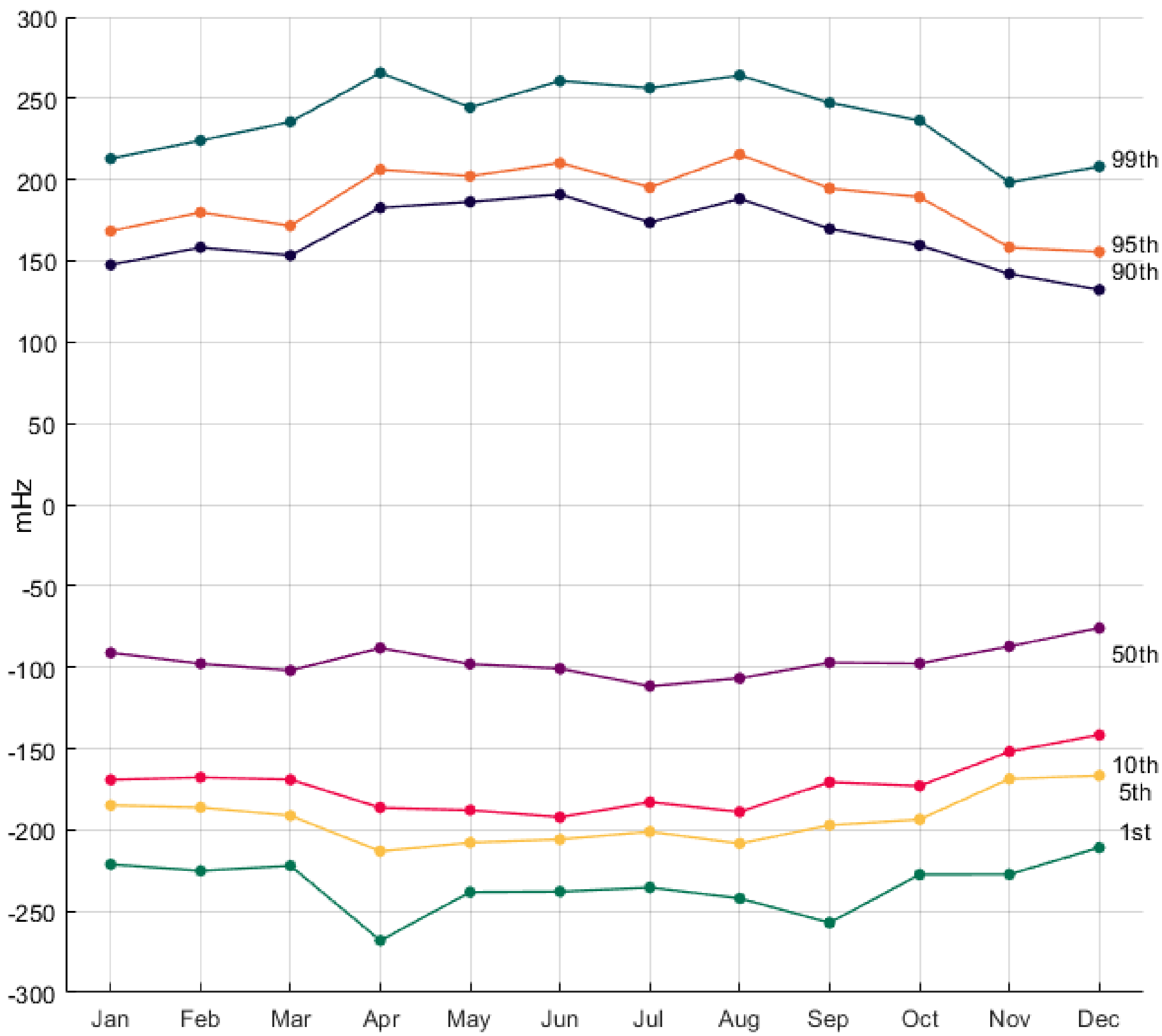
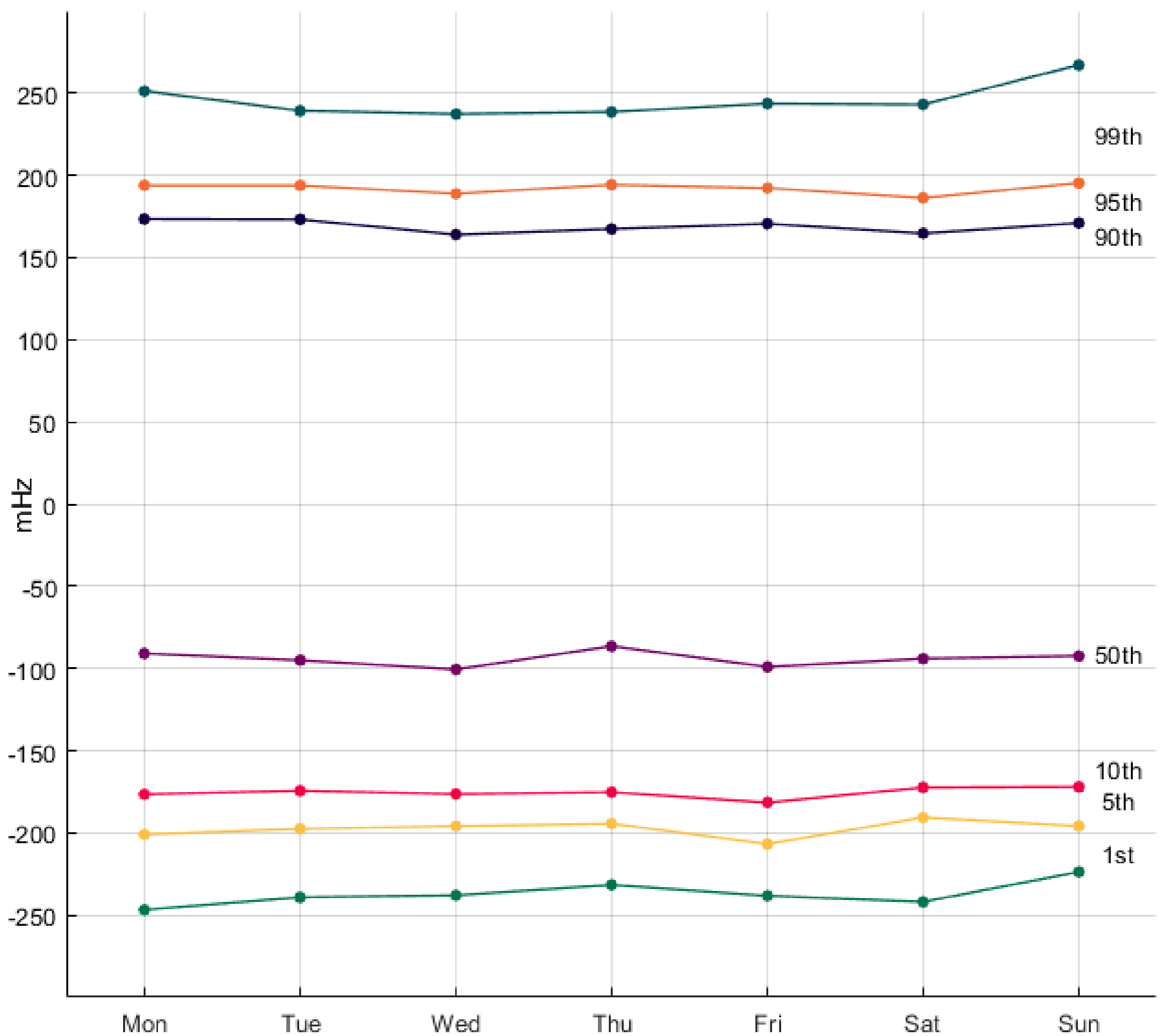


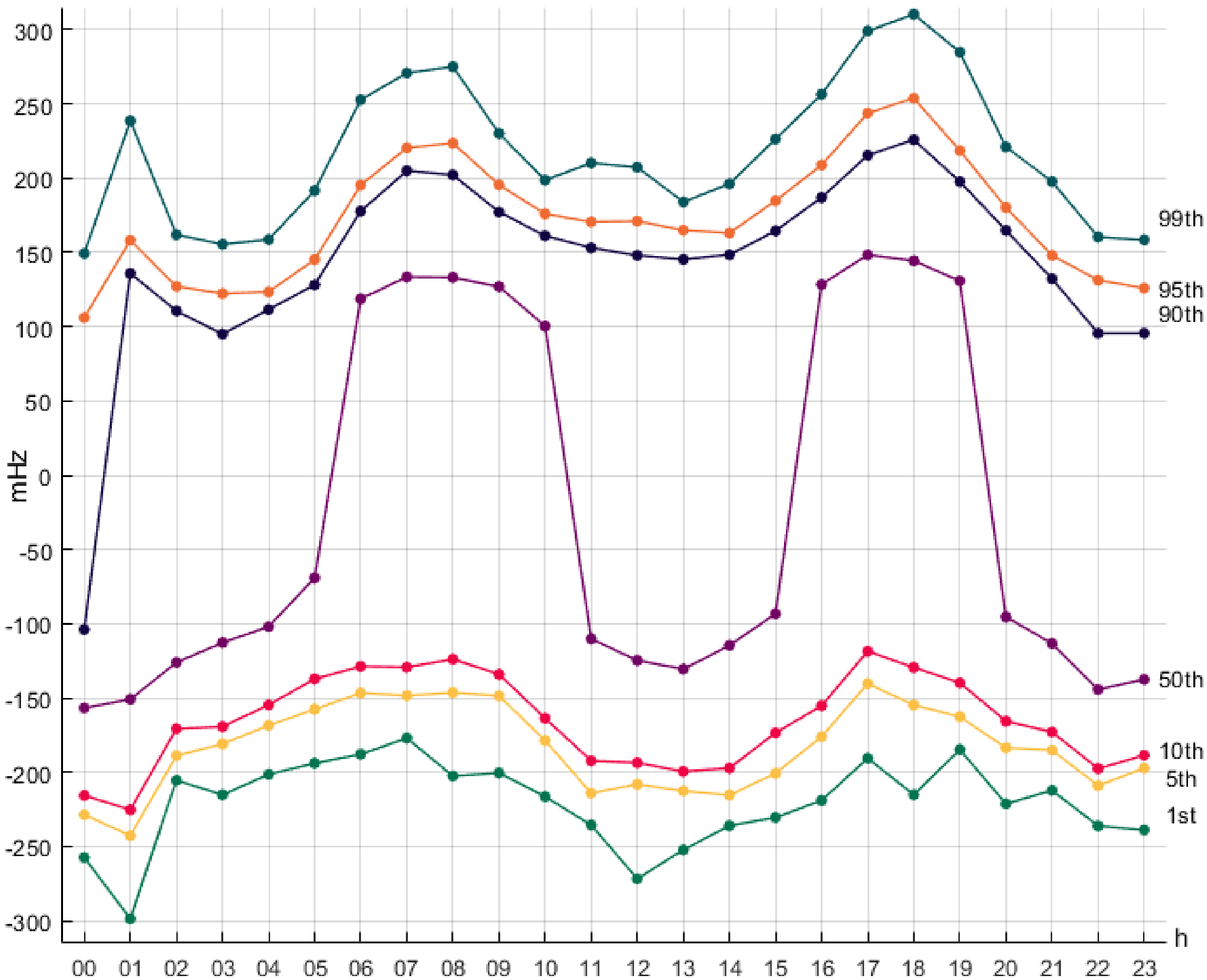
Figure 3.69 shows the percentiles around the hour shift for every day of the week in 2024. The 99th percentile is slightly higher in Monday and Sunday, and otherwise the 90th, 95th and 99th percentiles are spread fairly evenly through the week.

***Figure 3.69**. The 1st, 5th, 10th, 50th, 90th, 95th, and 99th percentiles of deterministic frequency deviation for every day of the week in 2024*



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 10 and in the evening from 16 to 19, 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 2024*

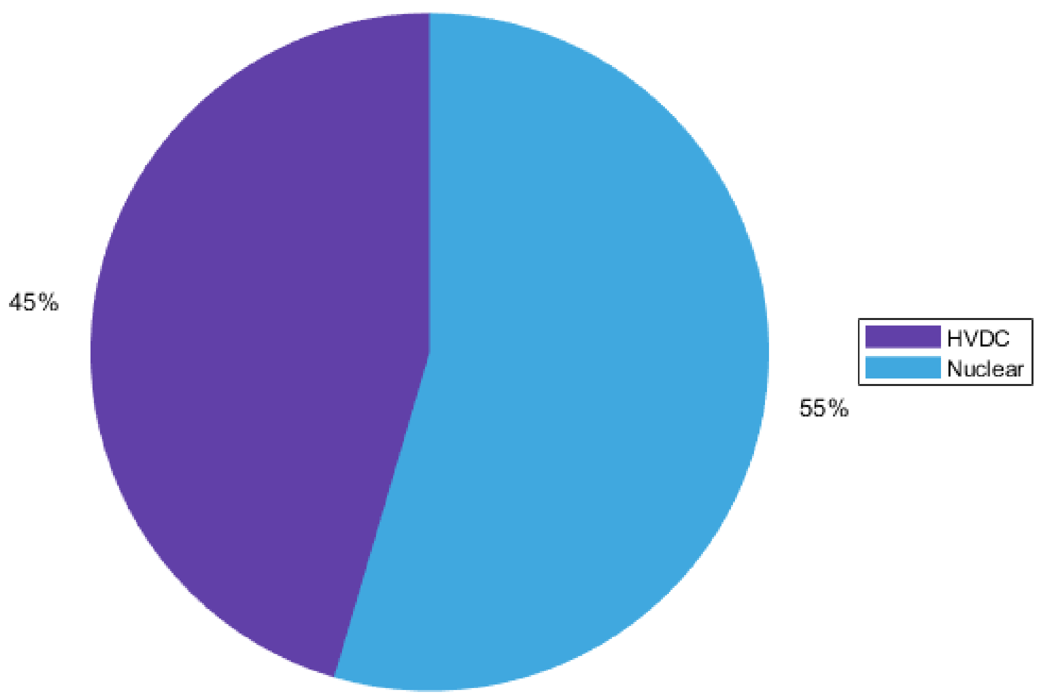


Chapter 4. Frequency disturbances exceeding 300 mHz frequency deviation

This chapter offers information on the major frequency disturbances in the Nordic synchronous system in 2024. 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 11 frequency disturbances in 2024, where the deviation exceeded 300 mHz. Six of those disturbances were caused by nuclear power plants and five by failures in HVDC links. Figure 4.1 represents the shares of the factors causing over 300 mHz deviations. The number of 300 mHz deviations decreased by 21.4% from the previous year and 31.3% from 2022. However, the number of these deviations has increased compared to years 2019-2021. Nuclear power plant failures are the most common reason for large deviations, similar to 2022.

***Figure 4.1**. Shares of the factors causing over 300 mHz disturbances in the Nordic synchronous system in 2024*



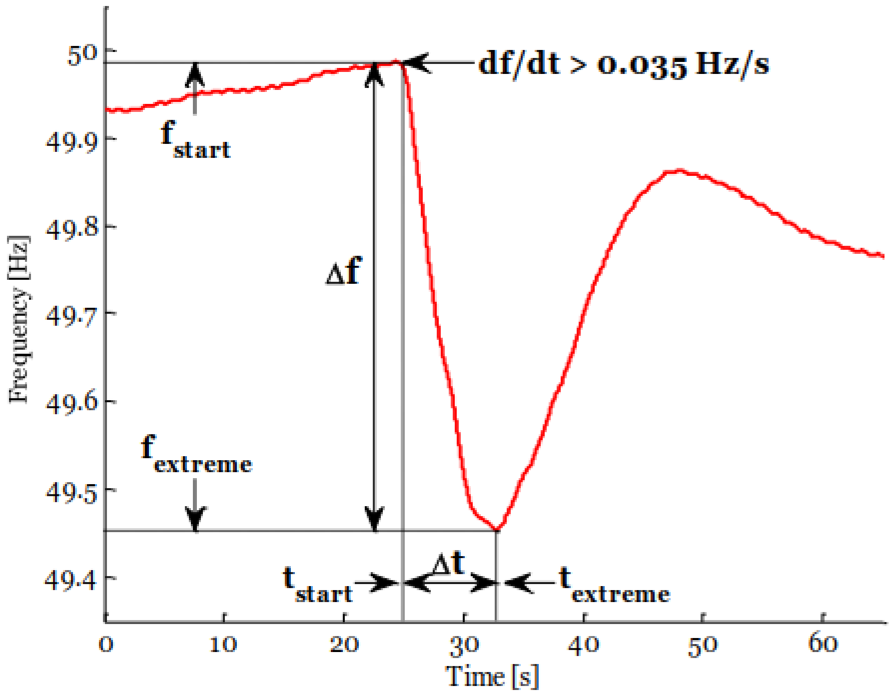
The largest under frequency deviation was caused by a fault in a nuclear power plant. The amplitude of this deviation was -0.475 Hz, and it was reported on the 3rd of June. The largest over frequency deviation occurred on the 5th of July, and its amplitude was 0.404 Hz. This deviation was caused by a fault in an HVDC link.

The following part of the chapter will go into more detail on every disturbance that took place in 2024. 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 4.2.

***Figure 4.2**. 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 4.2.
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 4.3-16 and Tables 4.2-15.

More detailed descriptions of the events listed in Table 4.1 are presented afterwards in Figures 4.3-16 and Tables 4.2-15.

Table 4.1. List of disturbance events in 2024

Event date	Δf (Hz)	ΔP (MW)	Δt (s)	E_k (GWs)	Cause	Page
05-May-2024 04:21:40	0.397	1234	3.3	156	HVDC	105
13-May-2024 08:13:29	-0.315	1030	5.6	188	Nuclear	106
03-Jun-2024 11:41:43	-0.475	1322	7.1	199	Nuclear	107
10-Jun-2024 11:20:34	-0.324	1059	6.4	189	Nuclear	108
12-Jun-2024 21:47:57	0.300	644	4.2	204	HVDC	109
05-Jul-2024 20:13:25	0.404	931	6.2	174	HVDC	110
03-Sep-2024 11:16:02	-0.293	843	8.8	195	Nuclear	111
10-Sep-2024 11:15:13	-0.334	850	8.5	148	Nuclear	112
12-Sep-2024 11:15:01	-0.417	1095	7.0	179	Nuclear	113
08-Oct-2024 10:47:57	0.396	1401	4.4	205	HVDC	114
30-Nov-2024 07:51:14	0.302	1020	6.2	209	HVDC	115

Figure 4.3. Disturbance 05-May-2024 04:21:40

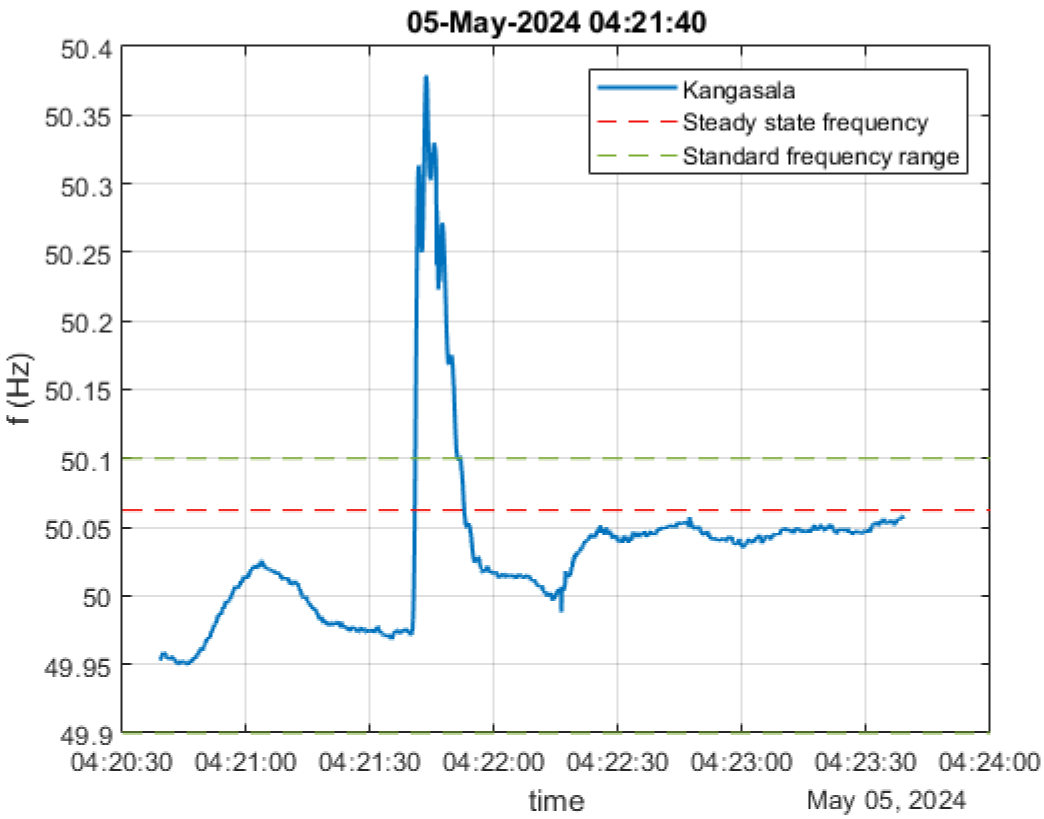


Table 4.2. Disturbance 05-May-2024 04:21:40

Date		**05-May-2024 04:21:40**	
f_{start}	49.978 Hz	$f_{steady\ state}$	50.062 Hz
$f_{extreme}$	50.376 Hz	$\Delta f_{steady\ state}$	0.084 Hz
Δf	0.397 Hz	$f_{extreme2}$	49.998 Hz
Δt	3.3 s	$f_{extreme3}$	50.054 Hz
ΔP	1234 MW	damping	15.00 %
E_k	156 GWs	FBF	14698 MW/Hz
cause		HVDC	

Figure 4.4. Disturbance 13-May-2024 08:13:29

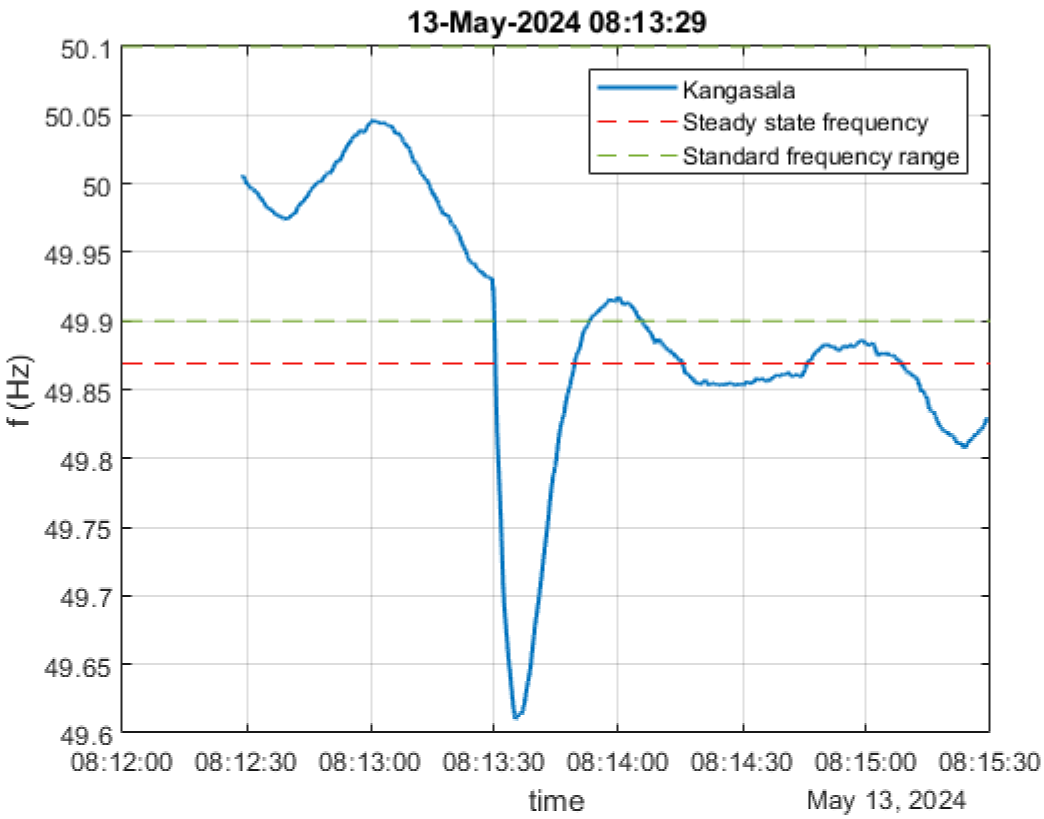


Table 4.3. Disturbance 13-May-2024 08:13:29

Date		**13-May-2024 08:13:29**	
f_{start}	49.925 Hz	$f_{steady\ state}$	49.869 Hz
$f_{extreme}$	49.611 Hz	$\Delta f_{steady\ state}$	0.056 Hz
Δf	-0.315 Hz	$f_{extreme2}$	49.917 Hz
Δt	5.6 s	$f_{extreme3}$	49.853 Hz
ΔP	1030 MW	damping	20.83 %
E_k	188 GWs	FBF	18303 MW/Hz
cause		Nuclear	

Figure 4.5. Disturbance 03-Jun-2024 11:41:43

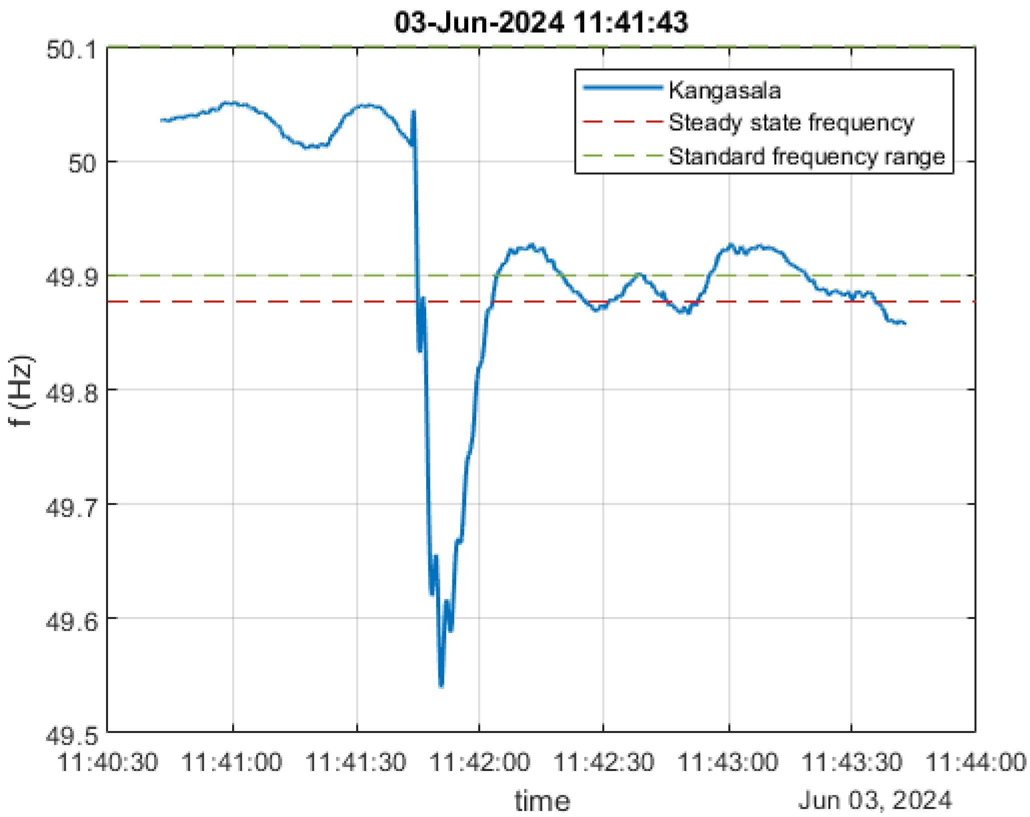


Table 4.4. Disturbance 03-Jun-2024 11:41:43

Date		03-Jun-2024 11:41:43	
f_{start}	50.017 Hz	$f_{steady\ state}$	49.877 Hz
$f_{extreme}$	49.542 Hz	$\Delta f_{steady\ state}$	0.140 Hz
Δf	-0.475 Hz	$f_{extreme2}$	49.927 Hz
Δt	7.1 s	$f_{extreme3}$	49.867 Hz
ΔP	1322 MW	damping	15.69 %
E_k	199 GWs	FBF	9429 MW/Hz
cause		Nuclear	

Figure 4.6. Disturbance 10-Jun-2024 11:20:34

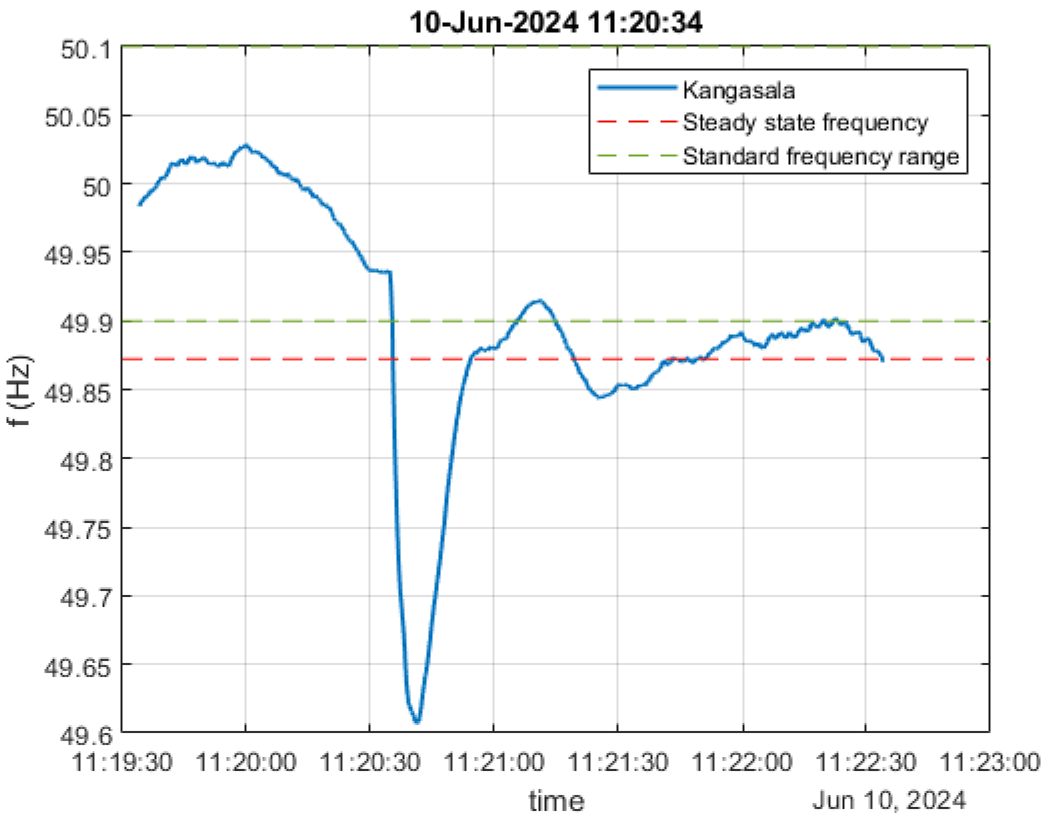


Table 4.5. Disturbance 10-Jun-2024 11:20:34

Date		**10-Jun-2024 11:20:34**	
f_{start}	49.931 Hz	$f_{steady\ state}$	49.872 Hz
$f_{extreme}$	49.607 Hz	$\Delta f_{steady\ state}$	0.059 Hz
Δf	-0.324 Hz	$f_{extreme2}$	49.915 Hz
Δt	6.4 s	$f_{extreme3}$	49.844 Hz
ΔP	1059 MW	damping	23.01 %
E_k	189 GWs	FBF	17967 MW/Hz
cause		Nuclear	

Figure 4.7. Disturbance 12-Jun-2024 21:47:57

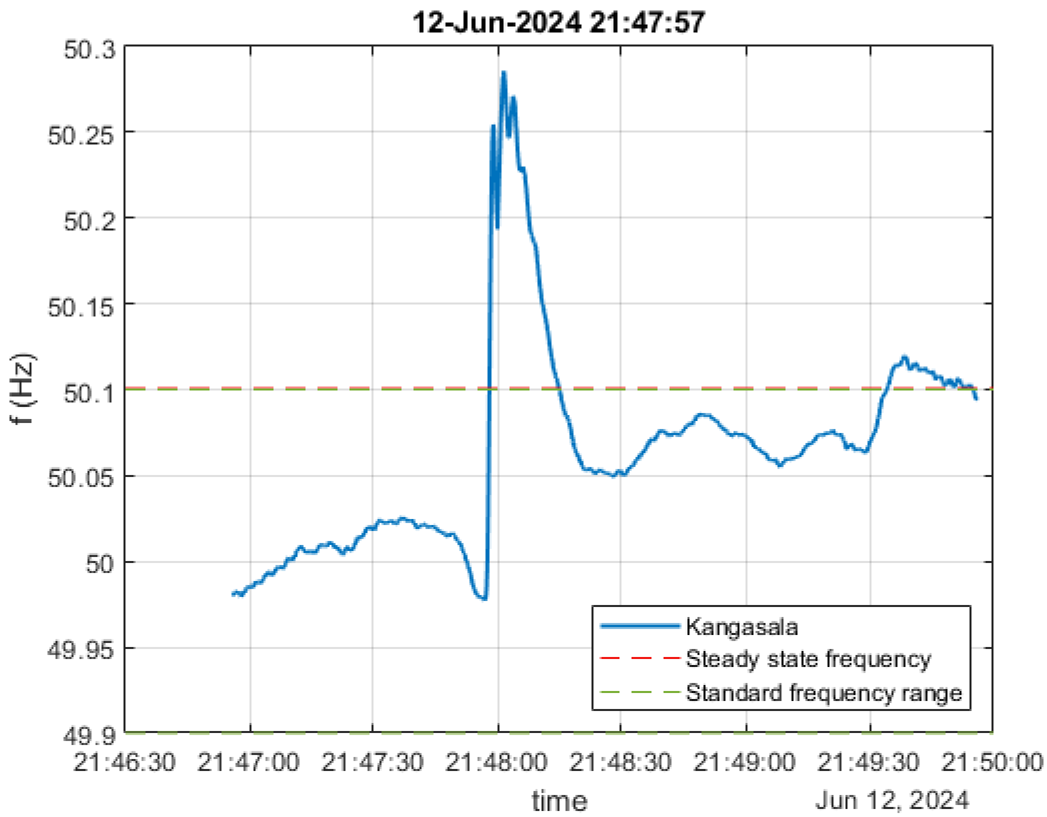


Table 4.6. Disturbance 12-Jun-2024 21:47:57

Date		**12-Jun-2024 21:47:57**	
f_{start}	49.984 Hz	$f_{steady\ state}$	50.101 Hz
$f_{extreme}$	50.284 Hz	$\Delta f_{steady\ state}$	0.117 Hz
Δf	0.300 Hz	$f_{extreme2}$	50.050 Hz
Δt	4.2 s	$f_{extreme3}$	50.086 Hz
ΔP	644 MW	damping	15.52 %
E_k	204 GWs	FBF	5514 MW/Hz
cause		HVDC	

Figure 4.8. Disturbance 05-Jul-2024 20:13:25

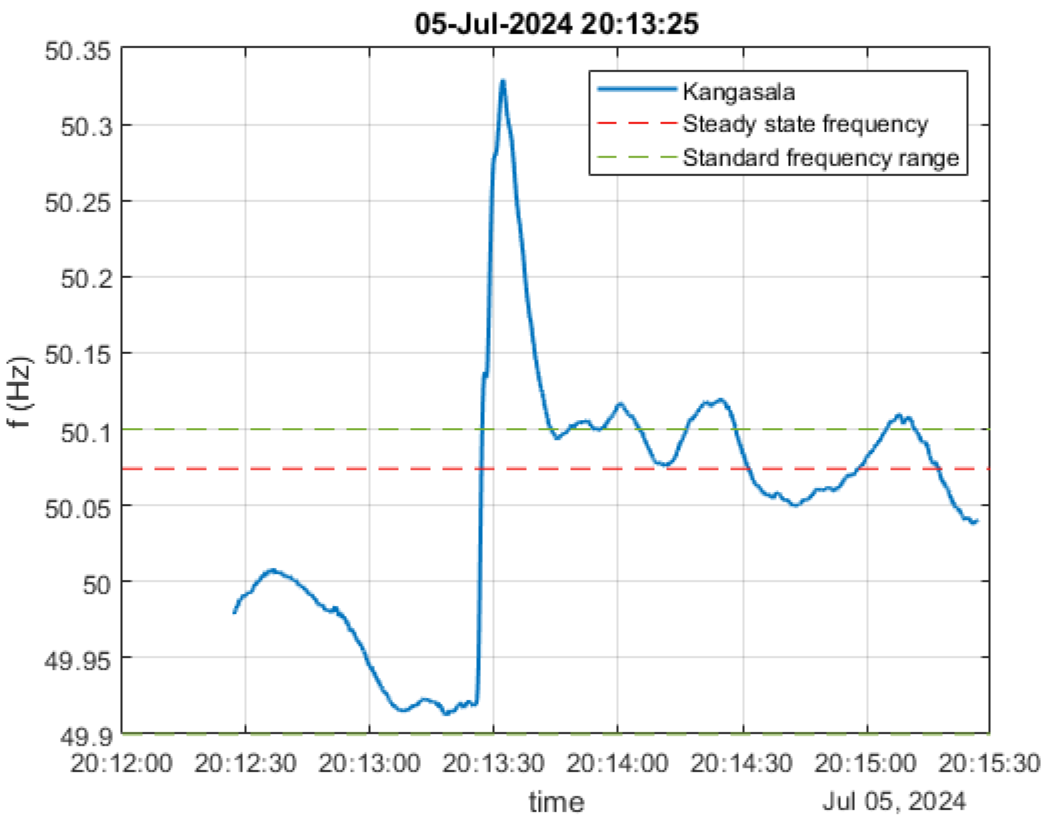


Table 4.7. Disturbance 05-Jul-2024 20:13:25

Date		**05-Jul-2024 20:13:25**	
f_{start}	49.925 Hz	$f_{steady\ state}$	50.074 Hz
$f_{extreme}$	50.329 Hz	$\Delta f_{steady\ state}$	0.150 Hz
Δf	0.404 Hz	$f_{extreme2}$	50.074 Hz
Δt	6.2 s	$f_{extreme3}$	50.036 Hz
ΔP	931 MW	damping	14.93 %
E_k	174 GWs	FBF	6222 MW/Hz
cause		HVDC	

Figure 4.9. Disturbance 03-Sep-2024 11:16:02

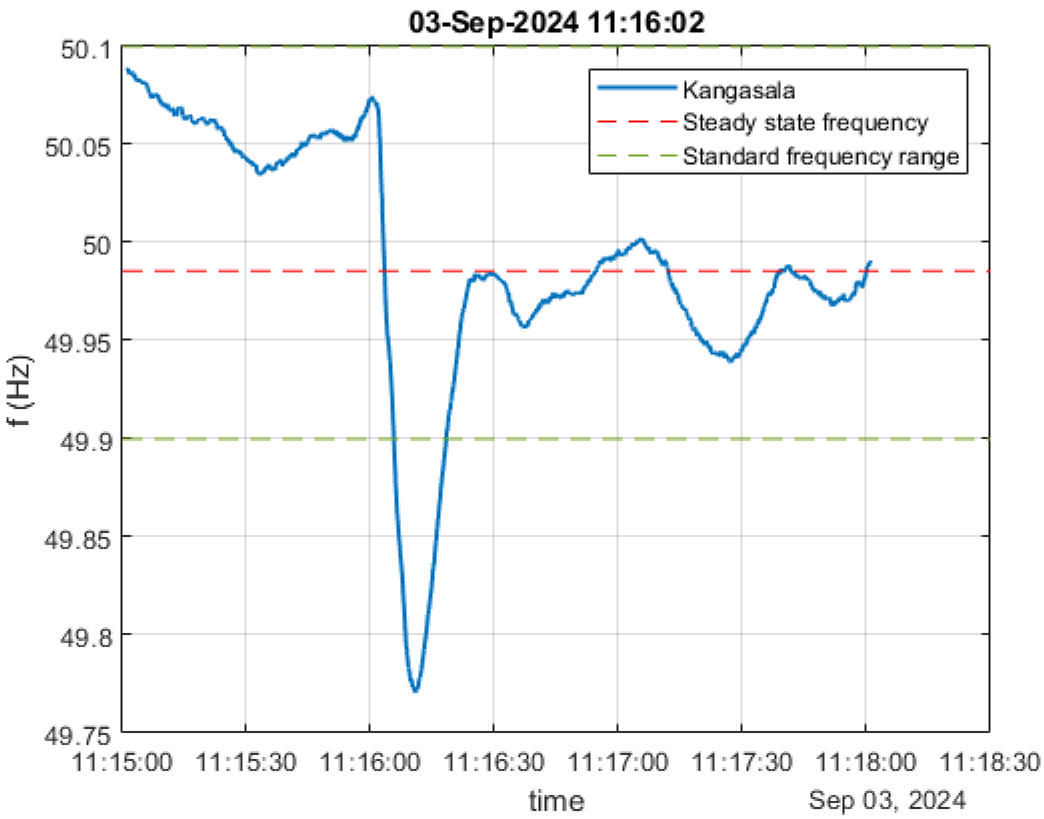


Table 4.8. Disturbance 03-Sep-2024 11:16:02

Date		**03-Sep-2024 11:16:02**	
f_{start}	50.064 Hz	$f_{steady\ state}$	49.985 Hz
$f_{extreme}$	49.771 Hz	$\Delta f_{steady\ state}$	0.079 Hz
Δf	-0.293 Hz	$f_{extreme2}$	50.002 Hz
Δt	8.8 s	$f_{extreme3}$	49.939 Hz
ΔP	843 MW	damping	27.09 %
E_k	195 GWs	FBF	10734 MW/Hz
cause		Nuclear	

Figure 4.10. Disturbance 10-Sep-2024 11:15:13

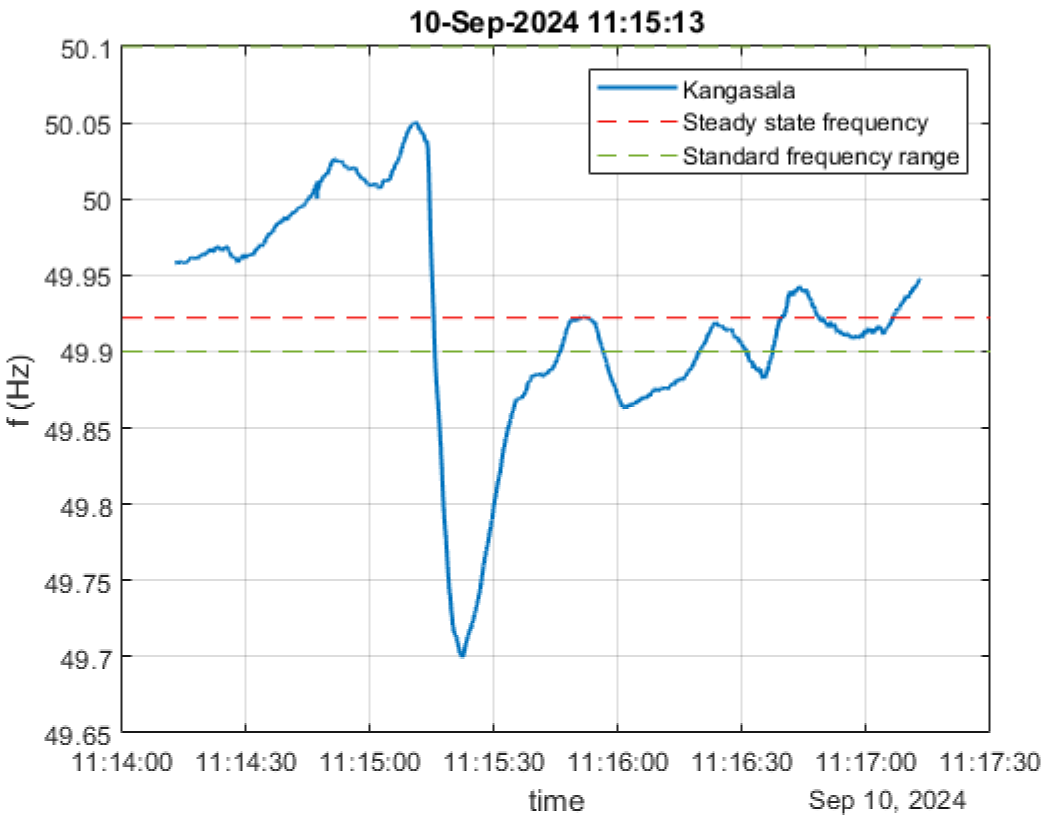


Table 4.9. Disturbance 10-Sep-2024 11:15:13

Date		**10-Sep-2024 11:15:13**	
f_{start}	50.034 Hz	$f_{steady\ state}$	49.922 Hz
$f_{extreme}$	49.700 Hz	$\Delta f_{steady\ state}$	0.112 Hz
Δf	-0.334 Hz	$f_{extreme2}$	49.922 Hz
Δt	8.5 s	$f_{extreme3}$	49.863 Hz
ΔP	850 MW	damping	26.57 %
E_k	148 GWs	FBF	7591 MW/Hz
cause		Nuclear	

Figure 4.11. Disturbance 12-Sep-2024 11:15:01

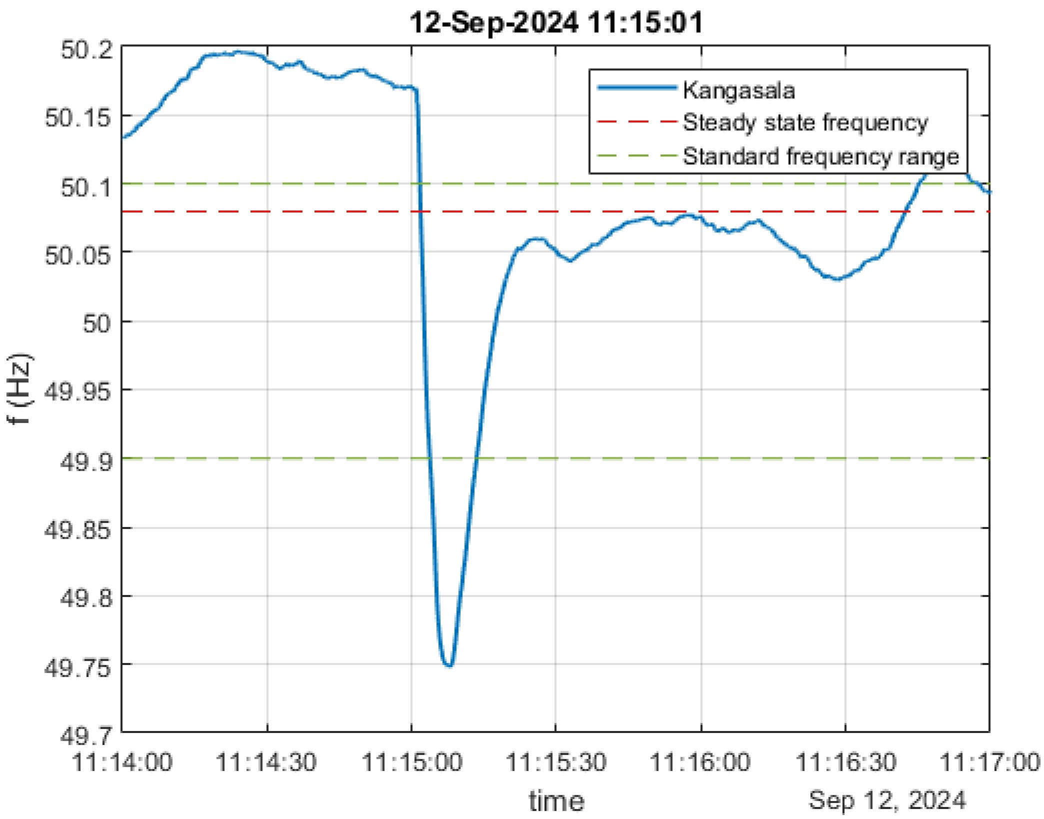


Table 4.10. Disturbance 12-Sep-2024 11:15:01

Date		**12-Sep-2024 11:15:01**	
f_{start}	50.166 Hz	$f_{steady\ state}$	50.080 Hz
$f_{extreme}$	49.749 Hz	$\Delta f_{steady\ state}$	0.086 Hz
Δf	-0.417 Hz	$f_{extreme2}$	50.077 Hz
Δt	7.0 s	$f_{extreme3}$	50.030 Hz
ΔP	1095 MW	damping	14.33 %
E_k	179 GWs	FBF	12732 MW/Hz
cause		Nuclear	

***Figure 4.12**. Disturbance 08-Oct-2024 10:47:57*

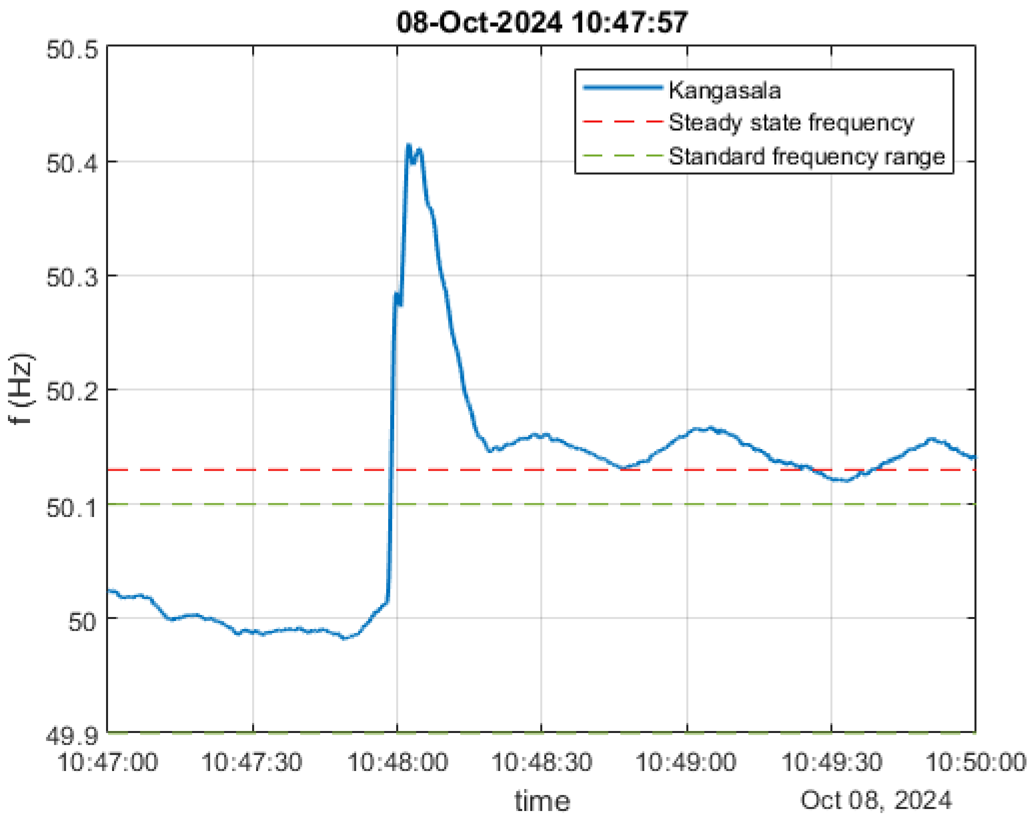


***Table 4.11**. Disturbance 08-Oct-2024 10:47:57*

Date		**08-Oct-2024 10:47:57**	
f_{start}	50.018 Hz	$f_{steady\ state}$	50.130 Hz
$f_{extreme}$	50.414 Hz	$\Delta f_{steady\ state}$	0.113 Hz
Δf	0.396 Hz	$f_{extreme2}$	50.132 Hz
Δt	4.4 s	$f_{extreme3}$	50.167 Hz
ΔP	1401 MW	damping	12.74 %
E_k	205 GWs	FBF	12432 MW/Hz
cause		HVDC	

Figure 4.13. Disturbance 30-Nov-2024 07:51:14

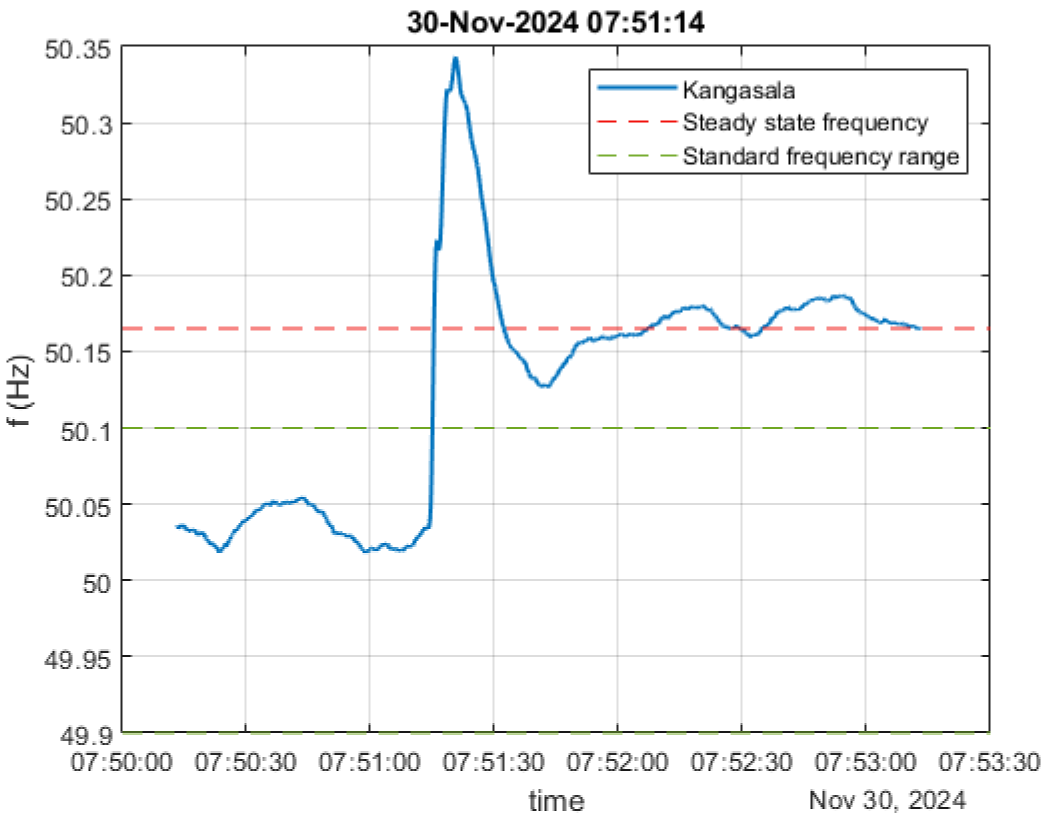


Table 4.12. Disturbance 30-Nov-2024 07:51:14

Date		**30-Nov-2024 07:51:14**	
f_{start}	50.041 Hz	$f_{steady\ state}$	50.165 Hz
$f_{extreme}$	50.343 Hz	$\Delta f_{steady\ state}$	0.124 Hz
Δf	0.302 Hz	$f_{extreme2}$	50.127 Hz
Δt	6.2 s	$f_{extreme3}$	50.180 Hz
ΔP	1020 MW	damping	24.44 %
E_k	209 GWs	FBF	8229 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 2024. The overall quality of frequency was similar to the year 2023. 2023 and 2024 share many common trends especially when mean values and standard deviations are used as performance metrics. Perhaps the most notable difference to 2023 and the years prior is the increase of short duration deviations and frequency crossings, as well as the increase of the frequency path length on monthly, weekly, hourly and minute-wise scale.

In terms of mean value, the best month was October, where a mean of 50.000 Hz was attained, while the worst month was September. In terms of standard deviation, the best month was December and the worst month was May, closely followed by April and June. Overall, the variability in frequency was lower in 2024 than in 2023, while the mean values remained similar. The reduction in variability was also reflected in the slightly lower values of frequency area in comparison to 2023. In terms of the performance metrics discussed here, the frequency quality was slightly better towards the end of the week, and accordingly, Monday performed the worst while Sunday performed the best. Contrary to 2023, there was no clear reduction in quality on Tuesday and Wednesday.

Similar trends were found in the hourly analysis, with a clear reduction of variablity, and thus, an increase of frequency quality during the early morning hours. On the other hand, the frequency quality was slightly worse from 4 pm to 6 pm. The worst hours in 2024 were 7 am and 5 pm. Within the hour, the quality is the best around the half hour mark, and the worst close to the hour shift, especially at the beginning of the hour. This has been a common trend in the whole observation period.

While the daily average number of minutes per year that the frequency was outside the standard frequency range in 2024 was similar to prior years, the cumulative minutes outside the standard range exceeded the target of 10 000 minutes. In addition, the average number of seconds per day that the frequency was outside 49.8-50.2 Hz increased by 75.8%. The number of frequency deviations also increased in several duration categories. In particular, short, 0-1 s deviations as well as deviations longer than 3 minutes increased. Threshold crossings of the standard frequency range remained similar to the prior years, while crossings that exceeded ±200 mHz increased approximately 26.5%. Finally, there has also been a notable increase in the length of the frequency path on each observation scale, which indicates that the frequency has traveled around the 50 Hz mark more than in prior years.

The amount of oscillation in 2024 is lower than in most of the prior years, especially towards the end of the year. This is noteworthy because 2024 represents the first clear instance of the oscillation reducing compared to the previous year. The mean value of oscillation was the highest in May and June. Removal of the oscillation by filtering the frequency data clearly reduces the time outside the standard frequency range. The reduction is a bit under 50% with the FFT-filtering method, which is similar to 2023, and slightly less than in 2021-2022.

There were 11 frequency disturbances in 2024, where the deviation exceeded 300 mHz. The majority was caused by failures in nuclear power plants, and the rest by failures in HVDC links. This is different from the previous year, where HVDC links accounted for the majority of the deviations. The number of frequency deviations exceeding 300 mHz is similar to 2022 and 2023 but has increased compared to years 2017-2020 where there have been around 6 deviations per year.

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 2019", Fingrid Oyj, 17.9.2020

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

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