Frequency quality analysis

2021

FINGRID

Table of Contents

Chapter 1. Introduction

This report presents the results of frequency quality study of the Nordic synchronous system for the year 2021. The results have been obtained by analyzing data from Fingrid's PMU (Phasor Measurement Unit) measurements. All times are given in Finnish time (CET+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 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 results from Fingrid's previous years' frequency quality analysis. The fourth chapter presents in detail 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. Current Nordic target level for 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 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 2021 is presented in Table 2.1. Availability of data per year for years 2016 to 2021 can be seen in Table 2.2 [2,3,4,5,6,7]. In 2021 there was valid measurement data for 99.92 % of the time. Some of the data is missing due to telecommunication errors. There are no significant differences in availability between months illustrated in table 2.1.

Table 2.1. The amount of valid measurement data available per month in 2021

Month	Available data
January	99.80 %
February	99.96 %
March	99.94 %
April	99.92 %
May	99.85 %
June	99.88 %
July	99.95 %
August	99.97 %
September	99.96 %
October	99.85 %
November	99.96 %
December	99.98 %

Table 2.2. The amount of valid measurement data available for years 2016-2021

Year	Available data
2016	99.37 %
2017	97.19 %
2018	98.90 %
2019	98.47 %
2020	97.82 %
2021	99.92 %

Chapter 3. Frequency Quality Indices

This chapter includes frequency quality indices defined and proposed by Frequency Quality, phase 2 Project Report for monitoring frequency quality at all times [8]. 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. The Article 131 is shown in the following page.

All input frequency data used to calculate the frequency indices is either 0.1 seconds or averages of the 0.1 second data. For example, a resolution of 1 second means that the average of ten 0.1 second values have 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 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 2021. 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. Average frequency has been very close to 50 Hz, as even for the worst months like January and February the averages have not deviated more than 0.3 mHz from 50 Hz. The average frequency in 2021 was a little better than the year before, since the maximum average frequency deviation in 2020 was close to 0.4 mHz from 50 Hz.

Figure 3.1. Average frequency for each month in 2021

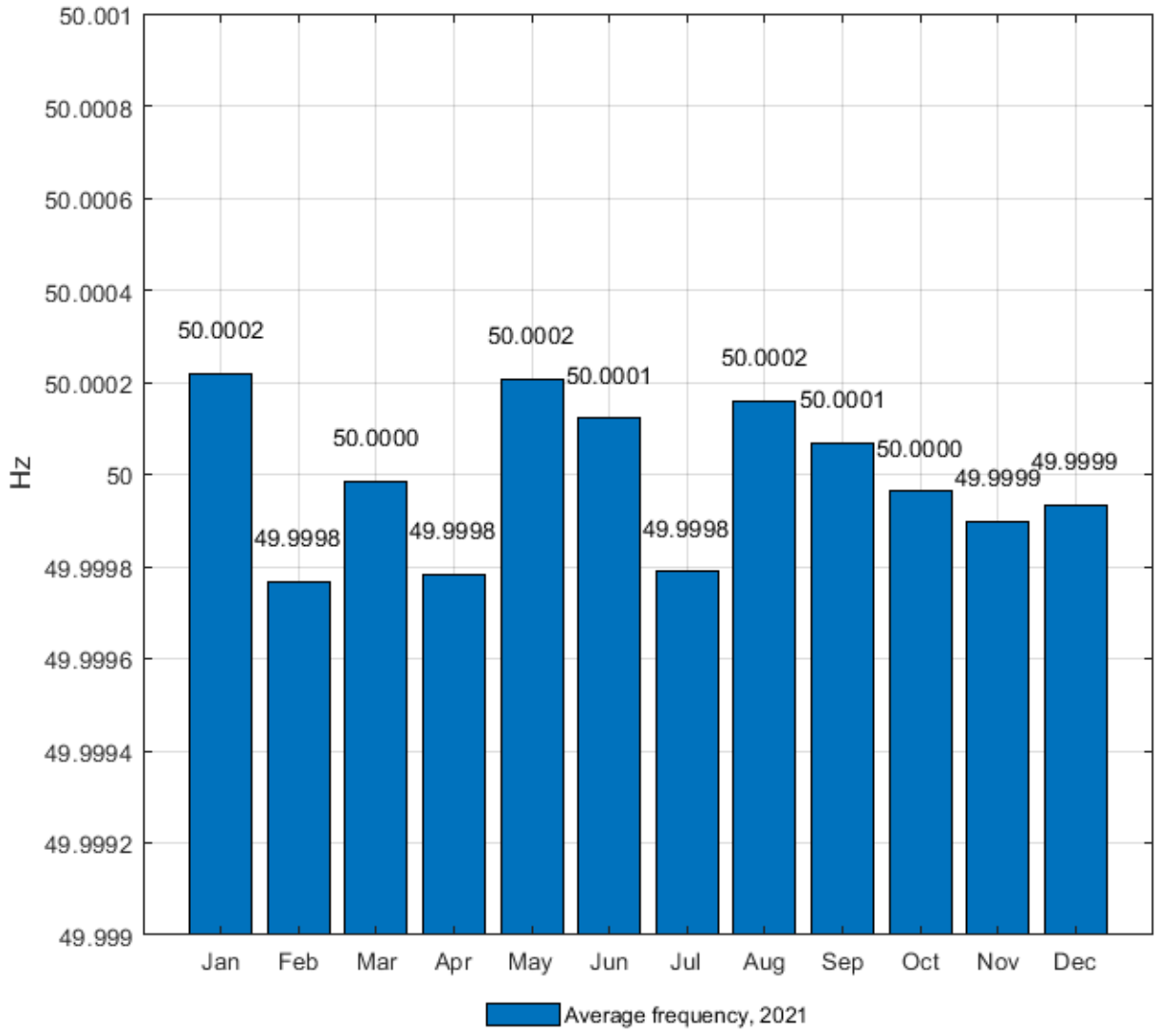


Figure 3.2 shows the average frequencies for each day of the week. The highest average frequency value has occured on Monday, after which the value of average frequency has decreased every day before the significant increase on Friday. During the weekend, the average frequency drops for Saturday and rises again on Sunday.

Figure 3.2. Average frequency for each day of the week in 2021

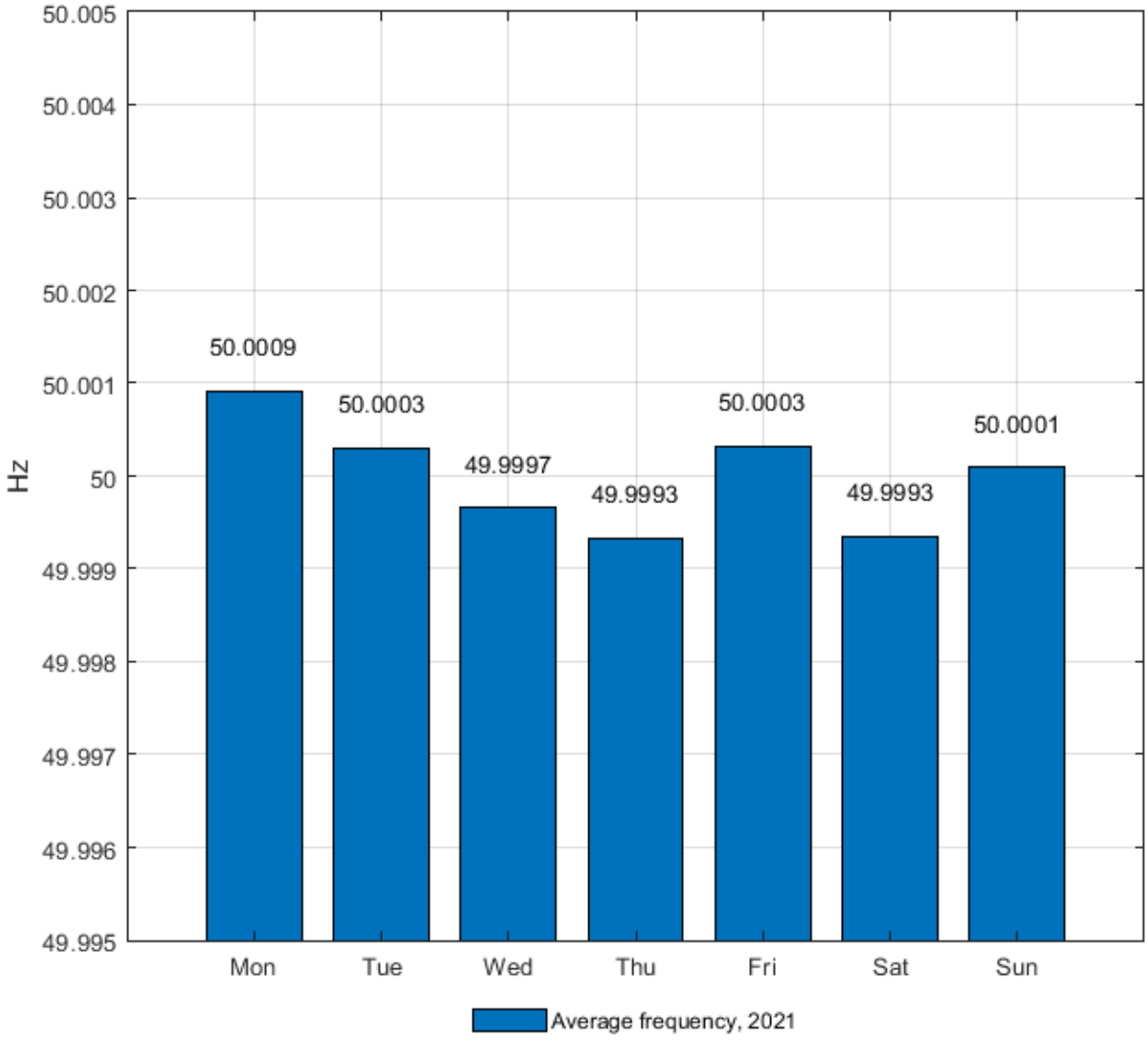


Figure 3.3 shows the average frequencies during each hour of the day. The frequency has been lower during hours from 1 a.m. to 9 a.m. and in the afternoon from 16 p.m. to 18 p.m. The frequency has been higher around noon, in the evening and around midnight.

Figure 3.3. Average frequency for each hour of the day in 2021

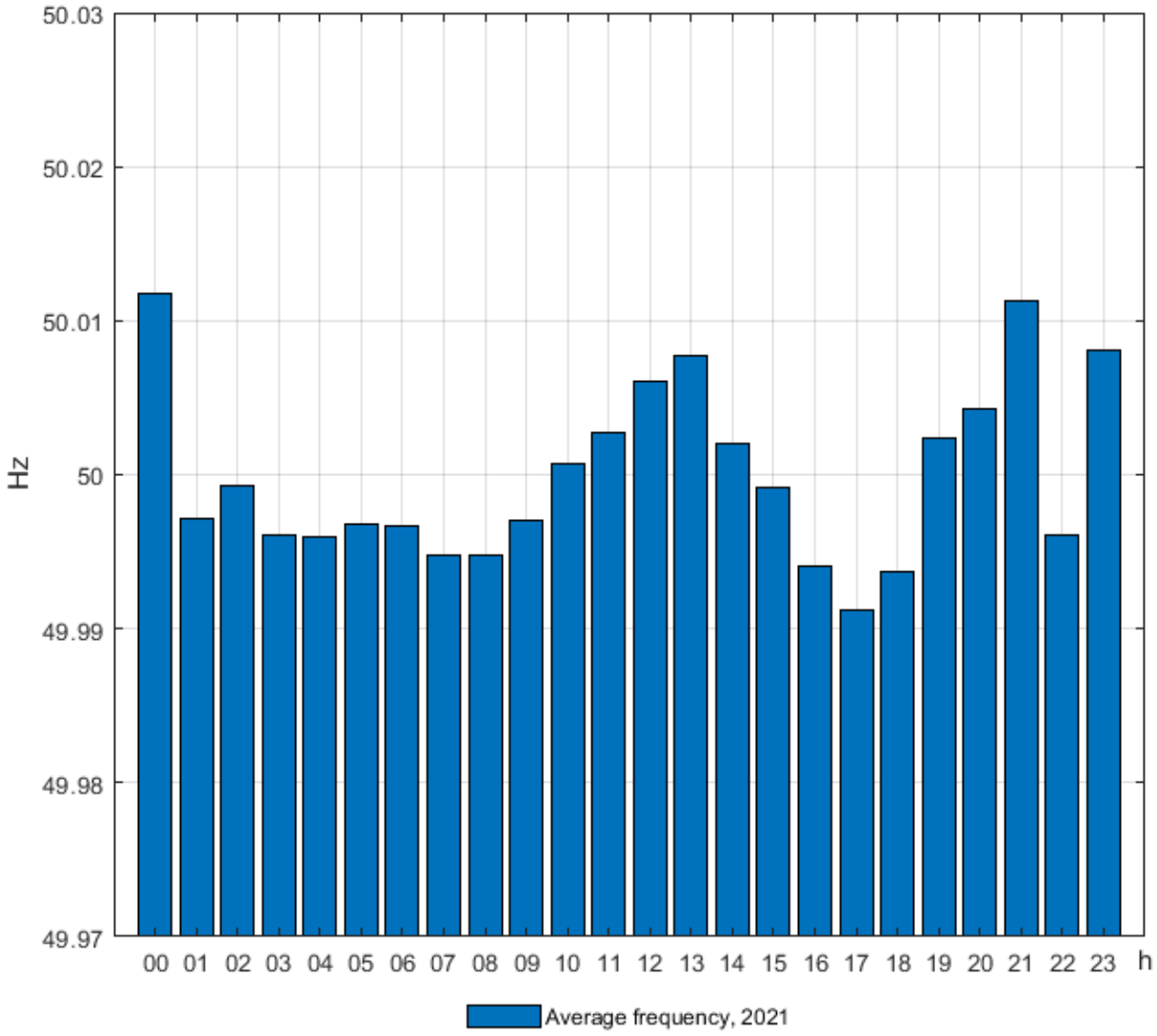
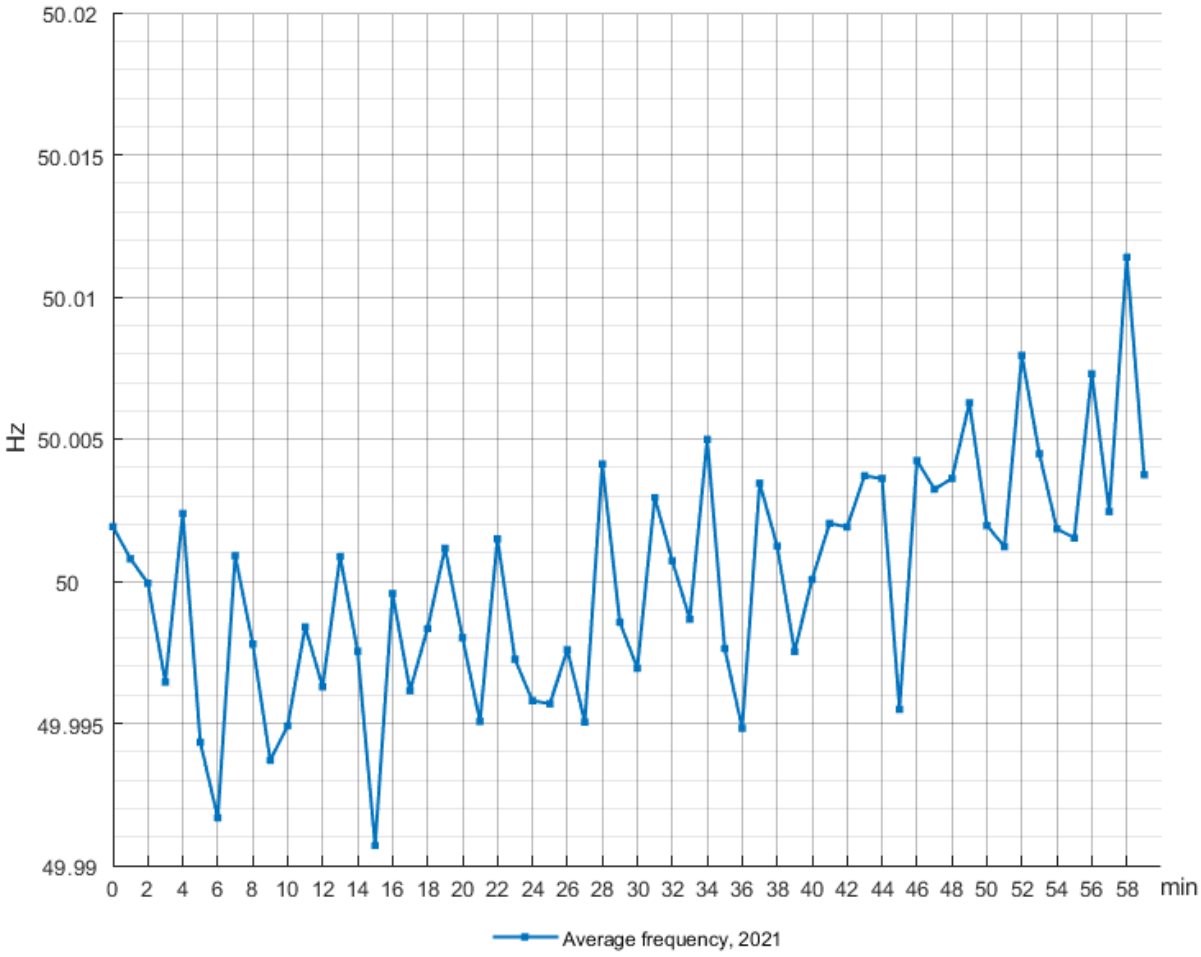


Figure 3.4 shows the average frequency inside the hour. In general, the frequency has been higher in the latter part of the hour. The difference between consecutive minutes varies between 0-9.2 mHz. The differences have decreased from year 2020. In 2020 the greatest difference was 12.5 mHz.

Figure 3.4. Average frequency for each minute of the hour in 2021



3.1.2 Standard deviation

This section includes the figures representing the standard deviation of frequency during the year 2021. 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 2021. The low standard deviations in January, July and December indicate that the 1 second frequency values have been closer to 50 Hz during those months. In April the standard deviation has been higher than in the other months. Overall, the frequency has deviated slightly more in 2021 than in 2020.

Figure 3.5. Standard deviation of the frequency for every month in 2021

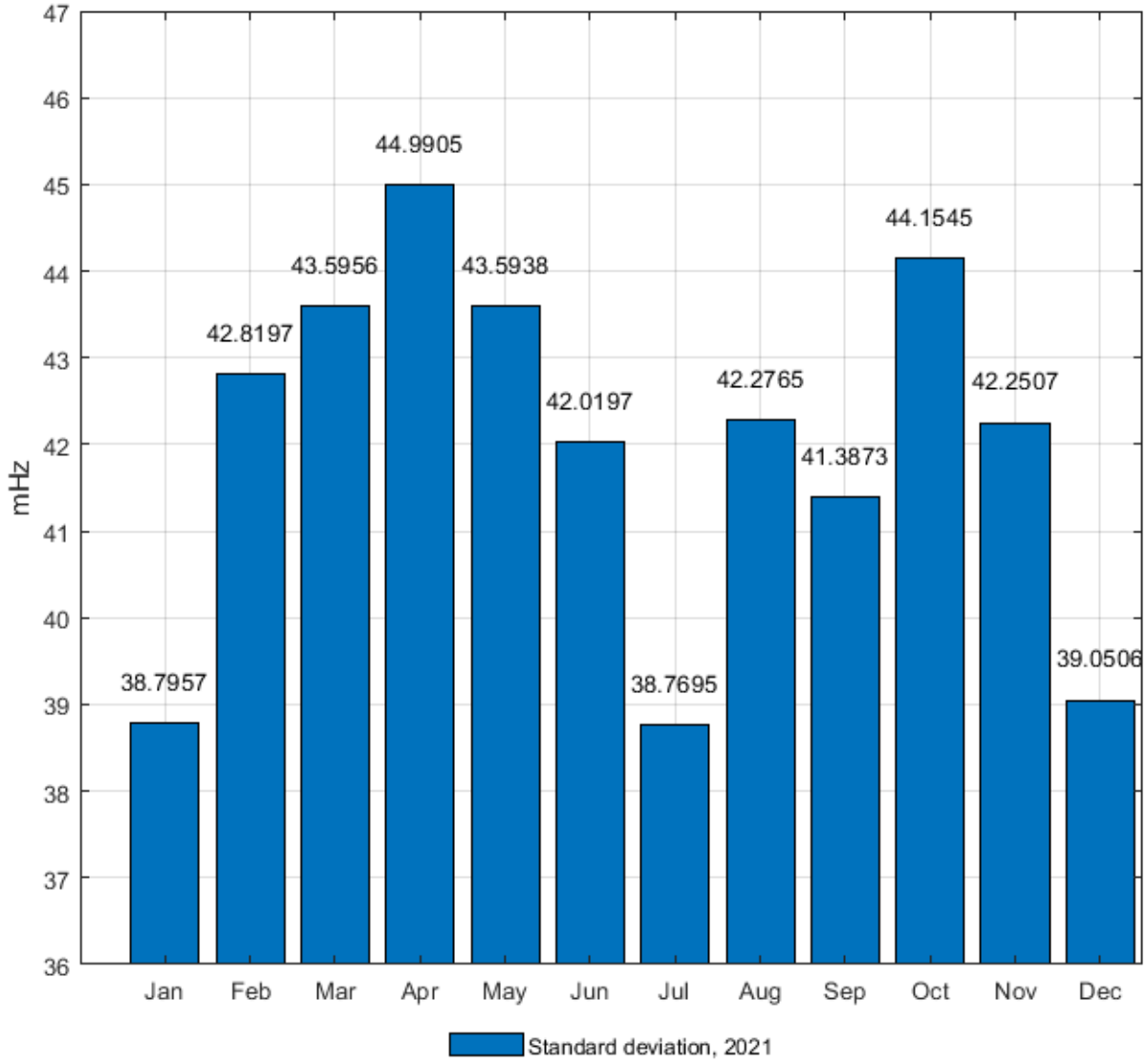


Figure 3.6 represents the standard deviation for every day of the week. Based on standard deviation, the quality of the frequency has been worst on Tuesdays and best on Mondays. The value of standard deviation of the frequency have remained fairly constant from Wednesday to Sunday. It is noteworthy that all the daily values in the figure are within 3 mHz from each other, where as monthtly deviation figure showed much greater differences between the consecutive months.

Figure 3.6. Standard deviation of the frequency for every day of the week in 2021

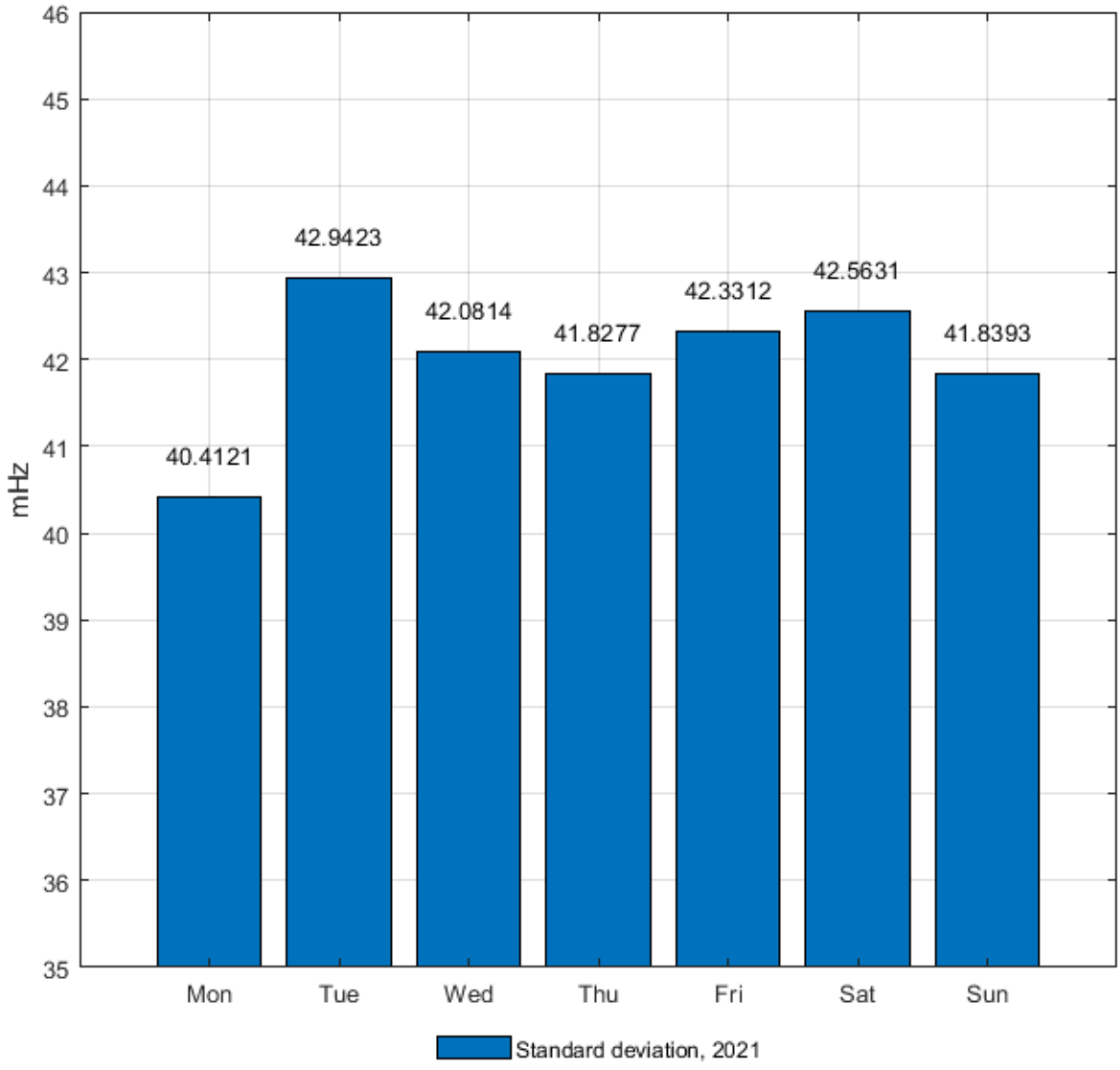


Figure 3.7 shows the standard deviation during the average day. The standard deviation has been higher around noon and lower in the evening. However, the highest and the lowest standard deviation values were experienced in the morning, at 7 am and 9 am. Compared to year 2020, there is more variation in the values of standard deviation in the hours from 1 am to 6 am.

Figure 3.7. Standard deviation of the frequency for every hour of the day in 2021

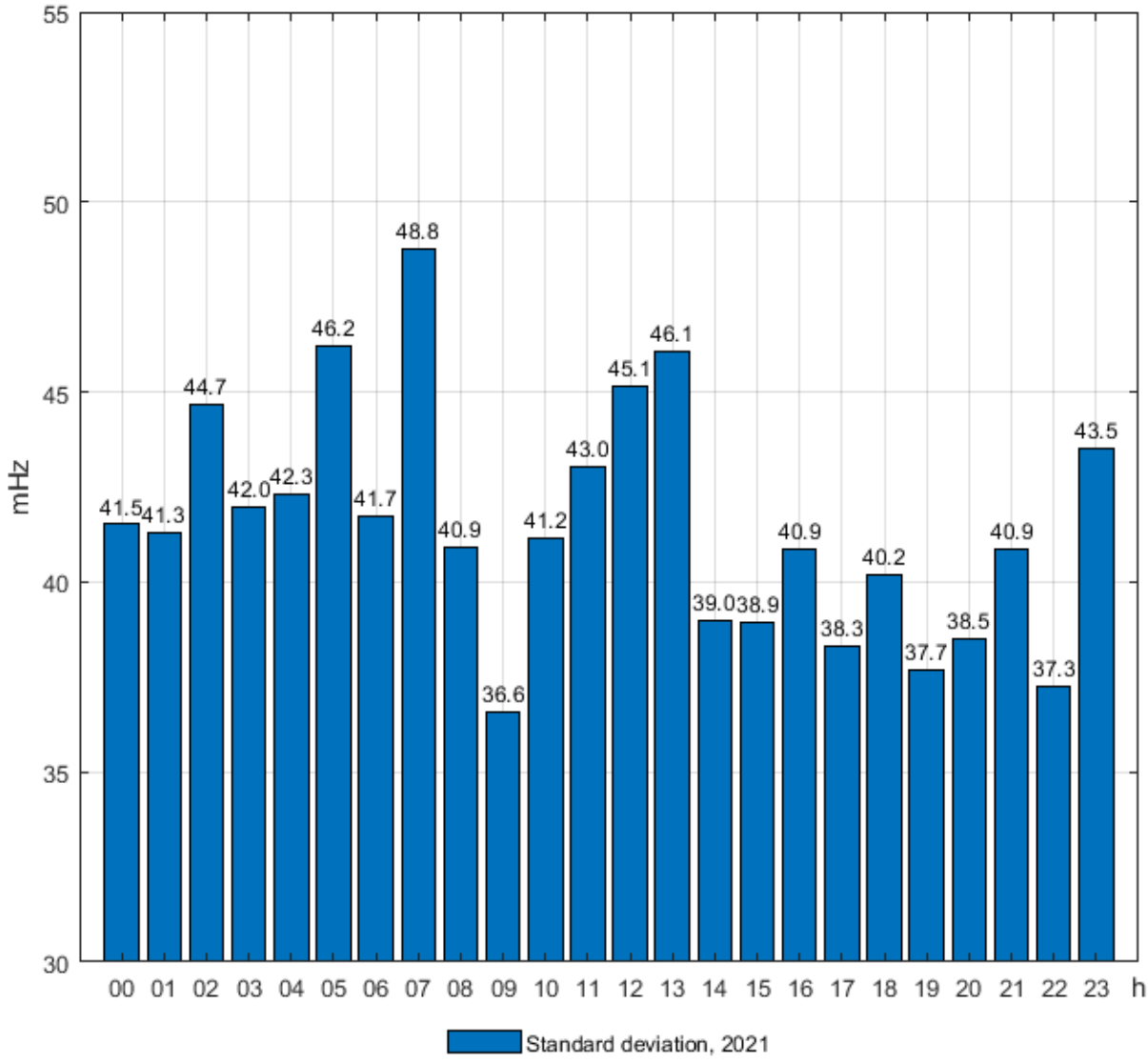
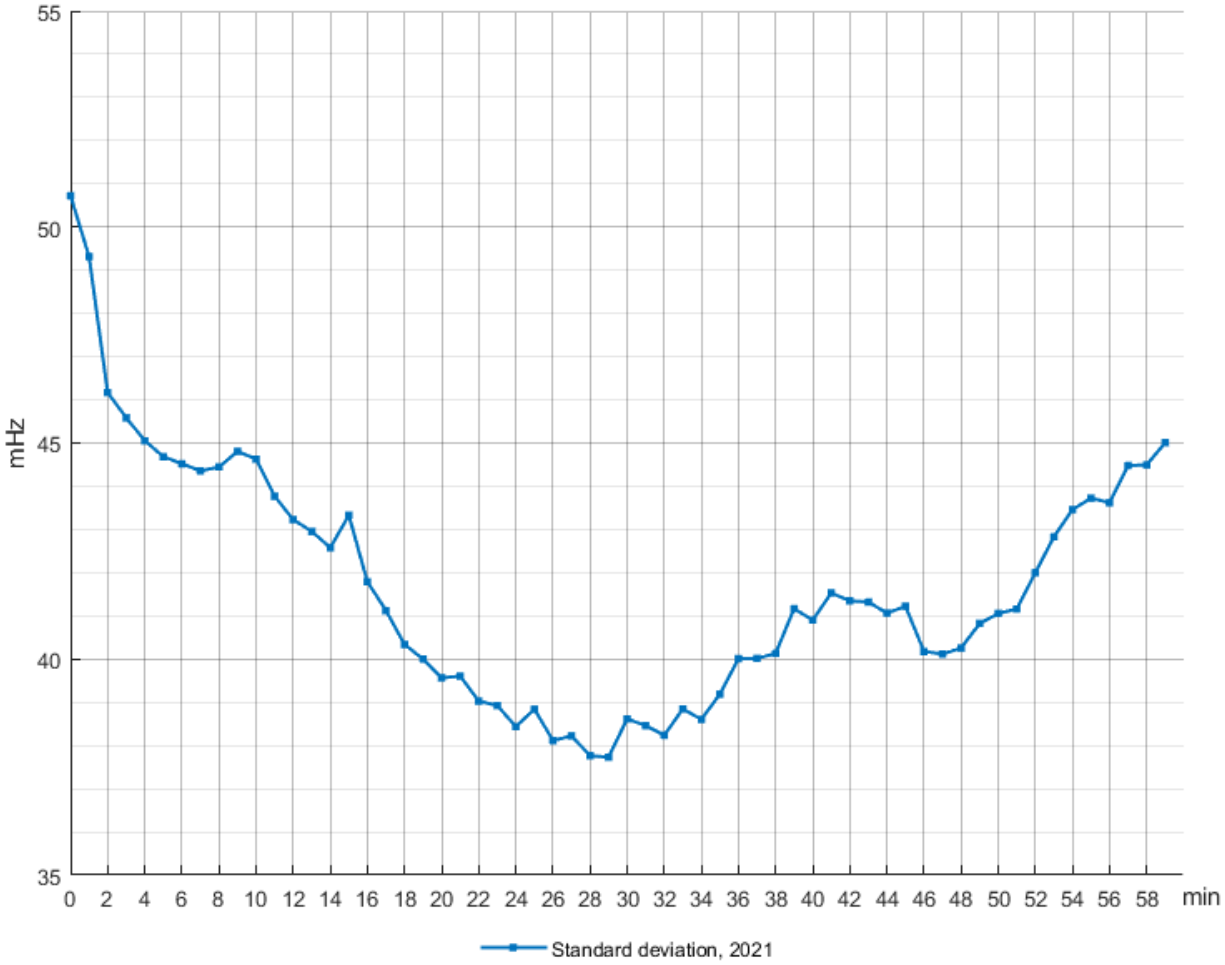


Figure 3.8 represents the standard deviation inside the hour. The standard deviation has the highest values in the beginning of the hour and it has decreased until the half hour mark from where it has increased again. There has also been a slight drop in the standard deviation around the 46th minute.

Figure 3.8. Standard deviation of the frequency for every minute of the hour in 2021



3.1.3 Mean value and standard deviation

Mean values and standard deviations of the frequency, according to SOGL Article 131(1)(a) (i) and (ii), month by month for years 2016 to 2021 can be found in Table 3.1 and Table 3.2. Same results are also presented in Figure 3.9. The resolution of the used data was one second.

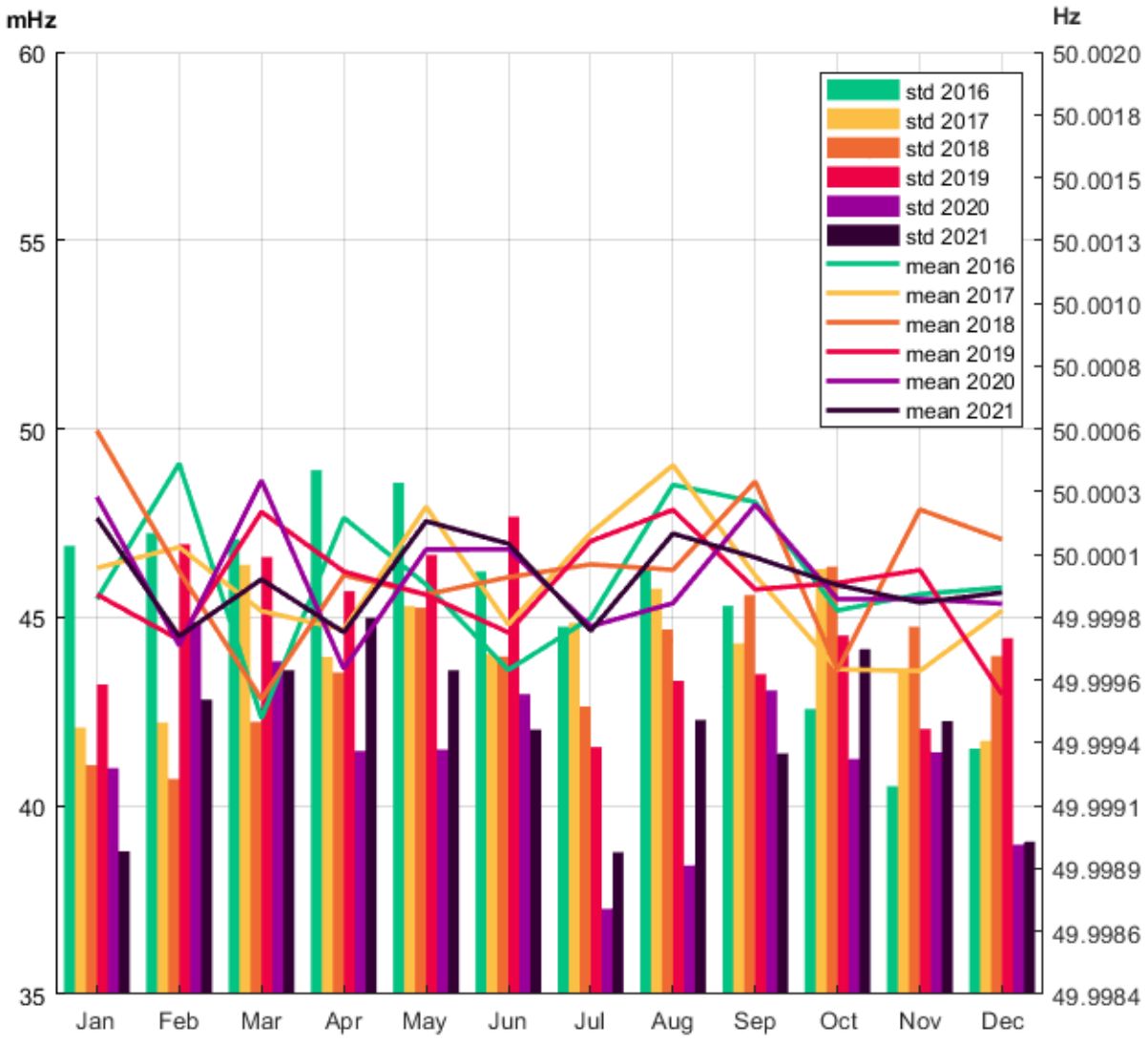
Table 3.1. Mean values and standard deviations for years 2016-2018

	2016		**2017**		**2018**	
Month	**Mean value (Hz)**	**Standard deviation (mHz)**	**Mean value (Hz)**	**Standard deviation (mHz)**	**Mean value (Hz)**	**Standard deviation (mHz)**
January	49.9999	46.9	50.0000	42.1	50.0006	41.1
February	50.0004	47.2	50.0001	42.2	50.0000	40.7
March	49.9995	47.1	49.9999	46.4	49.9995	42.2
April	50.0002	48.9	49.9998	44.0	50.0000	43.5
May	50.0000	48.6	50.0003	45.3	49.9999	45.3
June	49.9996	46.2	49.9998	44.0	50.0000	44.0
July	49.9998	44.8	50.0002	44.9	50.0000	42.6
August	50.0003	46.3	50.0004	45.8	50.0000	44.7
September	50.0003	45.3	50.0000	44.3	50.0004	45.6
October	49.9999	42.6	49.9996	46.3	49.9996	46.3
November	49.9999	40.5	49.9996	43.6	50.0003	44.8
December	50.0000	41.5	49.9999	41.7	50.0001	44.0
Entire year	**50.0000**	**45.5**	**50.0000**	**44.2**	**50.0000**	**43.8**

Table 3.2. 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**

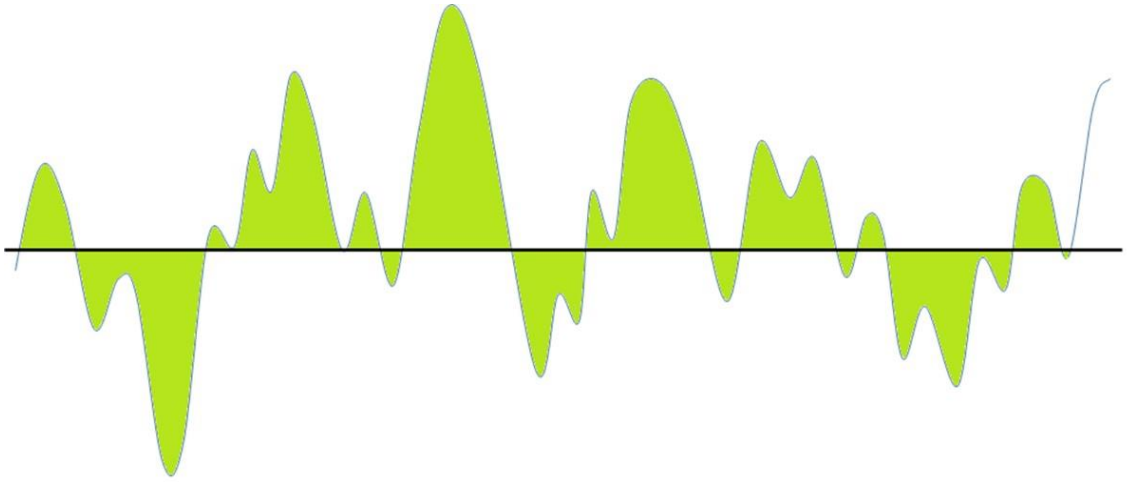
Figure 3.9. Mean values and standard deviations for years 2016-2021



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 portion of half of the normal frequency area (49.9-50.1 Hz). For example, if 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 input frequency data used is 0.1 s. Below Figure 3.10 is also the formula for determining the frequency area.

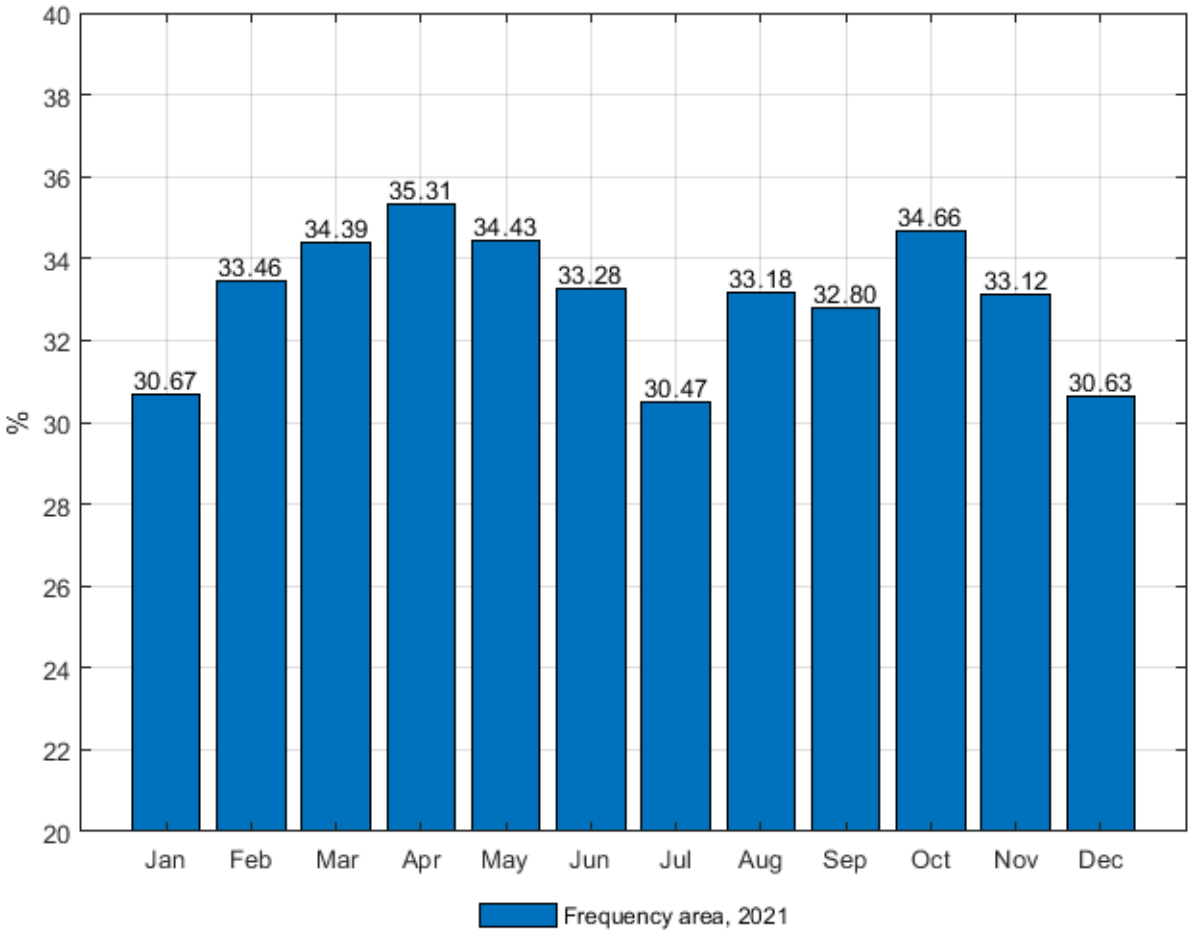
Figure 3.10**. **Frequency quality index: Frequency area [8]



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

Figure 3.11 represents the average frequency area for every month in 2021. The percentage of the area has been larger in April and October than in the other months. The percentage of the area has been considerably smaller in January, July and December compared to the other months. The average monthly frequency area was a bit larger in 2021 than in 2020.

Figure 3.11**. **The average frequency area for every month in 2021



The frequency area during each day of the week can be seen in Figure 3.12. The percentage of the area has been very close to equal between different days if Monday is not taken account.

Figure 3.12**. **The average frequency area for every day of the week in 2021

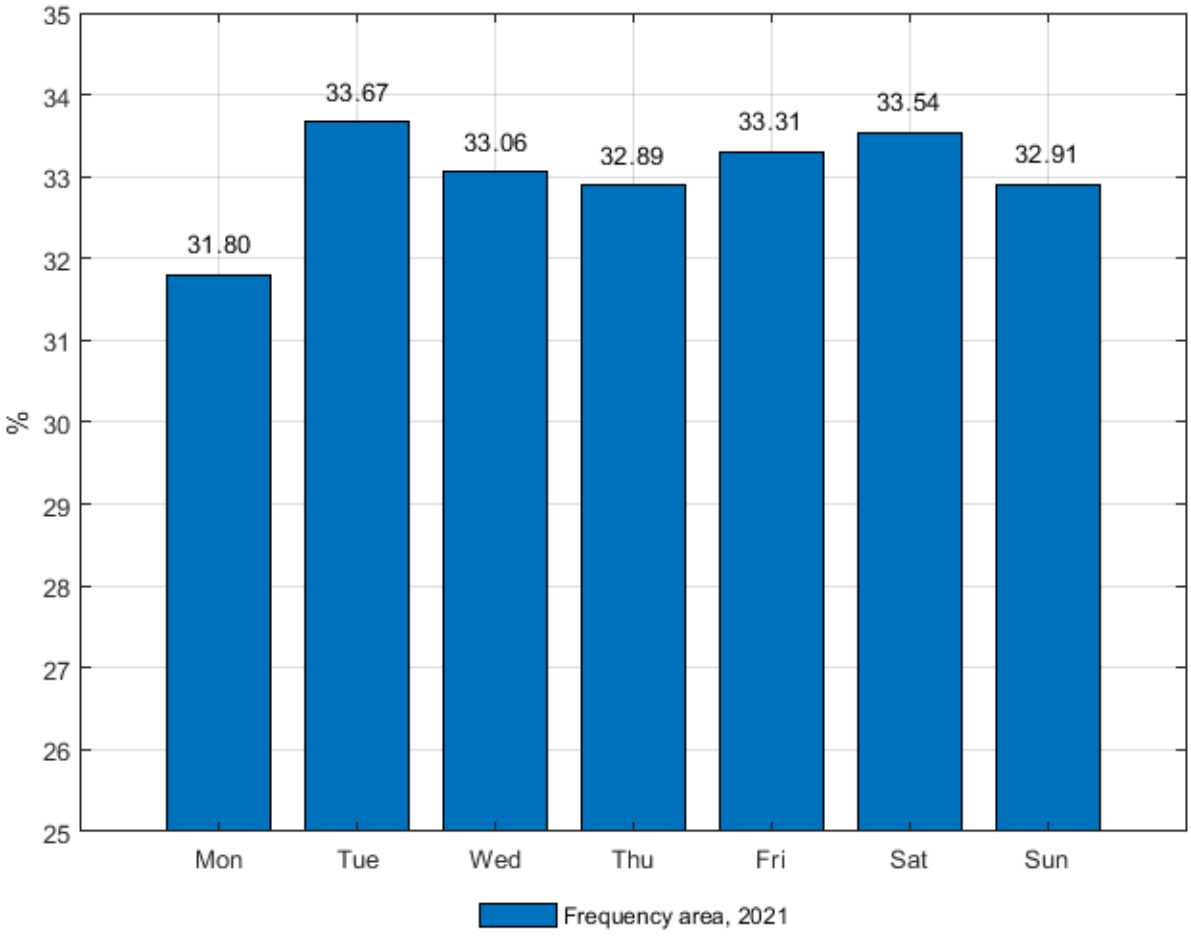


Figure 3.13 has the frequency area for every hour during the day. The figure shows that the deviation of the frequency from 50.0 Hz has been greater on average in the early morning and around the noon. The percentage of the frequency area has been smaller in the afternoon and especially in the evening.

***Figure 3.13**. The average frequency area for every hour inside the day in 2021*

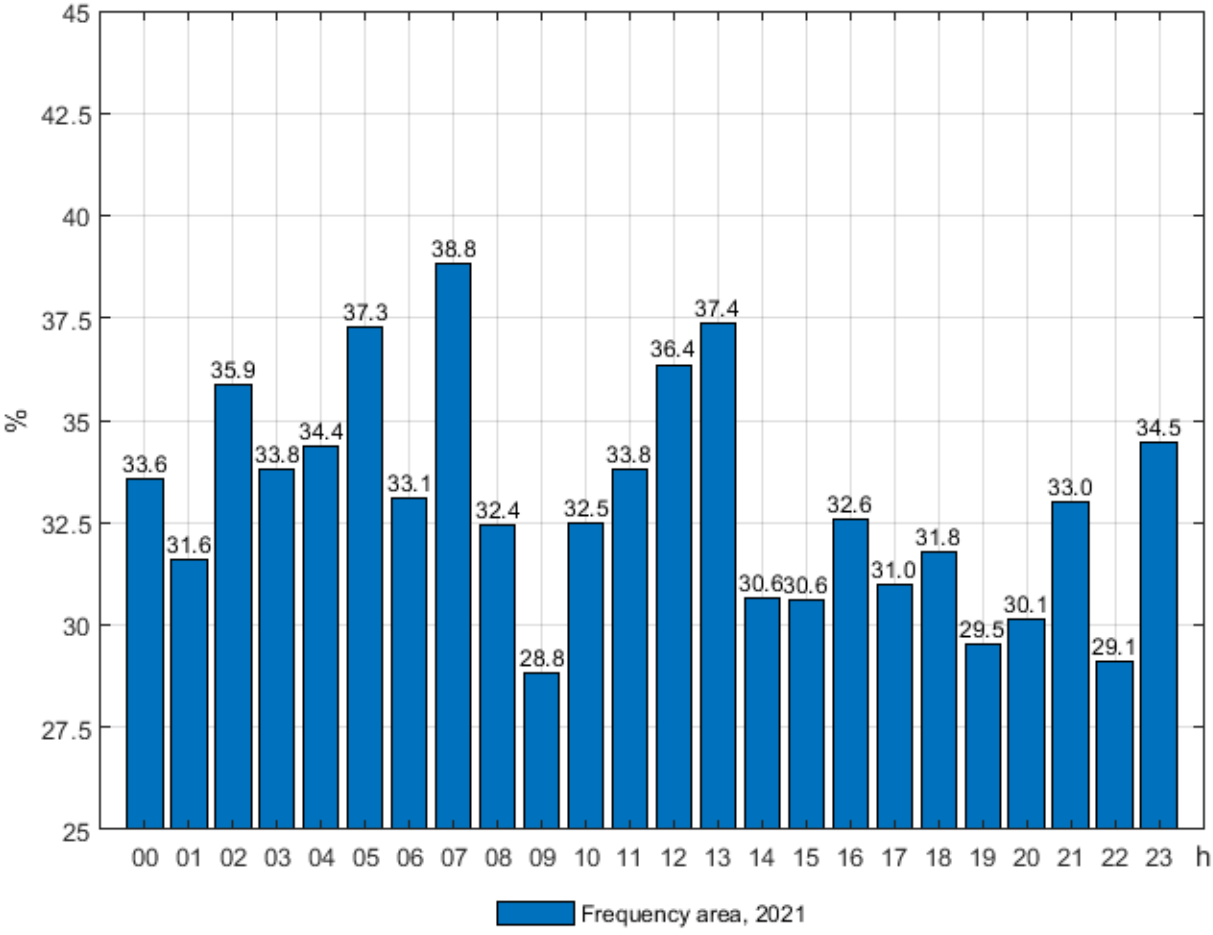
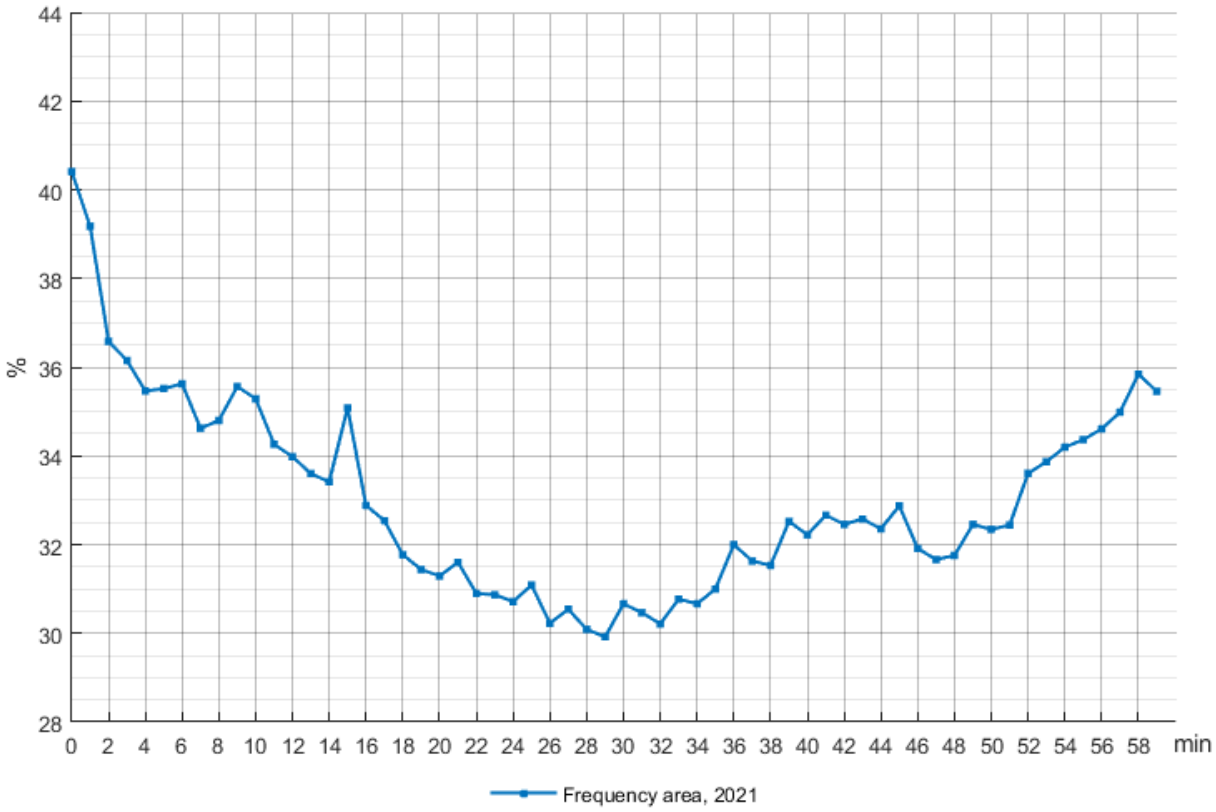


Figure 3.14 represents the frequency area within the hour. The percentage of the frequency area has been smaller in the middle of the hour while more deviation has occurred closer to the hour shift.

***Figure 3.14**. The average frequency area for every minute within the hour in 2021*



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 year 2016 to 2021. All results are summed up in Figure 3.15.

Table 3.3. The 1st, 5th, 10th, 90th, 95th and 99th percentiles for year 2016

	2016					
Month	**1st (Hz)**	**5th (Hz)**	**10th (Hz)**	**90th (Hz)**	**95th (Hz)**	**99th (Hz)**
Jan	49.897	49.925	49.940	50.060	50.077	50.110
Feb	49.892	49.925	49.941	50.061	50.078	50.110
Mar	49.896	49.924	49.939	50.061	50.077	50.108
Apr	49.887	49.920	49.937	50.063	50.080	50.111
May	49.887	49.922	49.939	50.062	50.080	50.117
Jun	49.893	49.924	49.941	50.058	50.075	50.108
Jul	49.897	49.927	49.943	50.057	50.073	50.105
Aug	49.896	49.926	49.941	50.060	50.077	50.109
Sep	49.896	49.928	49.943	50.059	50.075	50.106
Oct	49.903	49.931	49.946	50.055	50.070	50.100
Nov	49.905	49.933	49.948	50.052	50.067	50.094
Dec	49.905	49.934	49.948	50.052	50.069	50.103
Entire year	**49.896**	**49.926**	**49.942**	**50.058**	**50.075**	**50.107**

Table 3.4. The 1st, 5th, 10th, 90th, 95th and 99th percentiles for year 2017

	2017					
Month	**1st (Hz)**	**5th (Hz)**	**10th (Hz)**	**90th (Hz)**	**95th (Hz)**	**99th (Hz)**
Jan	49.905	49.932	49.946	50.054	50.069	50.097
Feb	49.903	49.931	49.946	50.055	50.069	50.095
Mar	49.893	49.925	49.941	50.059	50.076	50.108
Apr	49.899	49.928	49.944	50.056	50.071	50.102
May	49.892	49.926	49.943	50.058	50.074	50.105
Jun	49.895	49.927	49.944	50.057	50.073	50.103
Jul	49.897	49.927	49.943	50.058	50.074	50.104
Aug	49.895	49.926	49.942	50.060	50.076	50.106
Sep	49.899	49.929	49.944	50.057	50.074	50.105
Oct	49.892	49.925	49.942	50.059	50.077	50.113
Nov	49.896	49.928	49.944	50.055	50.070	50.100
Dec	49.908	49.932	49.946	50.053	50.068	50.098
Entire year	**49.898**	**49.928**	**49.944**	**50.057**	**50.073**	**50.103**

Table 3.5. The 1st, 5th, 10th, 90th, 95th and 99th percentiles for year 2018

	2018					
Month	**1st (Hz)**	**5th (Hz)**	**10th (Hz)**	**90th (Hz)**	**95th (Hz)**	**99th (Hz)**
Jan	49.905	49.934	49.949	50.054	50.069	50.098
Feb	49.907	49.933	49.948	50.053	50.067	50.094
Mar	49.901	49.932	49.946	50.054	50.069	50.100
Apr	49.897	49.929	49.945	50.056	50.072	50.104
May	49.894	49.926	49.943	50.057	50.074	50.108
Jun	49.900	49.929	49.944	50.056	50.073	50.106
Jul	49.901	49.931	49.946	50.053	50.069	50.102
Aug	49.896	49.927	49.943	50.057	50.073	50.106
Sep	49.894	49.926	49.942	50.058	50.074	50.106
Oct	49.891	49.924	49.940	50.059	50.076	50.108
Nov	49.899	49.928	49.943	50.058	50.074	50.106
Dec	49.898	49.930	49.945	50.057	50.073	50.102
Entire year	**49.898**	**49.929**	**49.945**	**50.056**	**50.072**	**50.104**

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

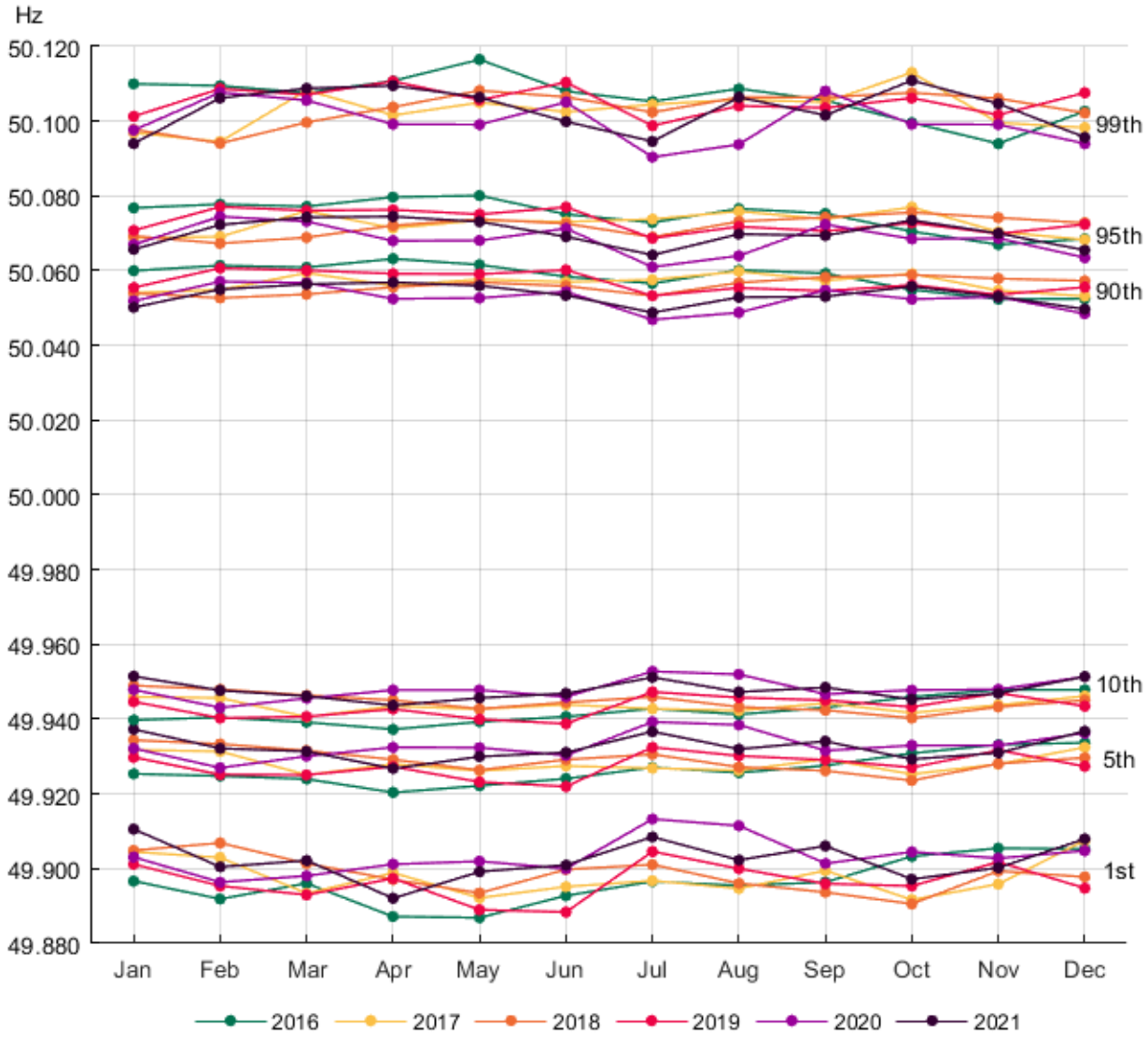
Table 3.7. The 1st, 5th, 10th, 90th, 95th and 99th percentiles for year 2020

	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 3.8. The 1st, 5th, 10th, 90th, 95th and 99th percentiles for 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**

***Figure 3.15**. The 1st, 5th, 10th, 90th, 95th and 99th percentiles for years 2016-2021*



More detailed results for the percentiles of 2021 are shown in the next figures. Figure 3.16 is a visual representation of the given percentiles for each month in 2021. The percentiles in April are furthest from 50 Hz, which indicates that the frequency has deviated the most during that month. Similarly, in July the percentiles are closest to 50 Hz which suggests that there have been least deviations during that month.

***Figure 3.16**. The 1st, 5th, 10th, 90th, 95th and 99th percentile of the frequency for every month in 2021*

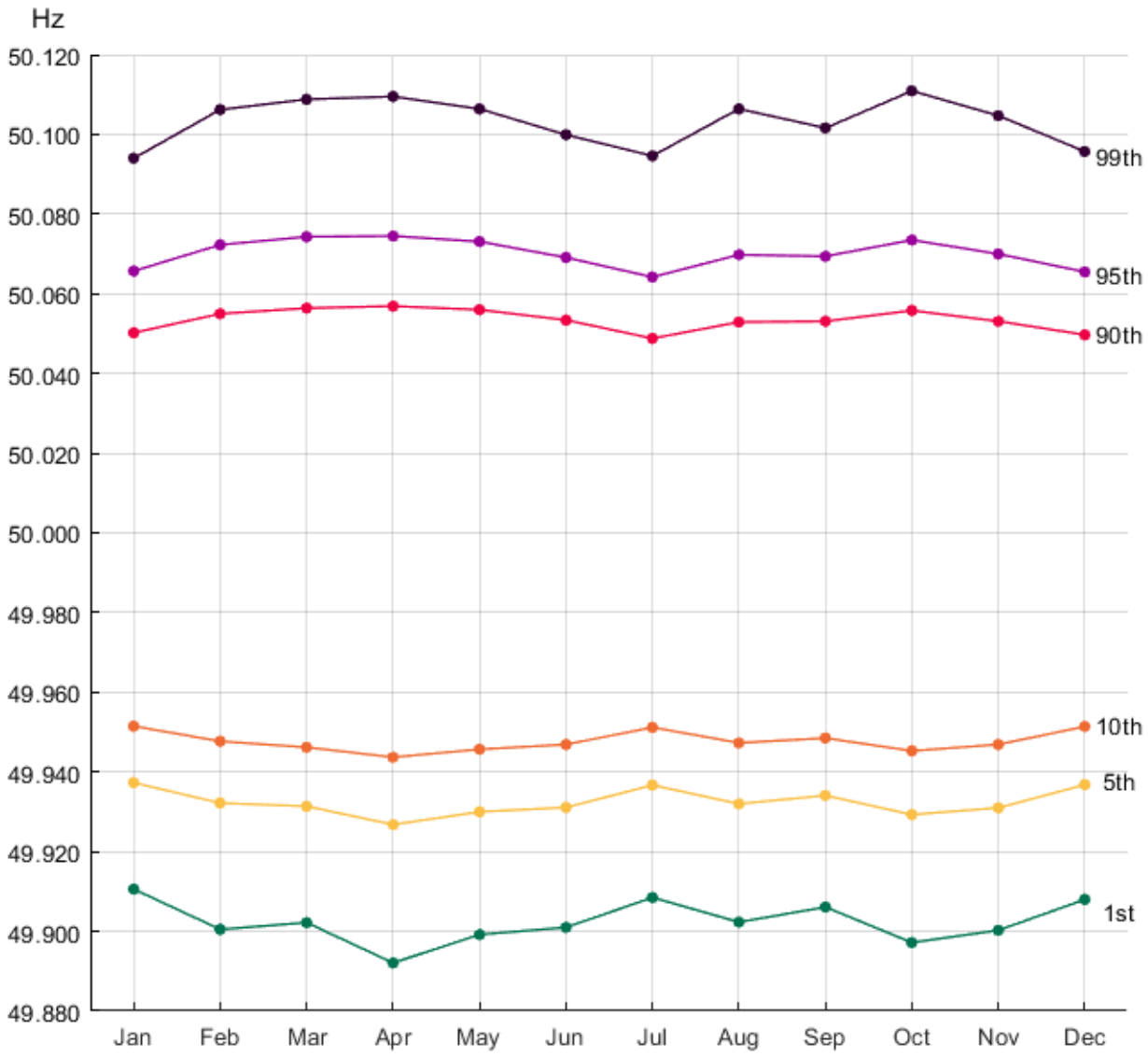


Figure 3.17 shows the percentiles for every day during the week. The percentiles on Tuesday are furthest from 50 Hz, which indicates that the fequency has deviated on a wider range during that day. Apart from subtle variations, the percentiles stay rather constant during the week.

***Figure 3.17**. The 1st, 5th, 10th, 90th, 95th and 99th percentile of the frequency for every day of the week in 2021*

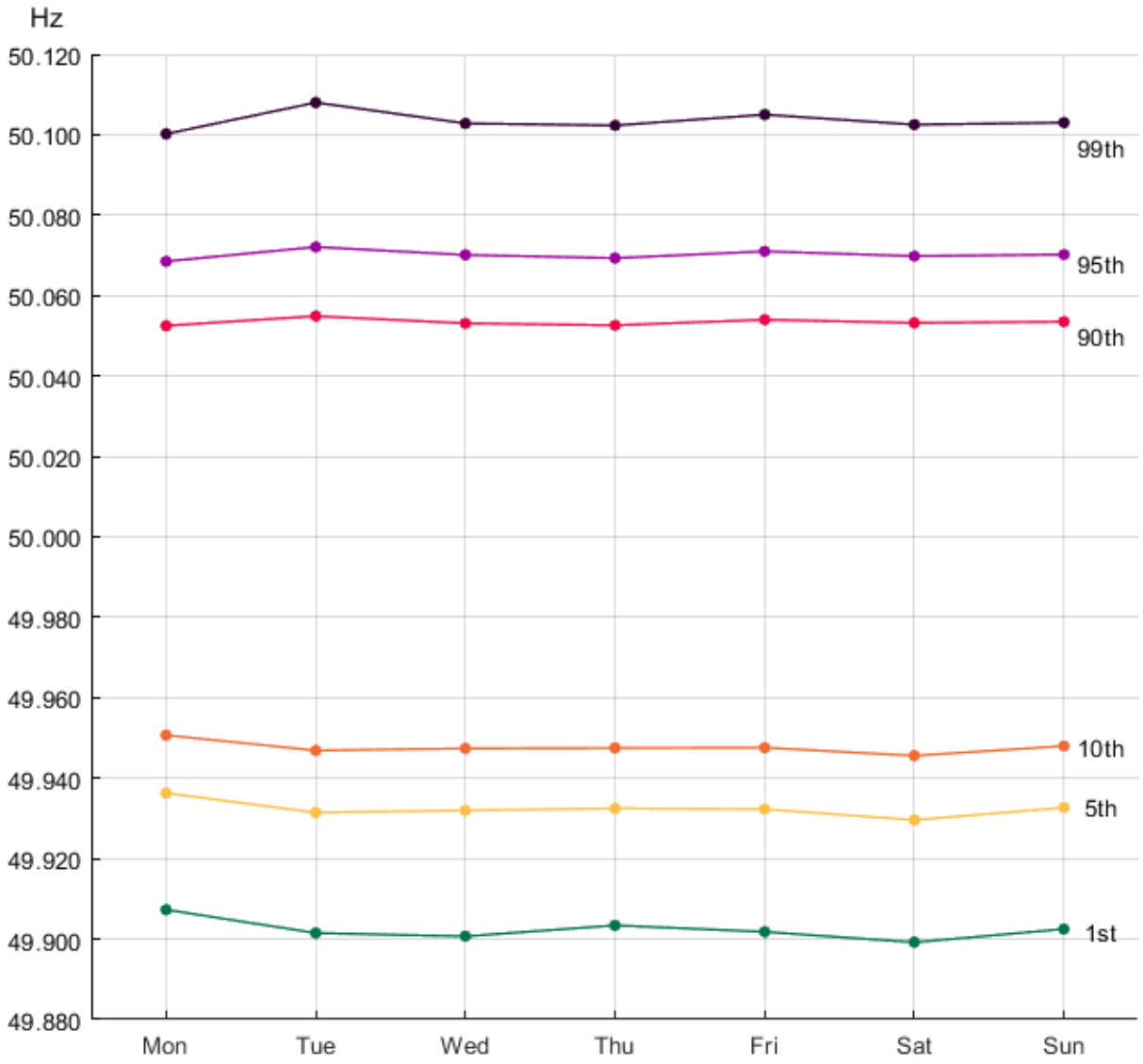


Figure 3.18 represents the percentiles inside the day. All percentiles gain higher values in the midnight, which indicates that there have been more over frequencies and less under frequencies in the midnight. On the next hour the situation is opposite. There have been less over frequencies and more under frequencies at 1 am.

Figure 3.18. The 1st, 5th, 10th, 90th, 95th and 99th percentile of the frequency for every hour of the day in 2021

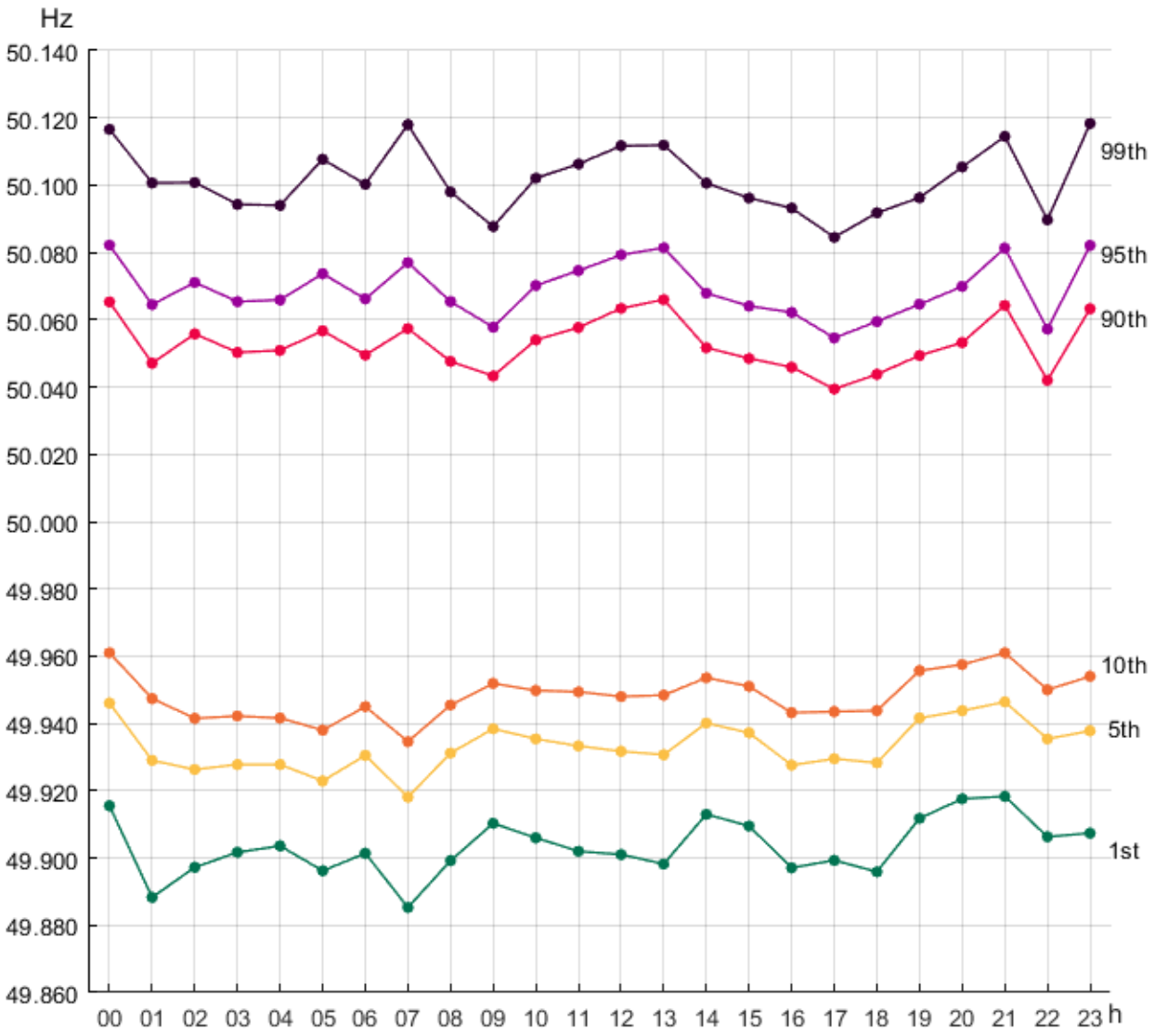
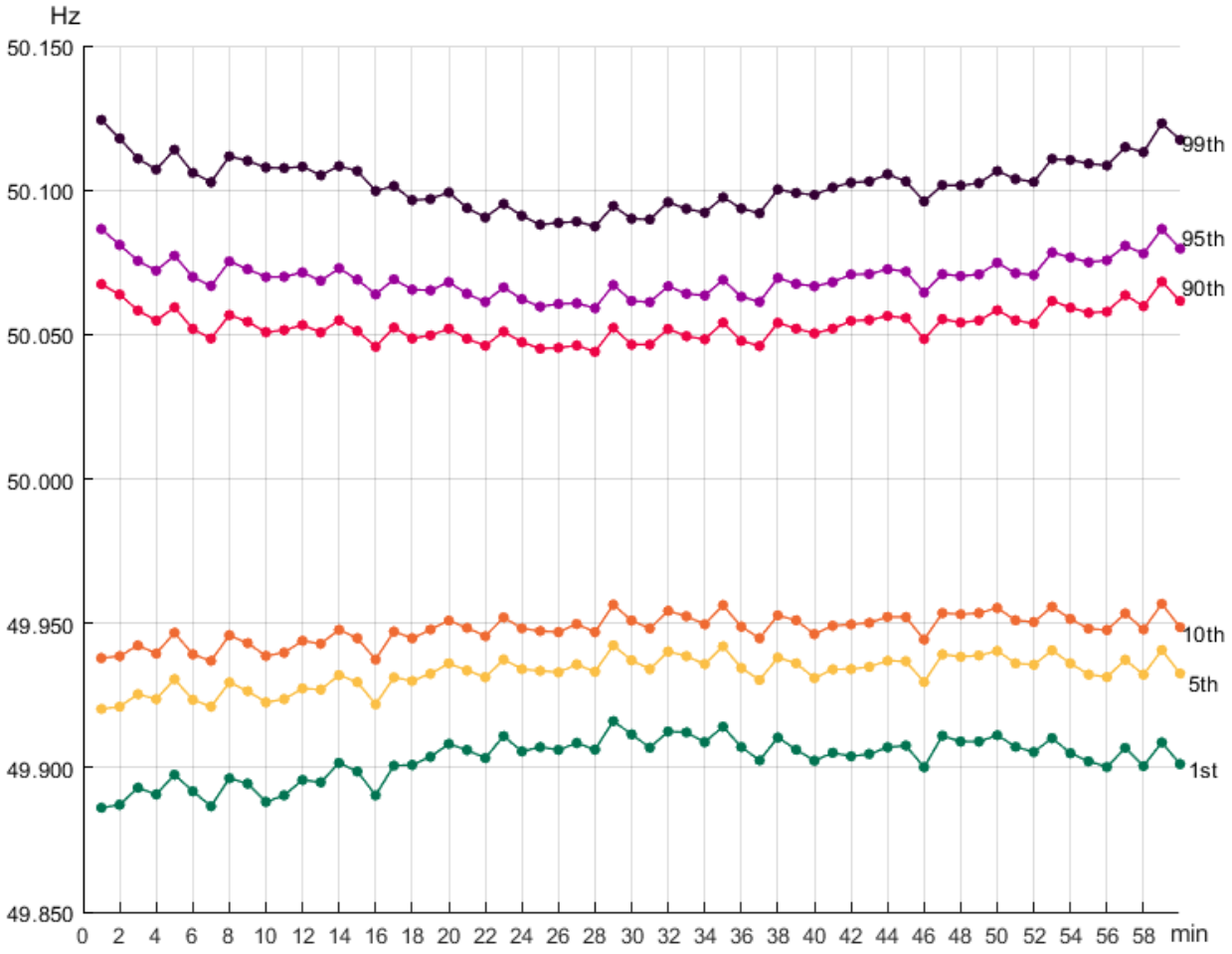


Figure 3.19 shows the percentiles inside the hour. Overall, more frequency deviation has occurred during the hour shift. The 90th, 95th and 99th percentiles gain the highest values during a time interval of few minutes at hour shift. The 10th, 5th and 1st percentiles gain the lowest values at the first minute 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 2021*



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 2021. The cumulative growth of minutes outside the standard frequency range has been fastest in the first half of the year. Compared to year 2020, the rate of cumulative growth has been more constant over the examined time period. The frequency has been outside the standard range less than 10900 minutes, close to 6200 minutes over 50.1 Hz and close to 4600 minutes under 49.9 Hz. The results mean that the current Nordic target level has been exceeded. The time outside standard frequency range has significantly increased from 2020.

Figure 3.20. Cumulative minutes outside the standard frequency range in 2021

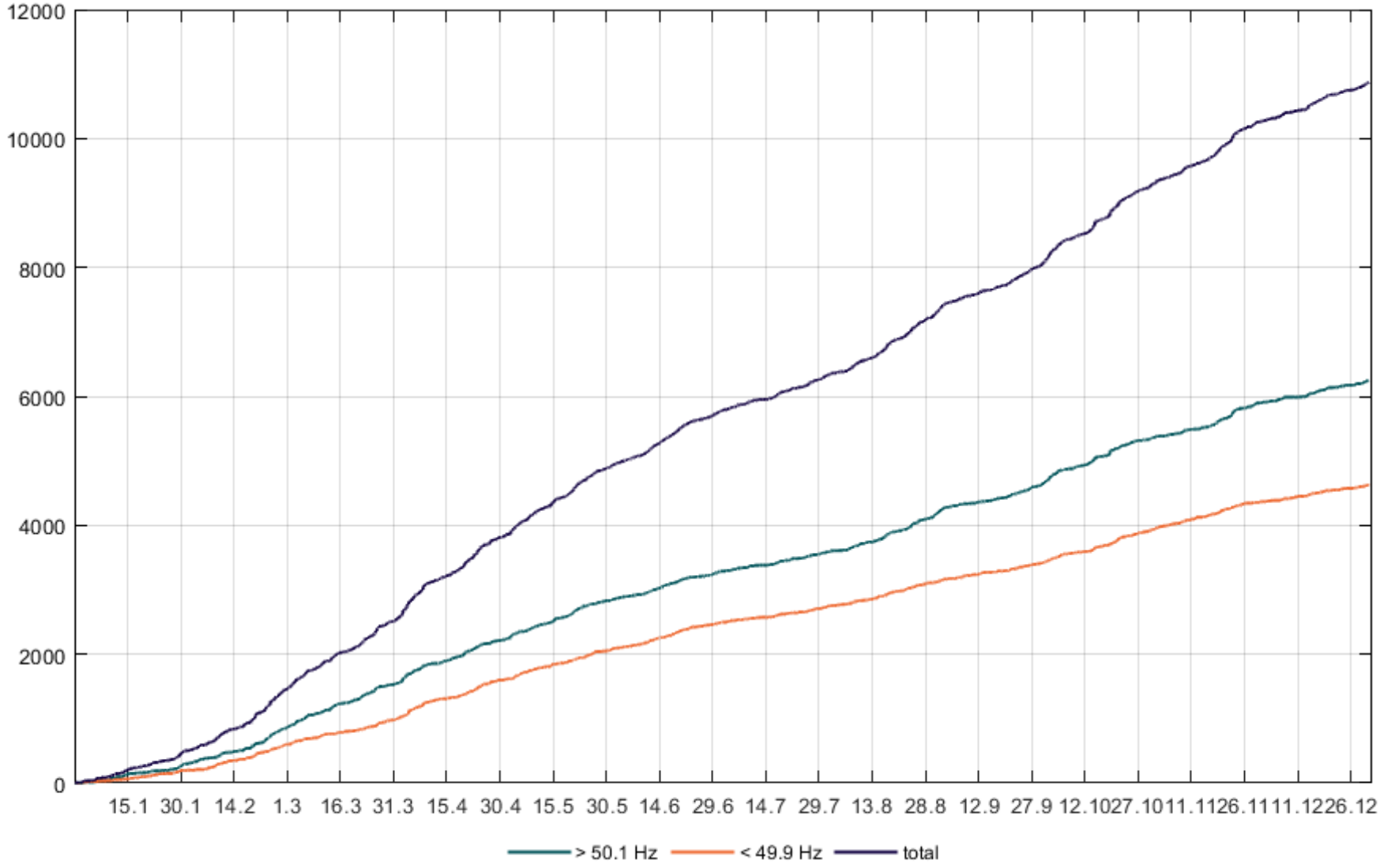
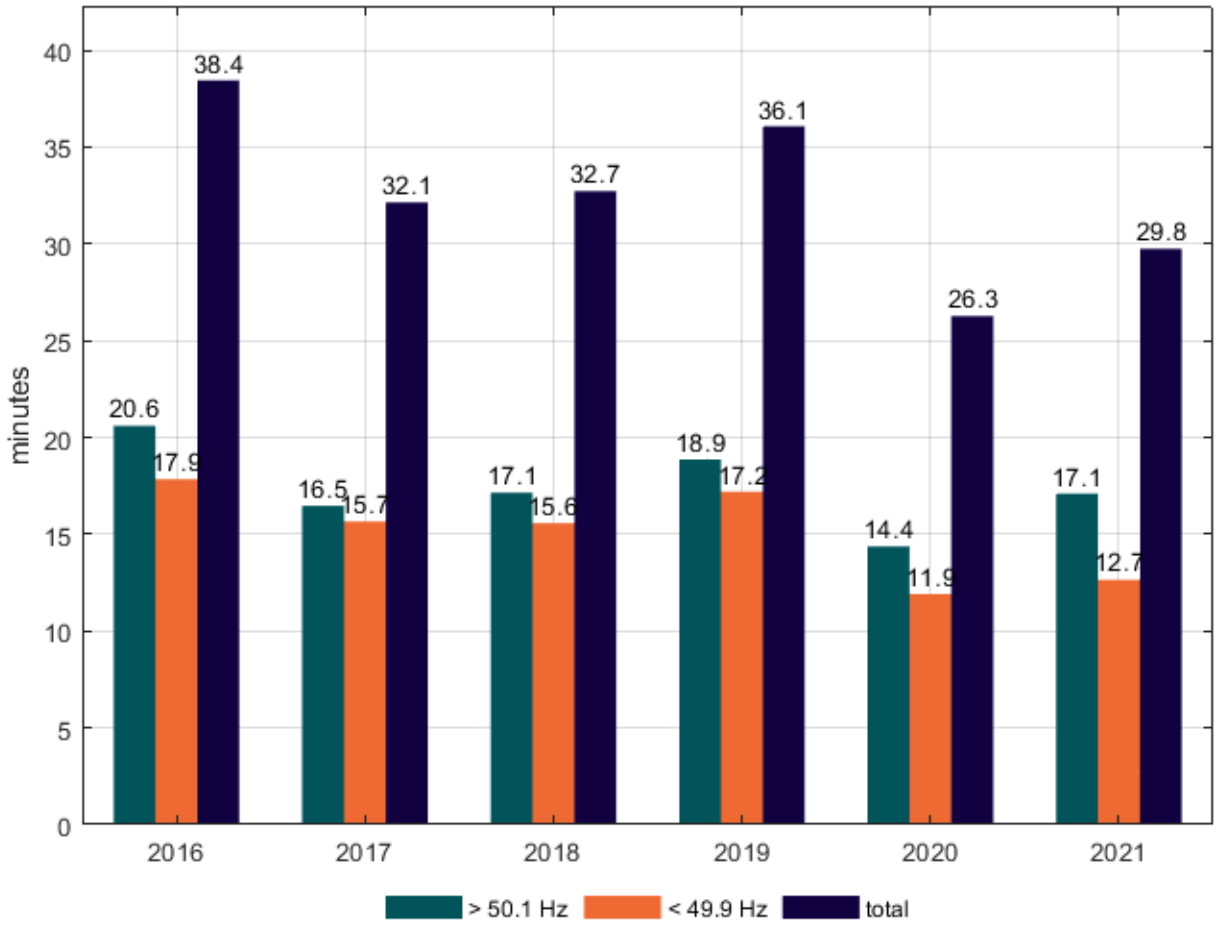


Figure 3.21 represents the daily average number of minutes per year that the frequency was outside the standard frequency range. The number of minutes outside the standard frequency range in 2021 has increased from the previous year. Every year there have been more over frequencies than under frequencies.

Figure 3.21. Daily average number of minutes per year that the frequency was outside the standard frequency range in 2016-2021



Same results can be seen in Table 3.9 as percentage of time in and outside the standard frequency range. The availability of data has been taken into account: 100 % corresponds to total time for which 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
2016	1.44 %	1.25 %	97.31 %
2017	1.18 %	1.12 %	97.70 %
2018	1.20 %	1.09 %	97.70 %
2019	1.33 %	1.21 %	97.46 %
2020	1.02 %	0.85 %	98.13 %
2021	1.19 %	0.88 %	97.93 %

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

Table 3.10. Minutes over and below the standard frequency range

Year	> 50.1 Hz (min)	< 49.9 Hz (min)	Total (min)
2016	7586	6574	14160
2017	6185	5884	12069
2018	6328	5755	12083
2019	6997	6377	13374
2020	5375	4456	9831
2021	6247	4621	10868

Tables 3.11 and 3.12 contain the total time (in minutes) in which the frequency was outside the standard frequency range (49.9-50.1 Hz) month by month for years 2016 to 2021. These results are based on the evaluation criteria defined in SO GL Article 131(1)(a) (iv). The results from previous tables are not entirely comparable due to differences in availability of measurement data. The same information is presented visually in Figure 3.22.

Table 3.11. Total time in which the frequency was outside the 49.9-50.1 Hz band in years 2016-2018

	2016		**2017**		**2018**	
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	723	526	362	345	386	340
February	687	612	272	338	272	266
March	679	566	669	611	436	415
April	779	809	471	460	529	501
May	962	820	577	642	582	547
June	607	594	501	549	588	436
July	587	537	569	530	495	419
August	704	572	504	476	608	549
September	584	523	564	442	598	585
October	434	362	703	573	662	708
November	288	310	420	522	596	447
December	504	325	399	266	508	497
Entire year	**7539**	**6555**	**6011**	**5756**	**6258**	**5709**

Table 3.12. Total time in 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**

Figure 3.22. Total time in which the frequency was outside the 49.9-50.1 band in years 2016-2021

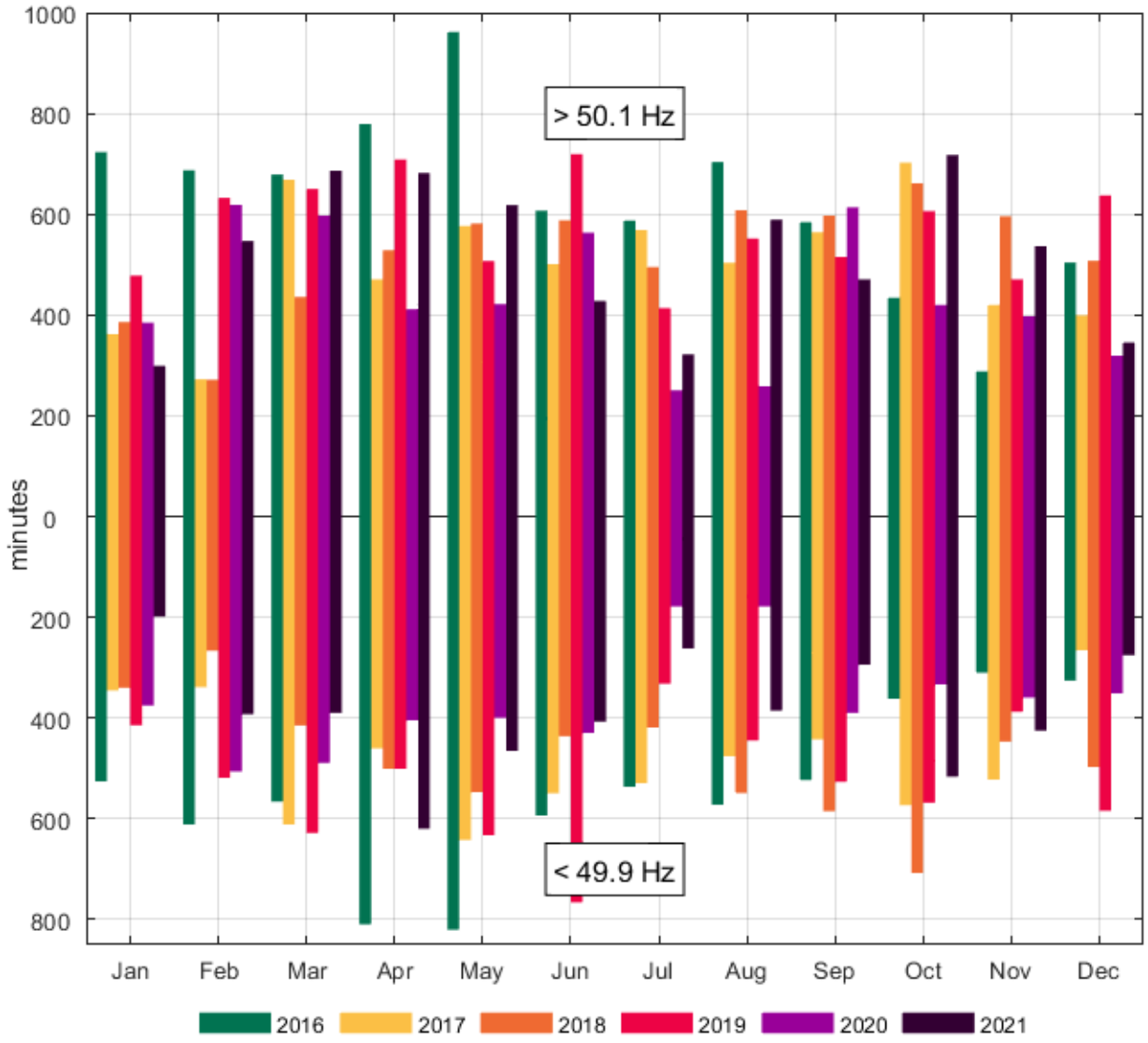


Figure 3.23 shows the daily average in minutes month by month when the frequency has been outside the standard frequency range in years 2016-2021. In 2021, April has had the longest time outside the standard frequency range. January and July have had the best frequency in this comparison.

Figure 3.23. Daily average time that the frequency was outside the standard frequency range month by month for years 2016-2021

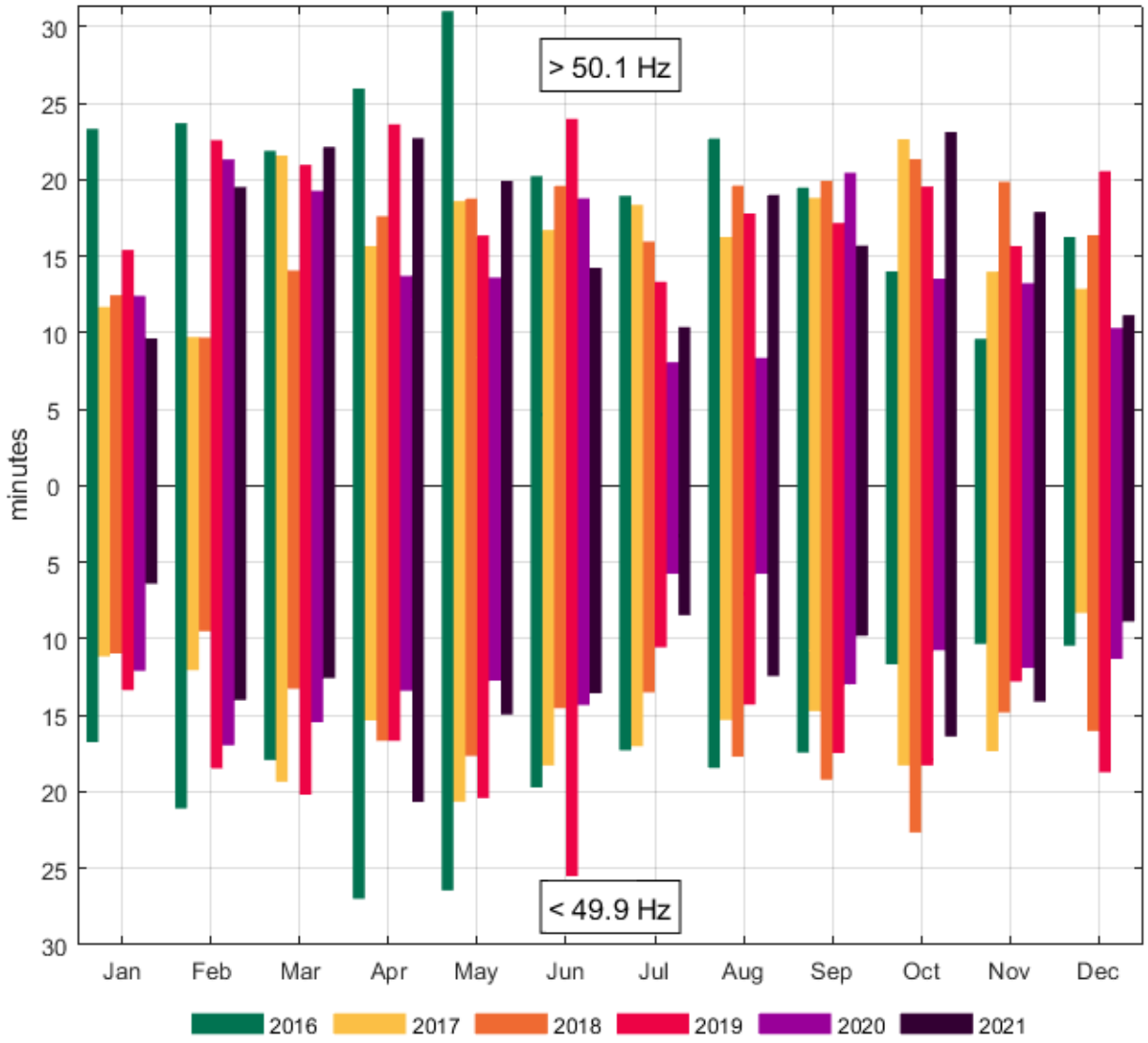


Figure 3.24 represents the daily averge time that the frequency has been outside the standard frequency range during each day of the week. In 2021 the frequency has been outside the standard frequency range the most on Tuesdays and the least on Mondays. Compared to year 2020 there is no clear reduction during weekends in amount of time the frequency was outside the standard frequency range.

Figure 3.24. Daily average time that the frequency was outside the standard frequency range during each day of the week for years 2016-2021

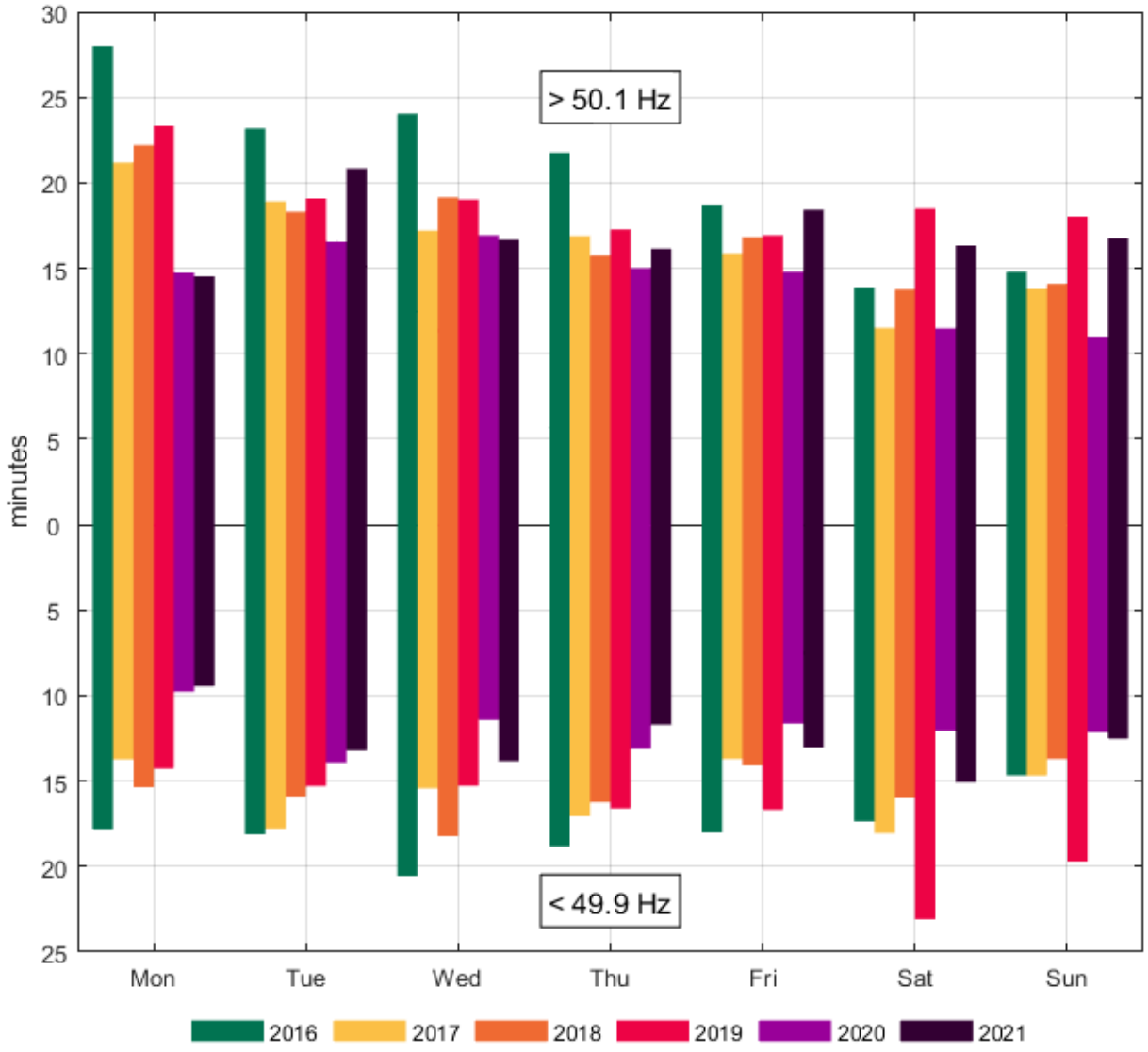


Figure 3.25 represents the daily average time that the frequency was outside the standard frequency range for each hour in the day. The hours are according to the Finnish time (UTC+2 / UTC+3 in the summer). In 2021, the frequency has been over 50.1 Hz the most at the hours 0, 21 and 23 and under 49.9 Hz the most at the hours 1, 5 and 7. The frequency has been outside the standard frequency range more frequently during the morning hours, except for hour 9, and in the early afternoon. Frequency has stayed inside the standard frequency range best during hours from 3 to 4 and from 19 to 20.

Figure 3.25. Daily average time that the frequency was outside the standard frequency range during each hour of the day for years 2016-2021

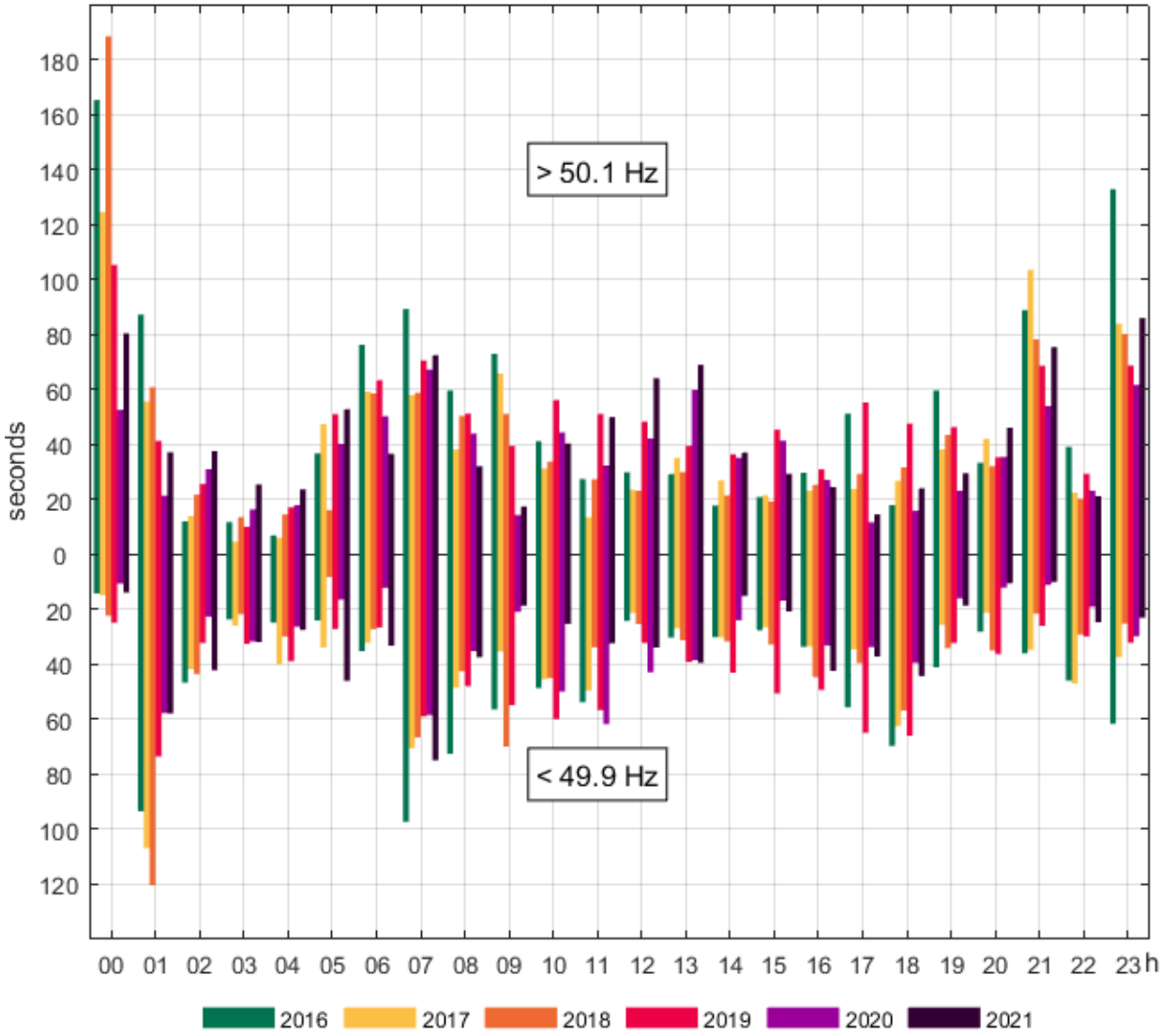


Figure 3.26 shows the daily average time outside the standard frequency range per hour and absolute value of Nordic consumption and production difference. Also transmission difference of HVDC links connecting the Nordic power system to Continental Europe and Russia is presented.

The differences were calculated by subtracting 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 was retrieved from the ENTSO-E Transparency platform website and the transmission powers of the HVDC links were direct measurement data. Hours are given in Finnish time (UTC+2 / UTC+3 in the summer).

In the morning the peaks for production and consumption differences are around 2300 MWh. Near midnight the peaks for production and consumption differences are around 1650 MWh. The highest value of frequency deviation occurs in hour 7 when the production and consumption difference curves peak. However, significant deviation also occurs in the afternoon when the differences in production, consumption and HVDC transmission are not very significant. Compared to the year 2020, the difference in HVDC transmission have increased around hours 17 to 20. Nordic production difference has also increased on average between hours 8 to 19 while comparing with year 2020.

Figure 3.26. Seconds per hour outside the standard frequency range and the absolute values of Nordic consumption, production and HVDC transmission differences in 2021

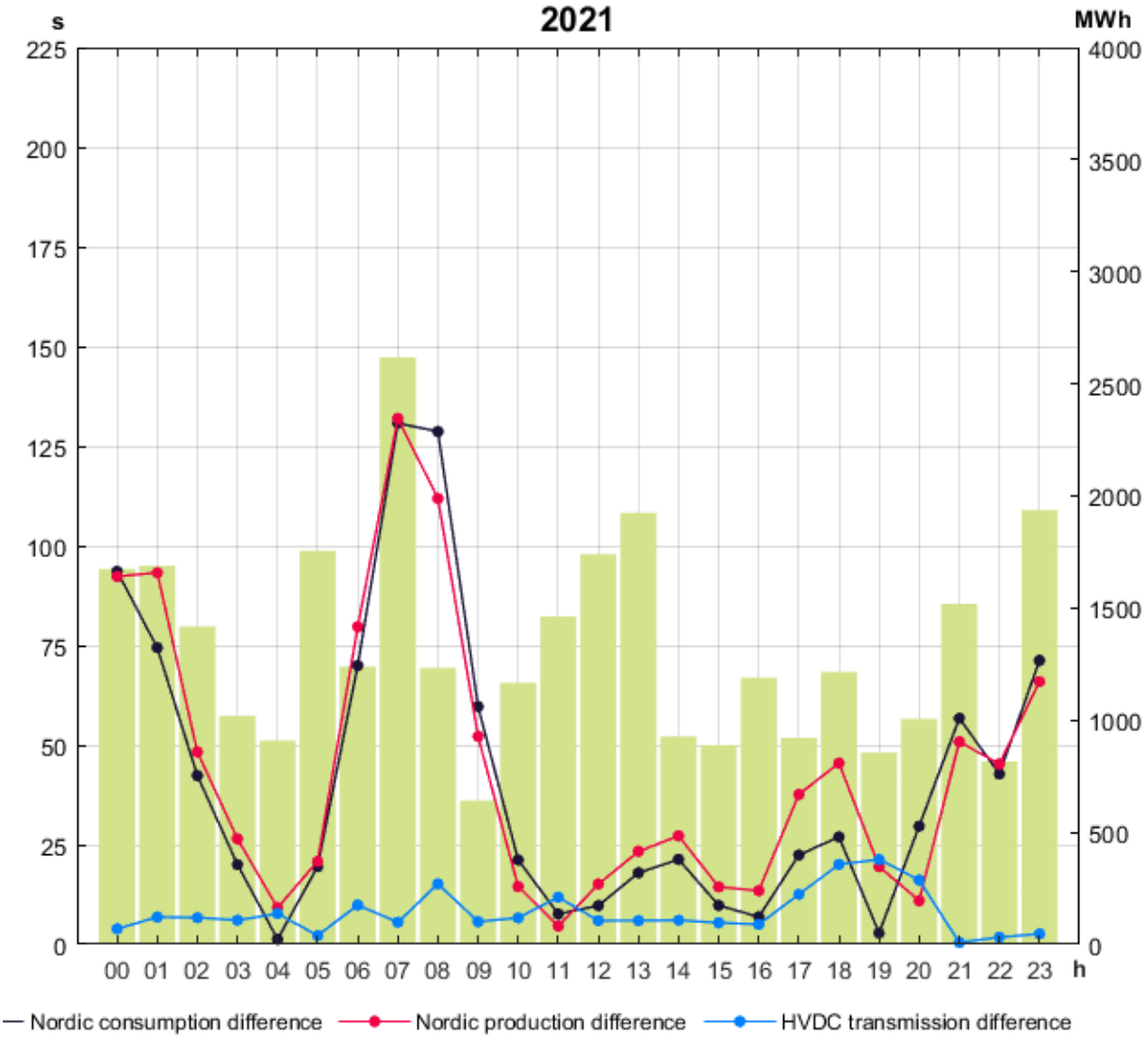


Figure 3.27 illustrates an average hour divided to 60 minutes. For each minute of the average hour there is a value in seconds per hour that frequency has been over or below the standard frequency range. In years 2016-2021 the frequency has been outside the standard frequency range most often in the beginning of the hour. The frequency has stayed 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.

Figure 3.27. Number of seconds per hour outside the standard frequency range in 2016-2021 for each minute of an average hour

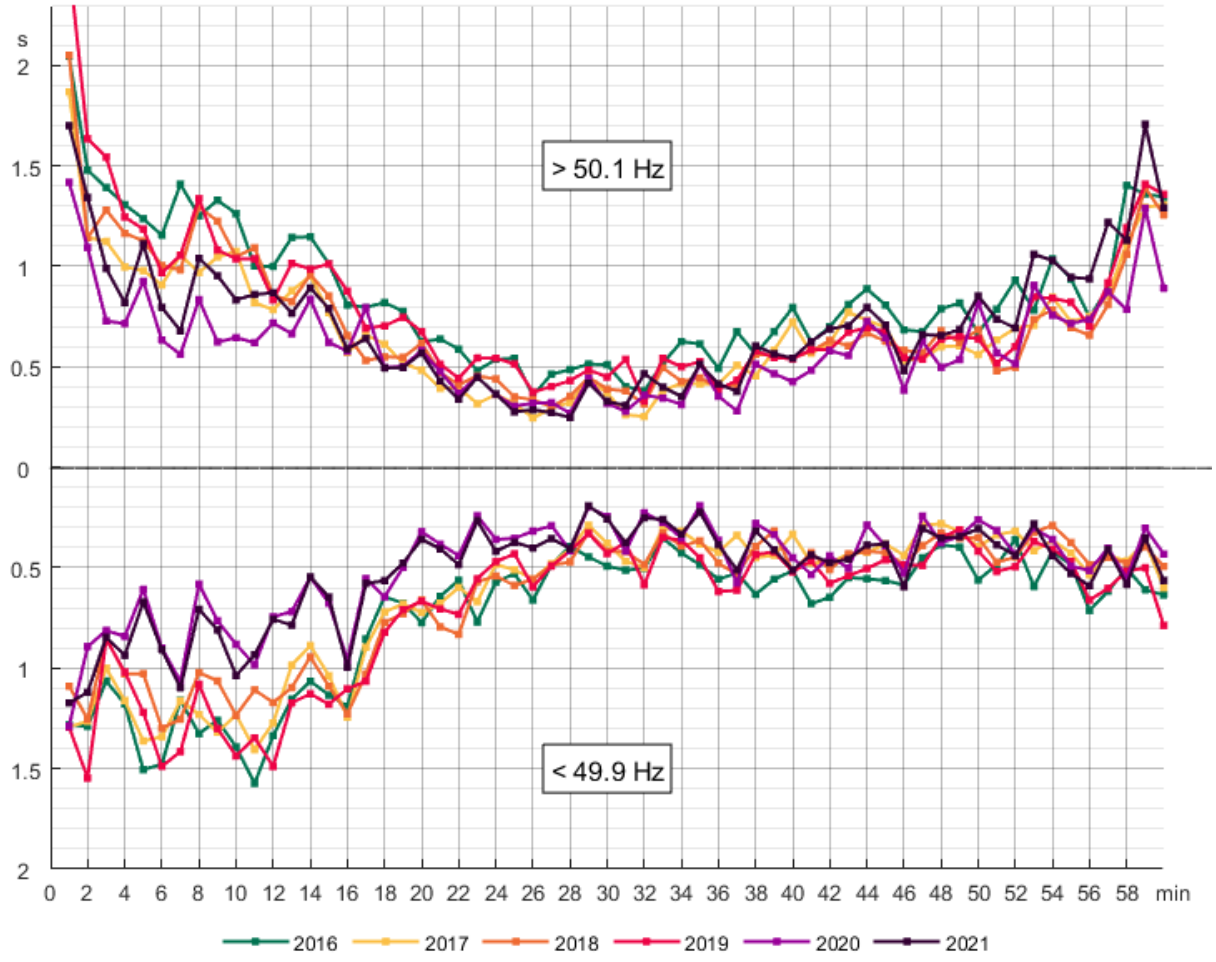
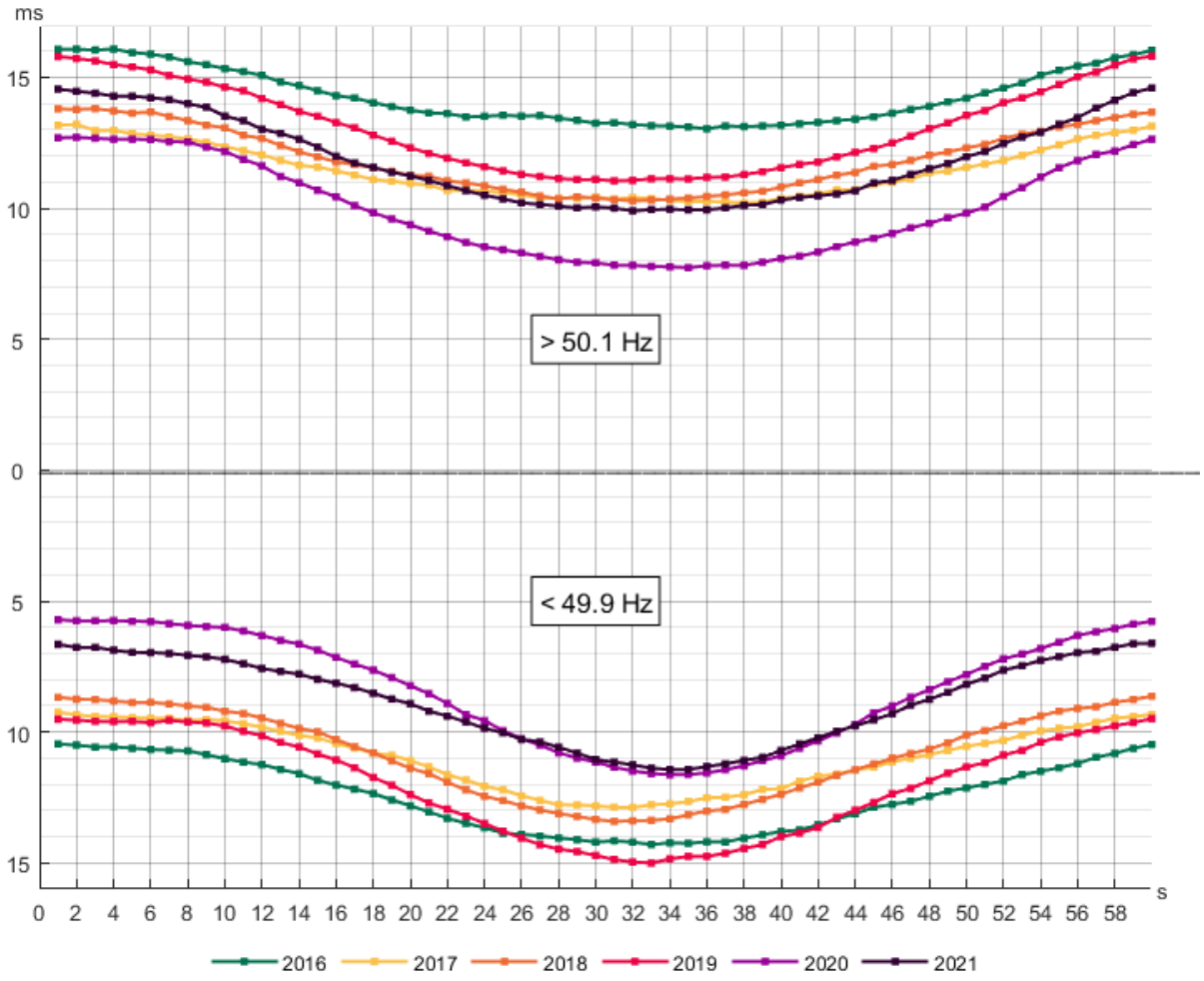


Figure 3.28 illustrates an average minute divided into 60 seconds. For each second of the average minute there is a value in milliseconds per minute that the frequency has been over or below the standard frequency range. There have been more over frequencies at the beginning and at the end of the average minute. Under frequencies have occurred more frequently in the middle of the minute. While comparing years 2021 and 2020, over and under frequencies have occured more frequently in year 2021 than in 2020. In the other hand, when comparing year 2021 to years 2016 to 2019, there has been major reducement in amount of under frequency occurance.

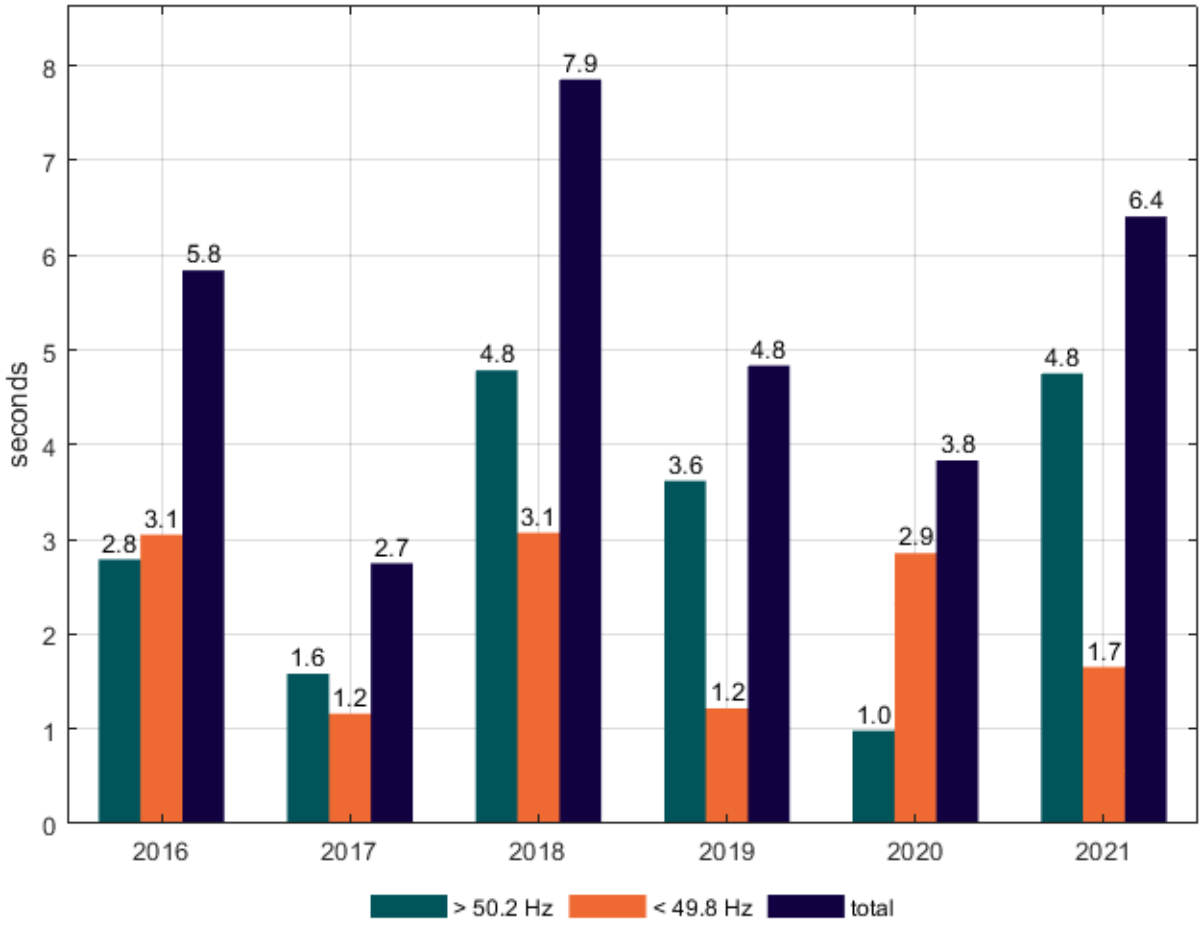
Figure 3.28**. **Number of milliseconds per minute outside the standard frequency range in 2016-2021 for each second of an average minute



3.4.2 Time outside 49.8-50.2 Hz

Figure 3.29 shows frequency deviations exceeding ±200 mHz as average number of seconds per day. The total time outside 49.8-50.2 Hz was higher in 2021 than in 2020. In 2021, over frequencies exceeding 200 mHz have been much more common than under frequencies. While examining years 2016 to 2021, year 2021 has the second largest total time outside 49.8-50.2 Hz.

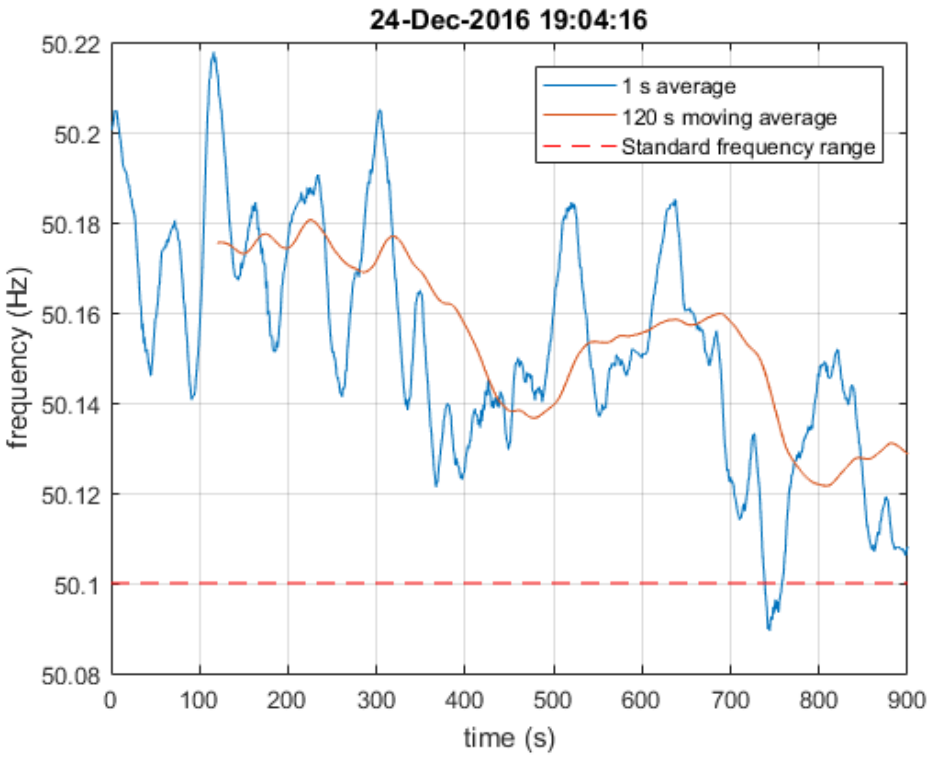
Figure 3.29. Average number of seconds per day that the frequency was outside the 49.8-50.2 Hz band for years 2016-2021



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 are 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 was 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 used resolution of the frequency data was 1 second.

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



The number of events in 2016-2021 that the frequency exceeded 49.8-50.2 Hz band and did not even momentarily return to the standard frequency range within 15 minutes are presented in Table 3.13. These results were calculated with 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.

	2016		**2017**		**2018**		**2019**		**2020**		**2021**	
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	1	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	1	0
March	0	0	0	0	0	0	0	0	0	0	1	0
April	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	1	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	0	0	0	1	0	0	1	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	0	0	1	1	0	0	1	0	**2**	**0**

Table 3.14 shows the number of events in 2016-2021 that the frequency exceeded the 49.8-50.2 Hz band and the 120 s moving average did not return to the standard frequency range within the next 15 minutes. These results were calculated with 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.

	2016		**2017**		**2018**		**2019**		**2020**		**2021**	
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	3	0	0	0	0	0	0	0	0	0	0	0
February	0	1	0	0	0	0	1	0	0	0	2	0
March	0	0	0	0	0	0	0	0	0	0	1	0
April	1	0	1	0	0	0	1	0	0	0	0	0
May	0	0	1	0	2	0	0	0	0	0	1	0
June	0	0	1	0	2	0	0	1	0	0	0	0
July	1	0	0	0	1	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	1	0	0	1	0	1	0
October	2	0	0	0	0	0	1	0	0	0	0	0
November	0	0	0	0	1	0	0	0	0	0	1	0
December	1	0	0	0	0	1	1	0	0	0	0	0
Entire year	9	1	3	0	6	2	4	1	1	0	**6**	**0**
Sum	**10**		**3**		**8**		**5**		**1**		**6**	

3.4.3 Time outside 49.0-51.0 Hz

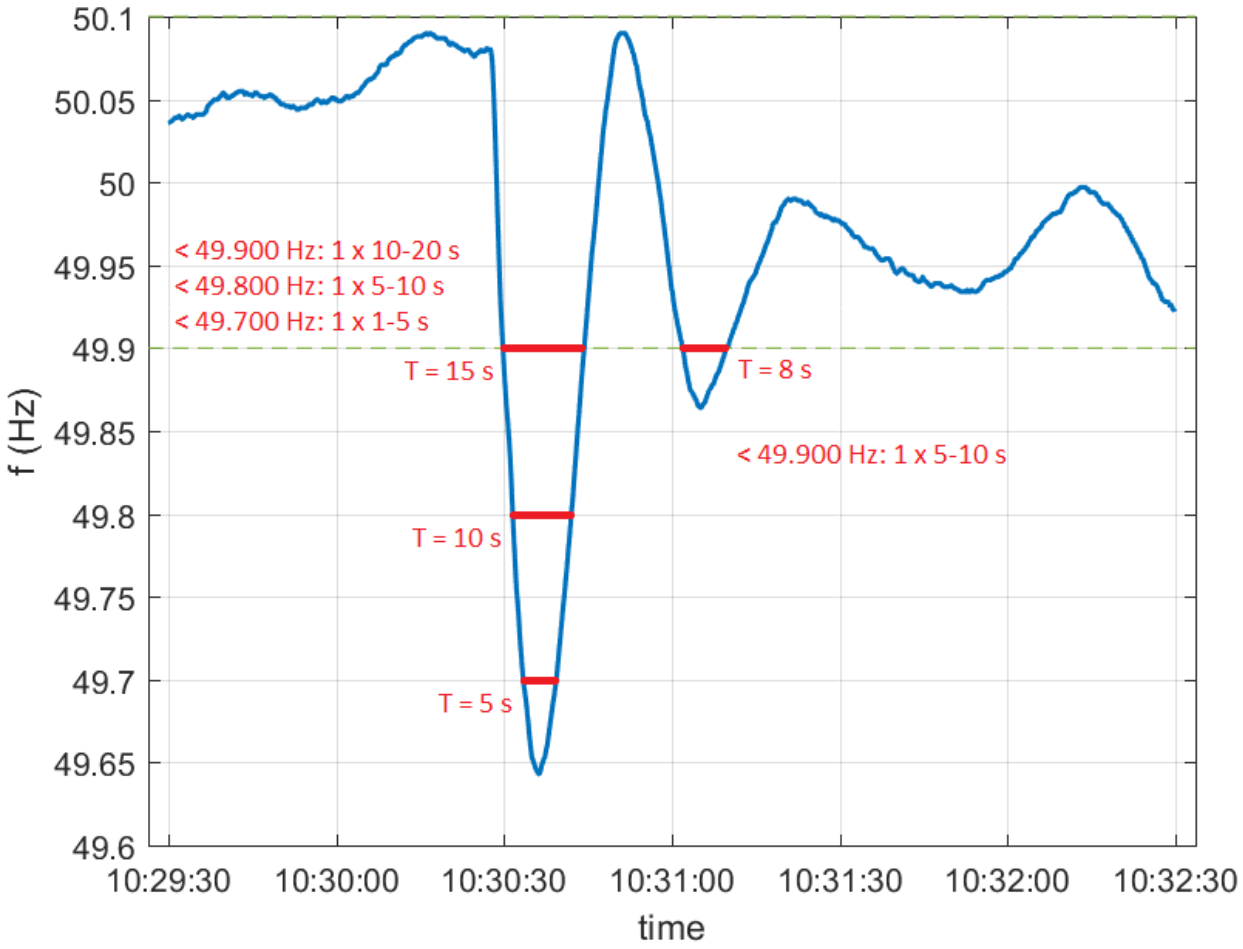
Time outside 49.0 Hz and 51.0 Hz is calculated by counting the number of samples that are below 49.0 Hz or above 51.0 Hz and multiplying the number by the time duration of the sample. The criteria are also defined in SO GL Article 131(1)(a) (v). The resolution of the data used was 1 second.

There were no instances in 2016-2021 where the frequency crossed 49.0 Hz or 51.0 Hz.

3.5 Number of frequency deviations with different durations

In this section, the frequencies outside the standard frequency range have been sorted according to amplitude and duration of the deviation, as well as whether the deviation was over or under the normal frequency range. Figure 3.31 gives an example on 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 10-20 s column and one to 5-10 s column. The other frequency deviation goes also below 49.800 Hz and 49.700 Hz. These will also be counted as one frequency deviation < 49.800 Hz with time from 5-10 s and one < 49.700 Hz with time from 1-5 s. Altogether, the example period is counted as four (4) frequency deviations. Also for example, time window of 5-10 s stands for frequency deviations lasting over five (5) seconds and under or exactly 10 seconds.

Figure 3.31. Example on 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 that was used is 0.1 seconds.

Tables 3.15-3.20 provide more detailed information about frequency deviations from year 2016 to 2021. These tables include the durations and amplitudes of the deviations, as well as total amount, maximum duration and average duration of deviations.

Table 3.15. Total number of frequency deviation in 2016

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	18827	6452	4288	6553	4249	955	857	150	42331	1418.20	10.45
> 50.2	44	30	43	20	11	0	1	0	149	75.70	7.10
> 50.3	1	8	0	0	0	0	0	0	9	4.70	2.88
< 49.9	17236	6454	3875	5762	3992	850	652	119	38940	549.50	9.82
< 49.8	52	36	43	27	5	2	2	0	167	69.50	6.87
< 49.7	1	2	3	2	0	0	0	0	8	11.90	6.43
< 49.6	0	1	1	0	0	0	0	0	2	5.60	4.35
< 49.5	0	0	0	0	0	0	0	0	0	0.00	0.00

Table 3.16. Total number of frequency deviation in 2017

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	14813	5217	3723	5441	3586	840	655	91	34366	895.60	10.24
> 50.2	19	8	17	17	5	1	0	0	67	43.90	8.90
> 50.3	0	1	1	0	0	0	0	0	2	5.10	4.85
< 49.9	14196	5284	3269	4948	3360	755	650	96	32558	995.90	10.29
< 49.8	43	17	36	8	1	0	0	0	105	27.50	4.29
< 49.7	0	1	1	1	0	0	0	0	3	10.70	7.03
< 49.6	0	1	0	0	0	0	0	0	1	2.90	2.90
< 49.5	0	0	0	0	0	0	0	0	0	0.00	0.00

Table 3.17. Total number of frequency deviation in 2018

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	17272	5397	3753	5435	3687	835	640	128	37147	2043.90	9.88
> 50.2	87	45	41	44	12	3	3	0	235	155.10	7.62
> 50.3	0	0	1	0	0	0	0	0	1	5.70	5.70
< 49.9	15238	5538	3345	5244	3432	693	558	108	34156	999.30	9.73
< 49.8	79	32	29	14	10	1	1	1	167	215.70	6.89
< 49.7	1	0	4	0	0	0	0	0	5	9.60	6.72
< 49.6	0	1	1	0	0	0	0	0	2	5.10	4.05
< 49.5	0	0	0	0	0	0	0	0	0	0.00	0.00

Table 3.18. 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 3.19. 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 3.20. 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	0.00

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. Year 2020 has had the smallest number of deviations in the observation period whereas year 2016 has had the most deviations in the observation period.

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

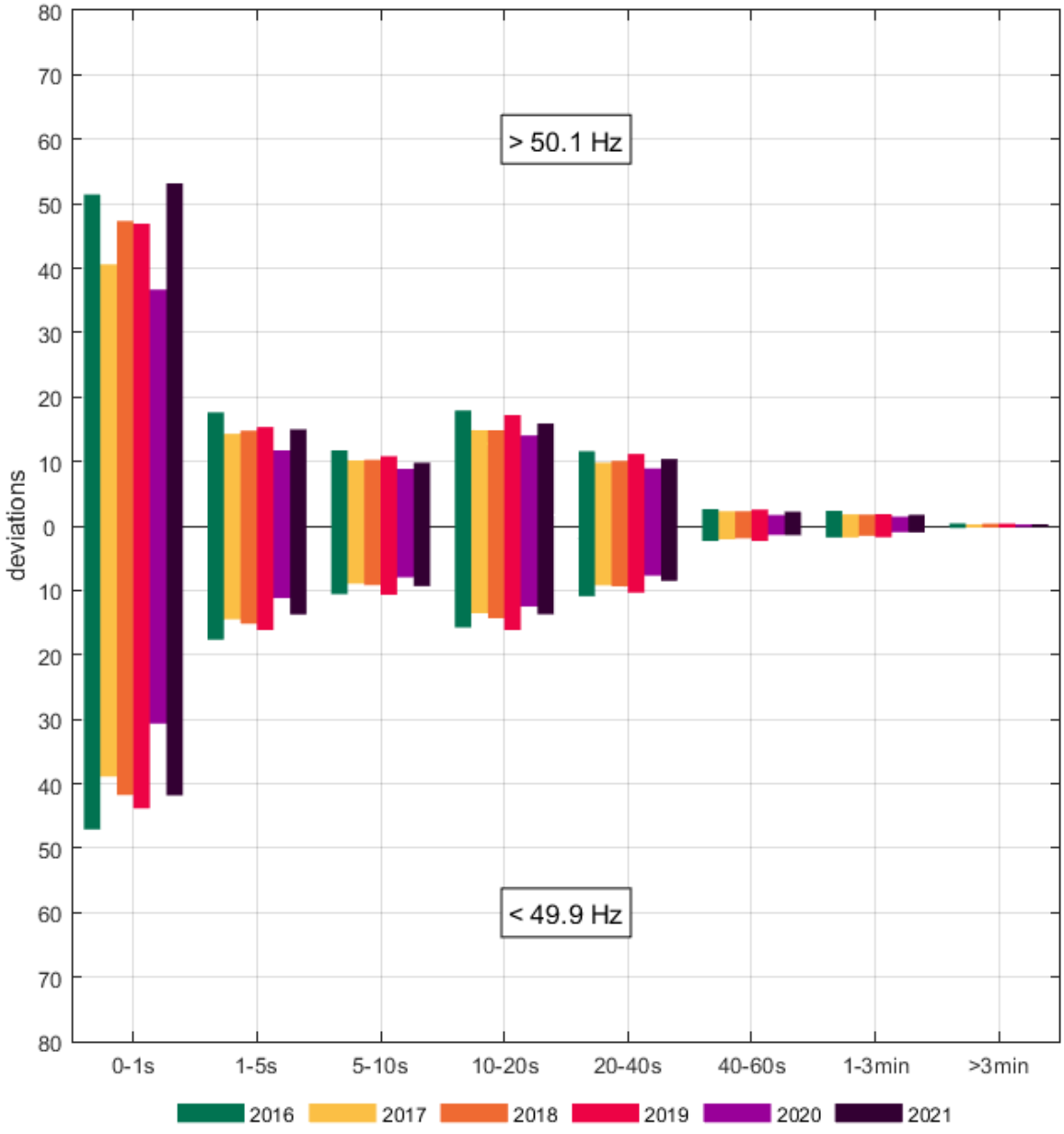
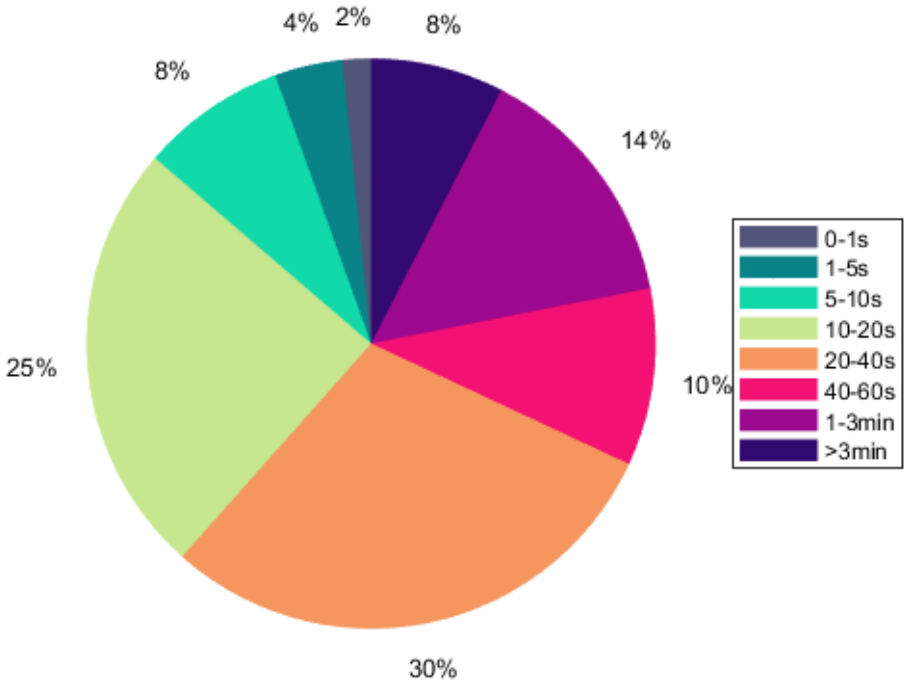


Table 3.21 shows how deviations of different duration affected to the total time outside the standard frequency range in 2021. Times are given in minutes. Pie chart in Figure 3.33 shows in percentages how the total time outside the standard frequency range was divided between deviations of different duration. Percentages of pie chart are rounded to nearest whole number and thus the sum of percentages differs from 100 %. Deviations with duration of 10-20 s and 20-40 s lasted more than half of the total time outside the standard frequency range.

Table 3.21. Total minutes in 2021 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	94	214	451	1411	1729	650	979	579	6107
< 49.9 Hz	76	195	424	1208	1410	417	537	224	4492
total	171	409	874	2619	3139	1067	1517	802	10598

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 the year 2021. Figure 3.34 represents the total number of deviations per duration for each month in 2021. Most of the deviations have lasted only between 0-1 seconds. Most deviations have occured in August and May. Also June, September and October have been prominent in the number of deviations. July has had the smallest number of deviations.

Figure 3.34**. **Total number of frequency deviations per duration for each month in 2021

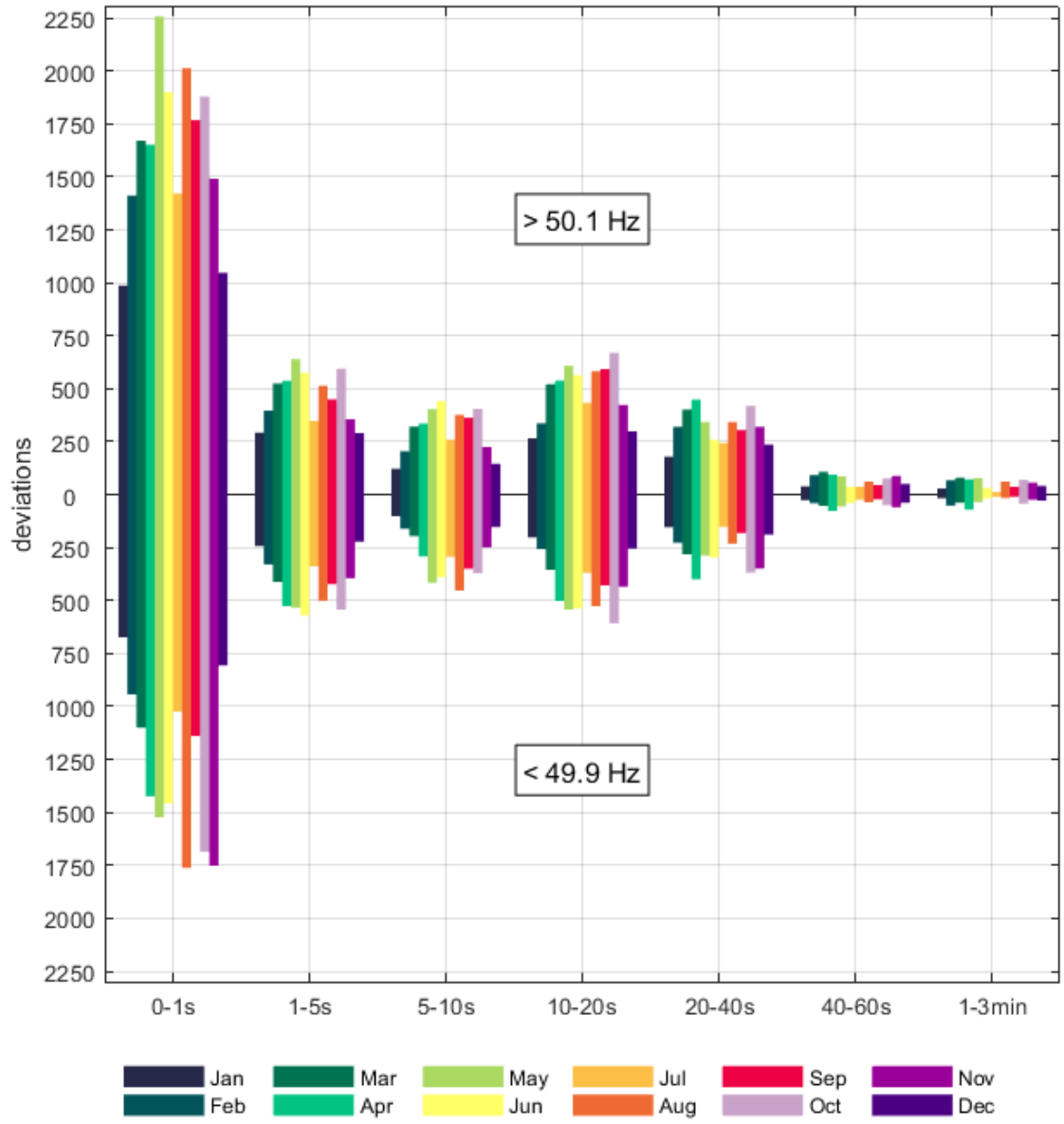
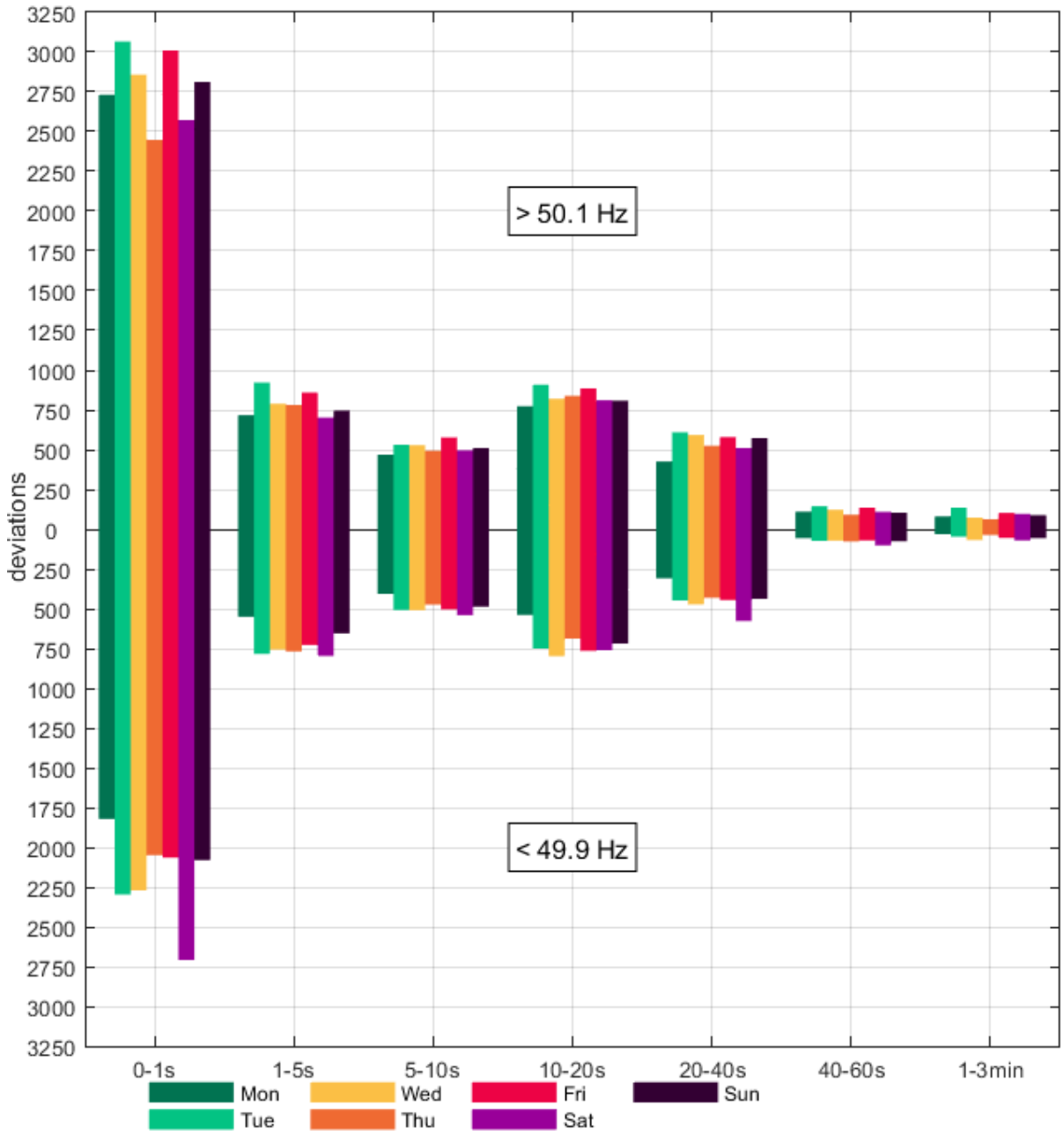


Figure 3.35 shows the number of deviations for every day of the week. Under 49.9 Hz deviations of 0-1 s have been most common on Saturdays on every duration expect 10-20 s. Compared to year 2020 the number of frequency deviations lasting 0-1 s have increased substantially.

Figure 3.35. Total number of frequency deviations per duration for each day of the week in 2021



Figures 3.36 and 3.37 illustrate the number of deviations per duration inside the day. Figure 3.36 includes the hours 0-11 and Figure 3.37 the hours 12-23. Most deviations over the standard frequency range have occurred after midnight, in the late morning and in the afternoon. Also evening hours 21 and 23 and morning hour 7 have clearly had more deviations.

Figure 3.36. Total number of frequency deviations per duration for hours 0-11 in 2021

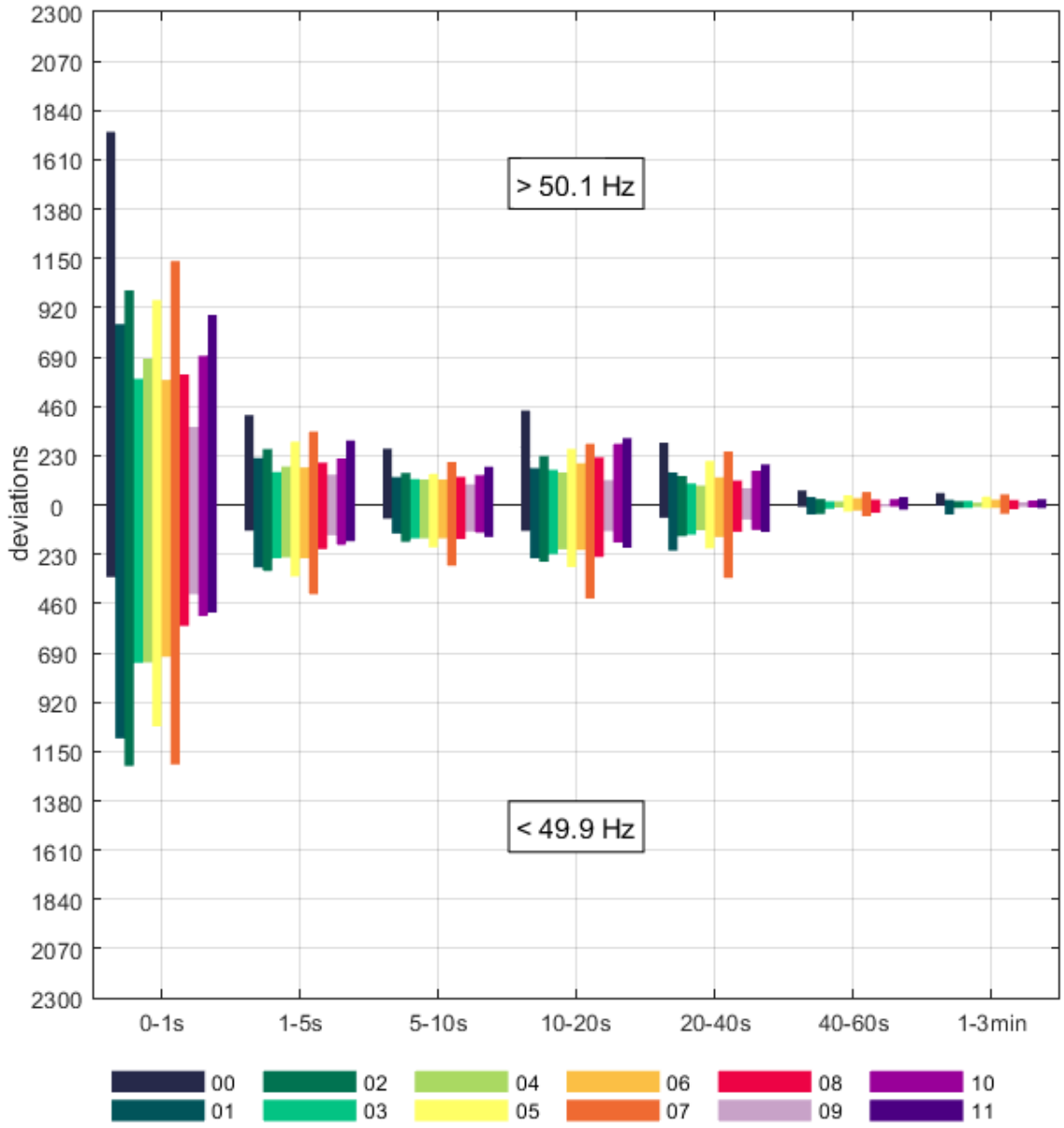


Figure 3.37. Total number of frequency deviations per duration for hours 12-23 in 2021

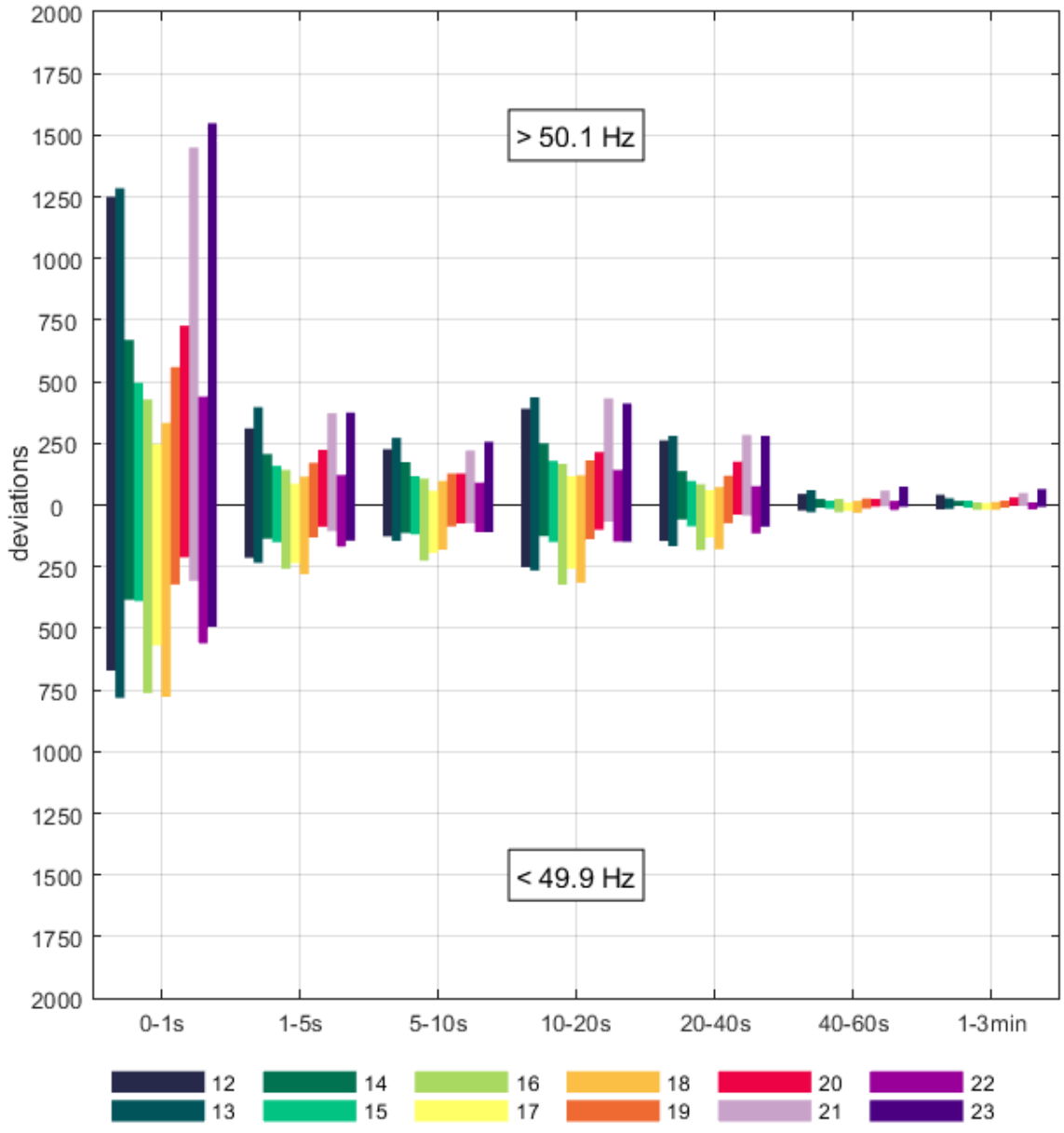
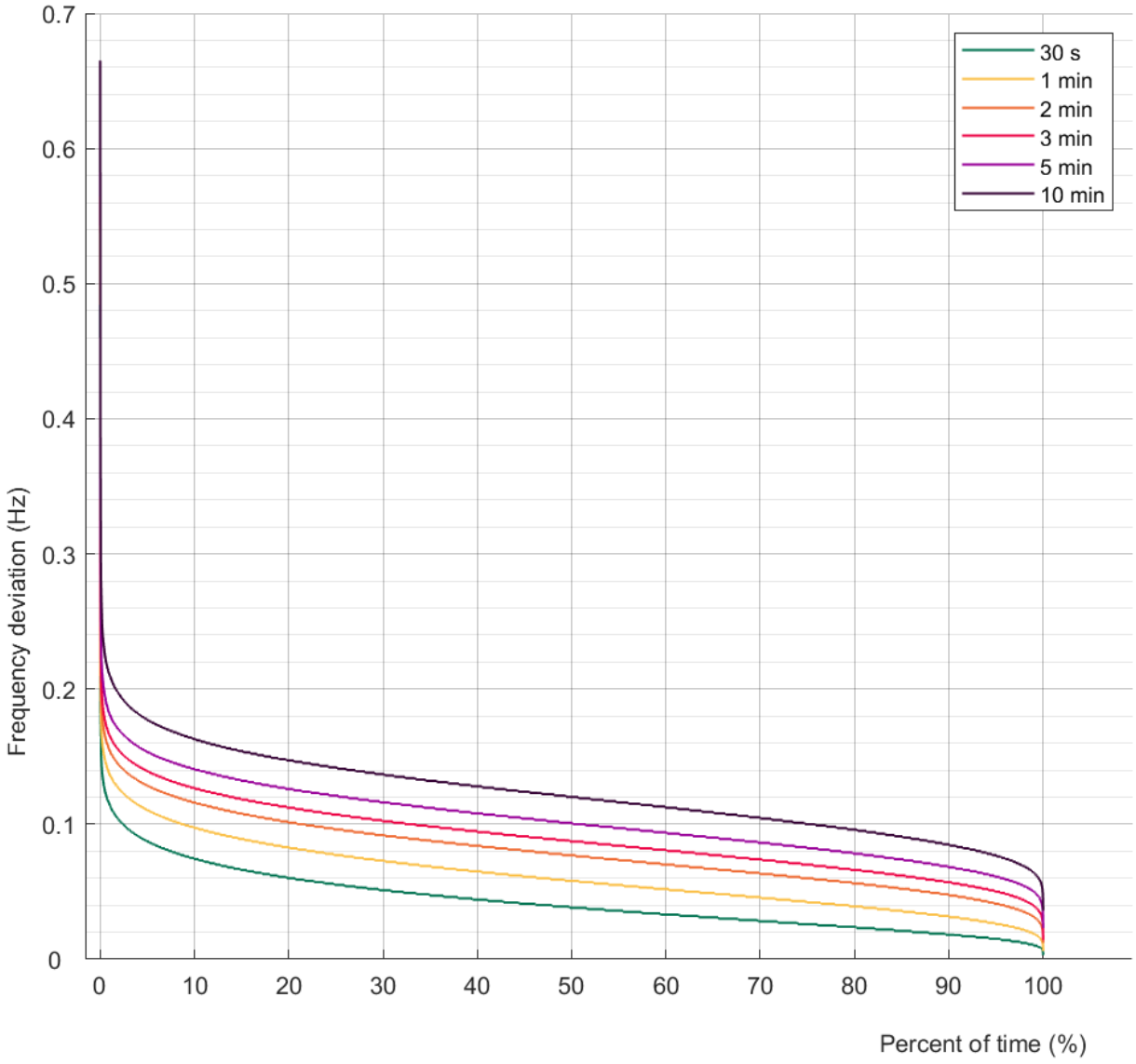


Figure 3.38 represents the duration curve of maximum frequency deviation inside different time windows in year 2021. The time window was slid through the year with a time interval of one second. Studied time windows can be found from legend of the Figure 3.38. Chapter 4 shows in detail the frequency disturbances of over 0.3 Hz which can be seen here as a peak near 0% permanence.

Figure 3.38. Duration curve of maximum frequency deviation inside different time windows in 2021



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 deviations for years between 2016-2021. The number of over frequency deviations has increased slightly from the previous year. When comparing year 2021 to years 2016-2019, the number of deviations has subtantially decreased.

Figure 3.39**. **Total number of longer frequency deviations per duration between 2016-2021

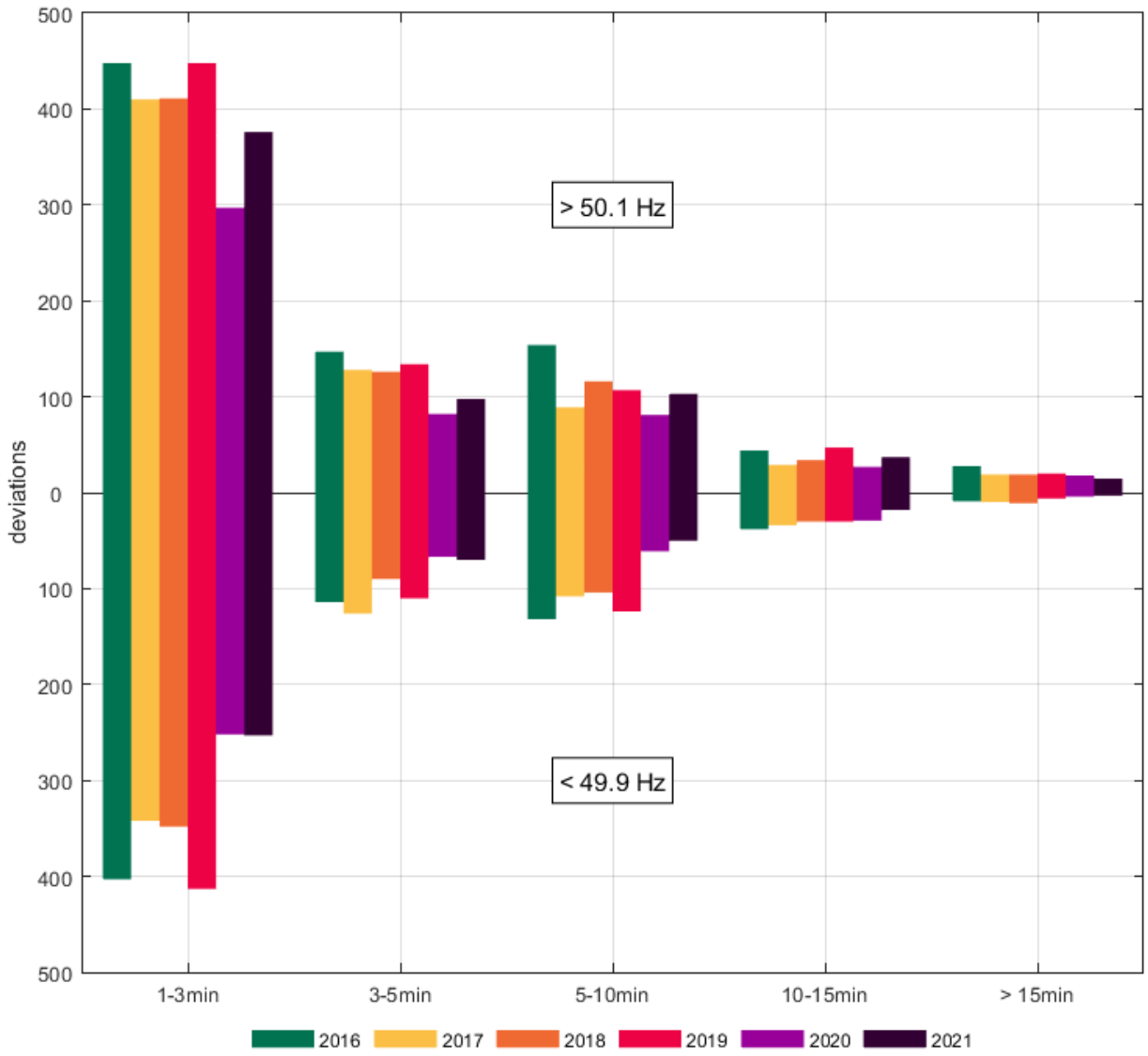


Figure 3.40 shows the total number of longer deviations for each month in 2021. Compared to year 2020, the number of longer frequency deviations has increased.

Figure 3.40**. **Total number of longer frequency deviations per duration for each month in 2021

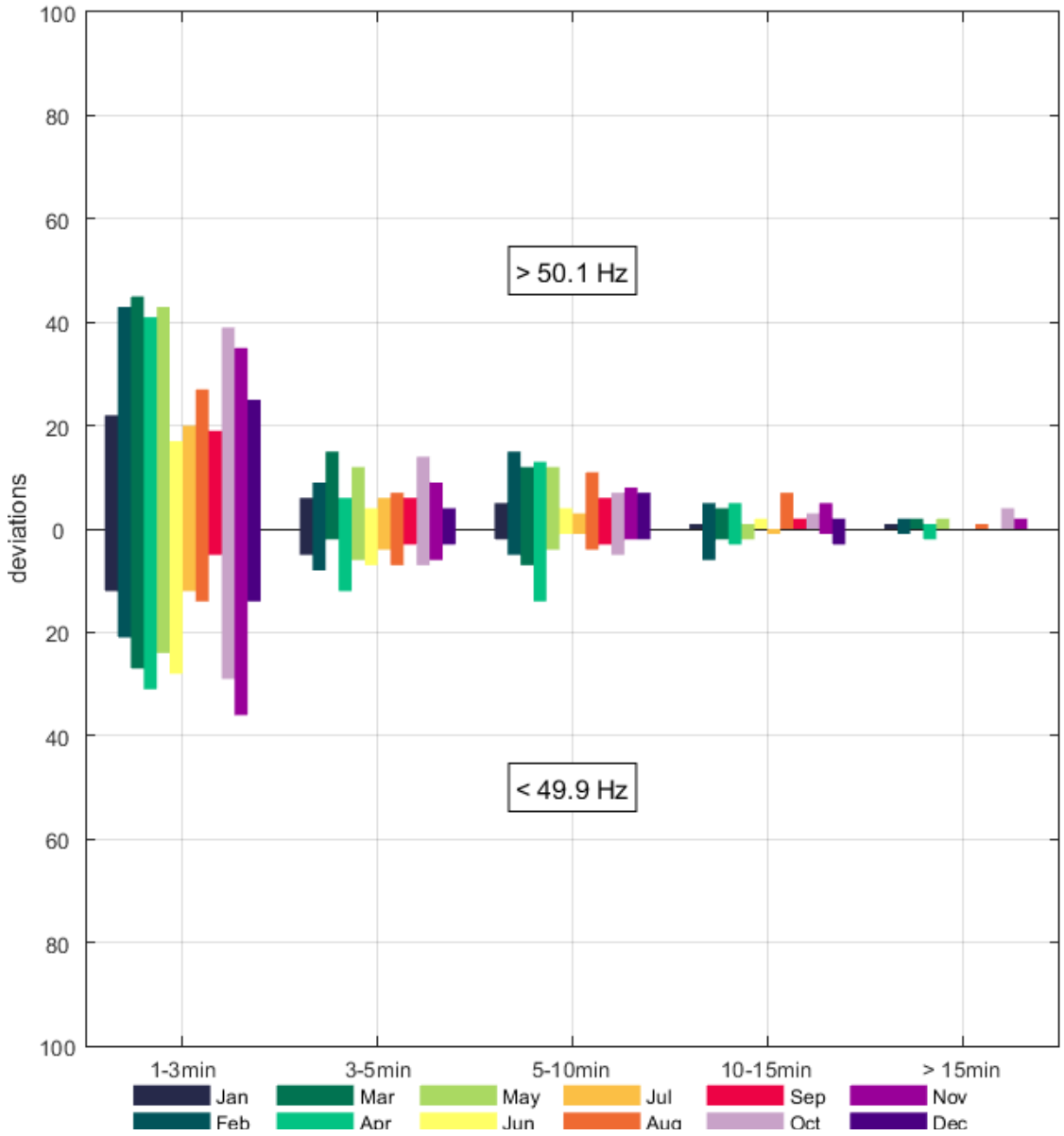
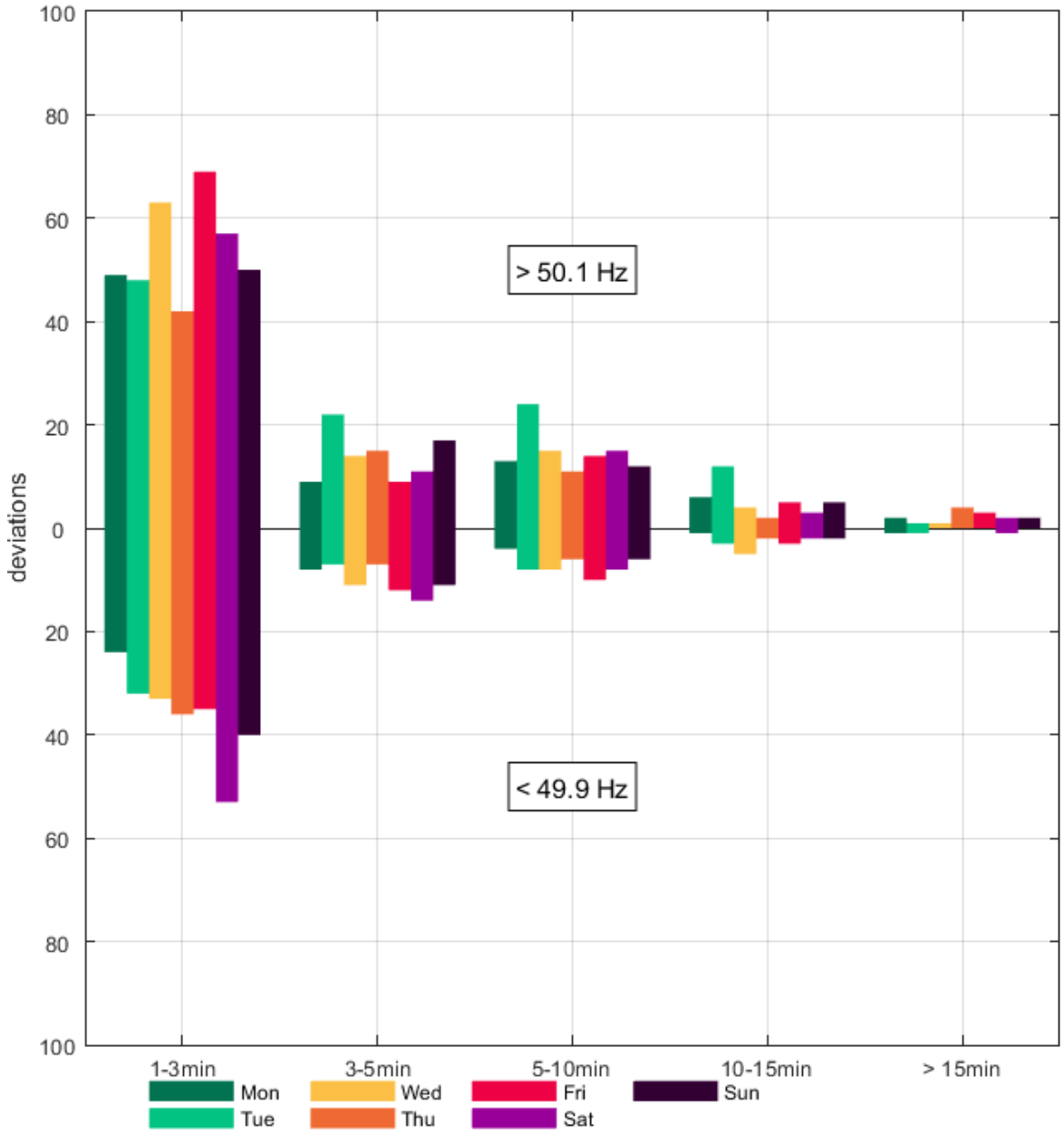


Figure 3.41 represents the number of deviations with different durations during every day of the week in 2021. The peaks of number of longer frequency deviations are more evenly distributed between days of the week than in year 2020.

Figure 3.41**. **Total number of longer frequency deviations per duration for each day of the week in 2021



Figures 3.42 and 3.43 follow the same pattern as the figures representing the shorter durations with most deviations taking place in the morning, early afternoon and close to midnight. Also hour 21 has had significant amount of longer frequency deviations.

Figure 3.42**. **Total number of longer frequency deviations per duration for hours 0-11 in 2021

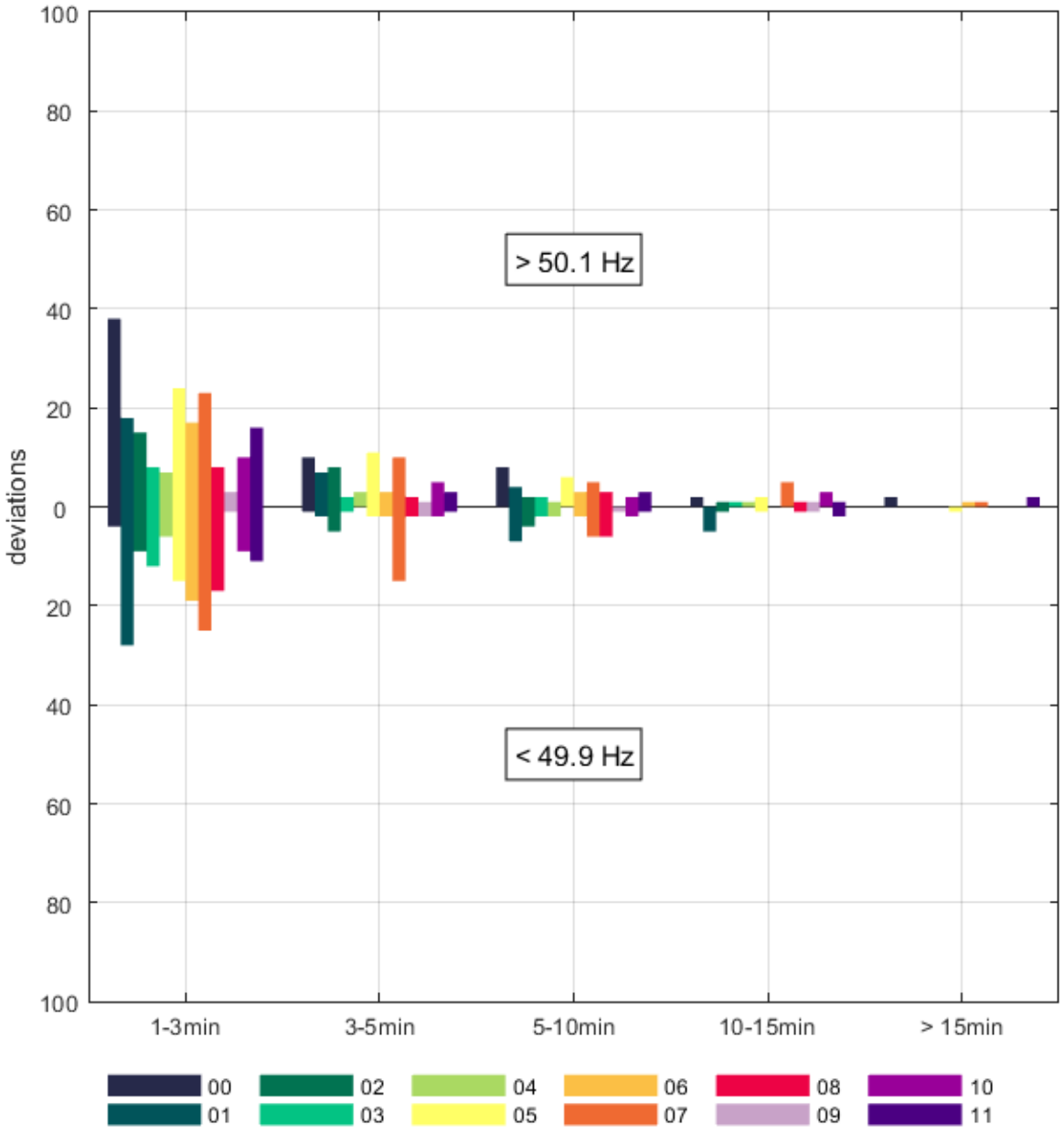
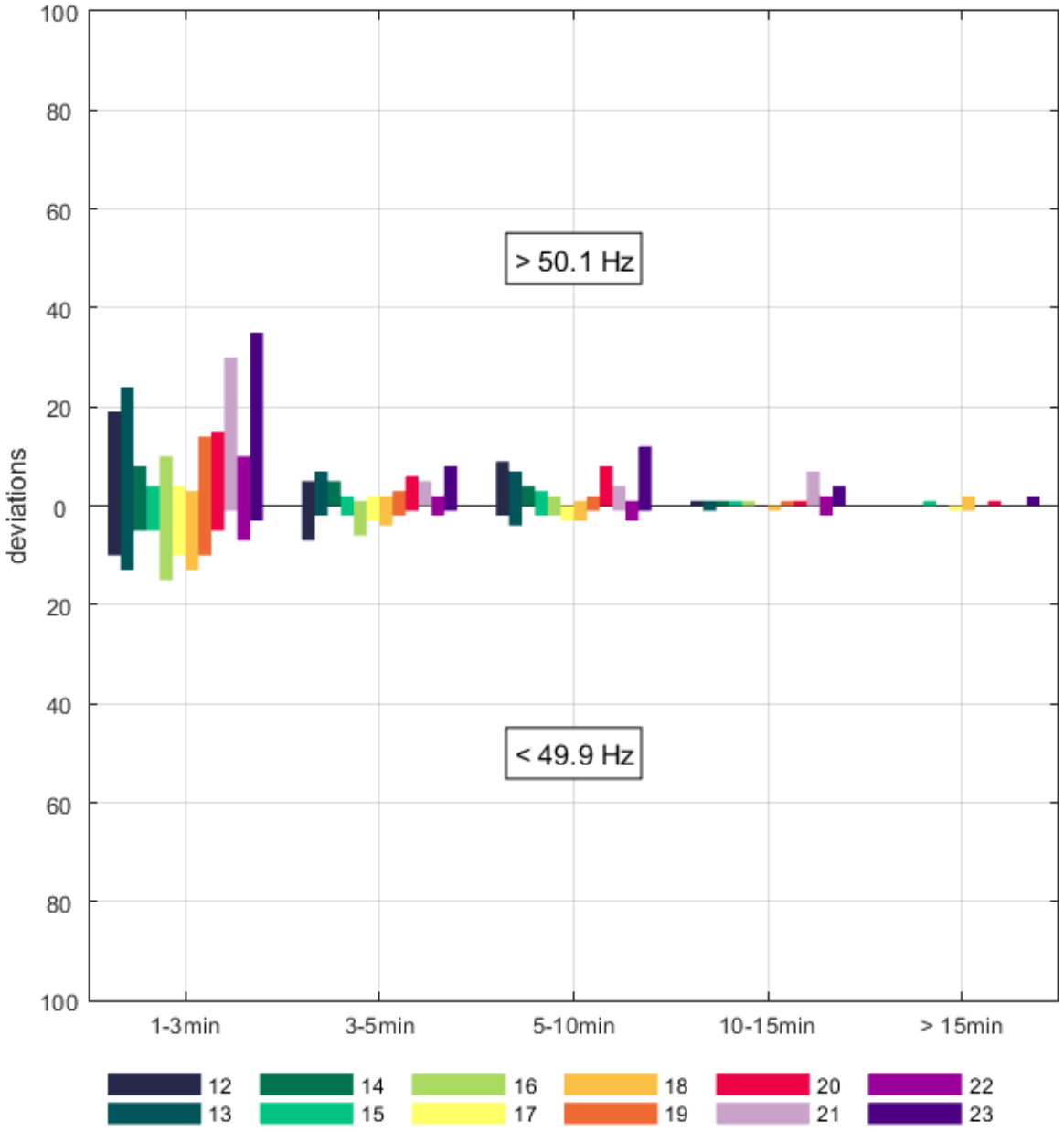


***Figure 3.43**. Total number of longer frequency deviations per duration for hours 12-23 in 2021*



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 on how many times per given time period Frequency Containment Reserve for Disturbances (FCR-D) is activated. The crossings are calculated separately for the number of occasions the frequency goes over and under the frequency range. The resolution of the frequency is one second.

3.6.1 Number of 49.9-50.1 Hz crossings

Figure 3.44 shows the daily average numbers of over and under frequency deviations from 2016 to 2021. Year 2021 had the second lowest number of crossings right after year 2020. Every year there have been slightly more threshold crossings over 50.1 Hz than under 49.9 Hz.

Figure 3.44. Daily average number of frequency deviations for years 2016-2021

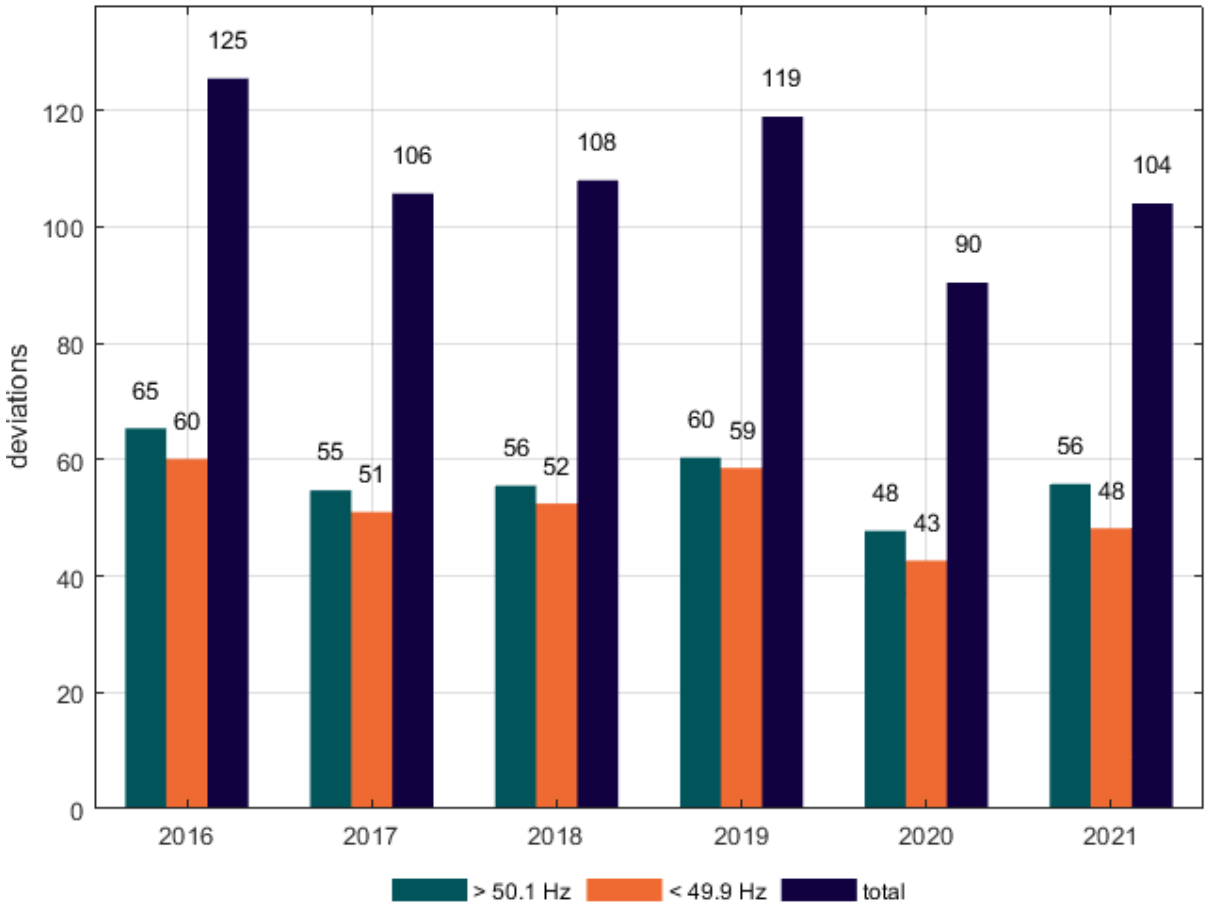


Figure 3.45 represents the daily average number of threshold crossings for each month in 2021. The frequency has crossed the threshold most often in April, May and October. January and December have had the smallest number of treshold crossings.

Figure 3.45**. **Daily average number of threshold crossings for every month in 2021

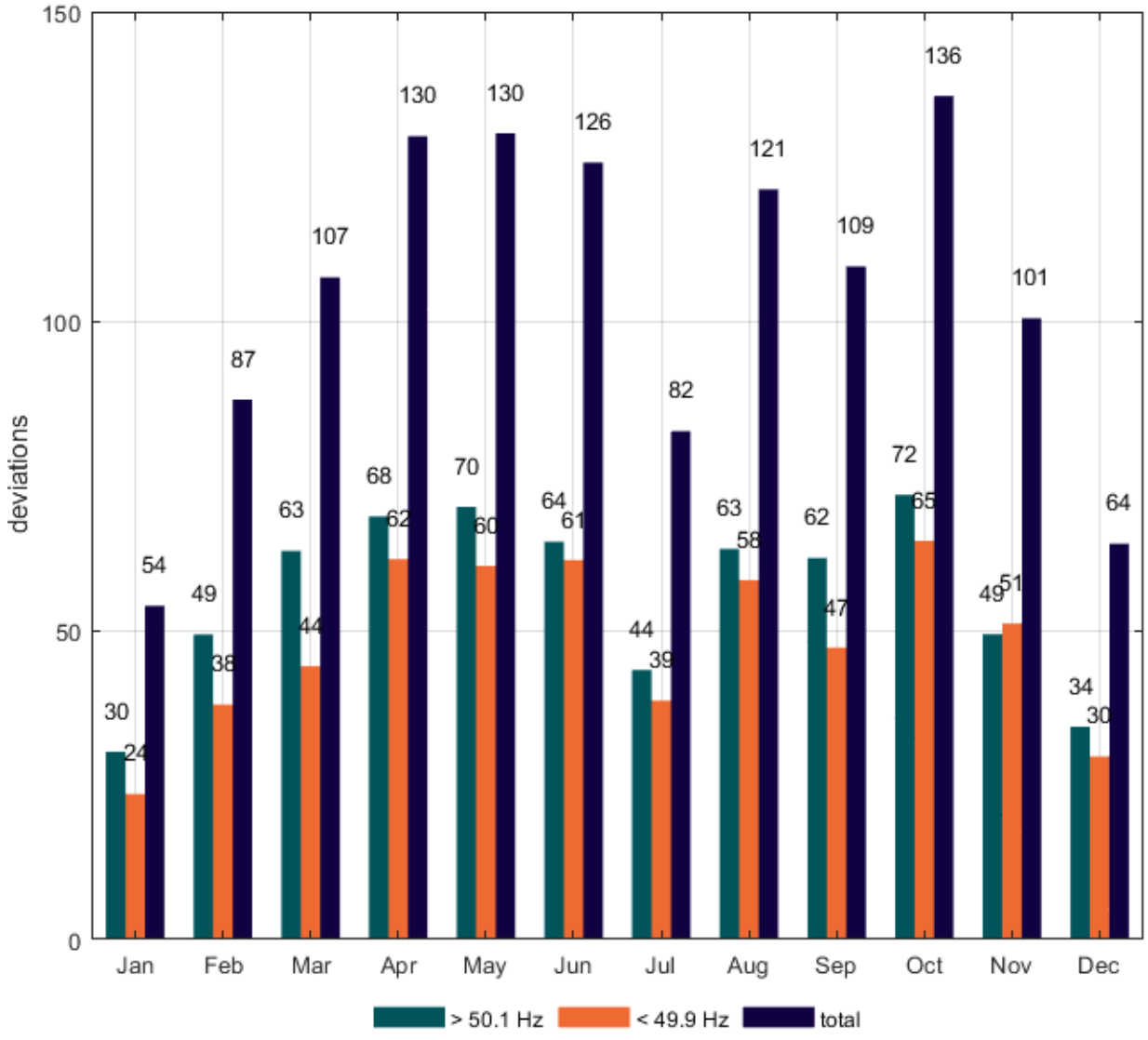
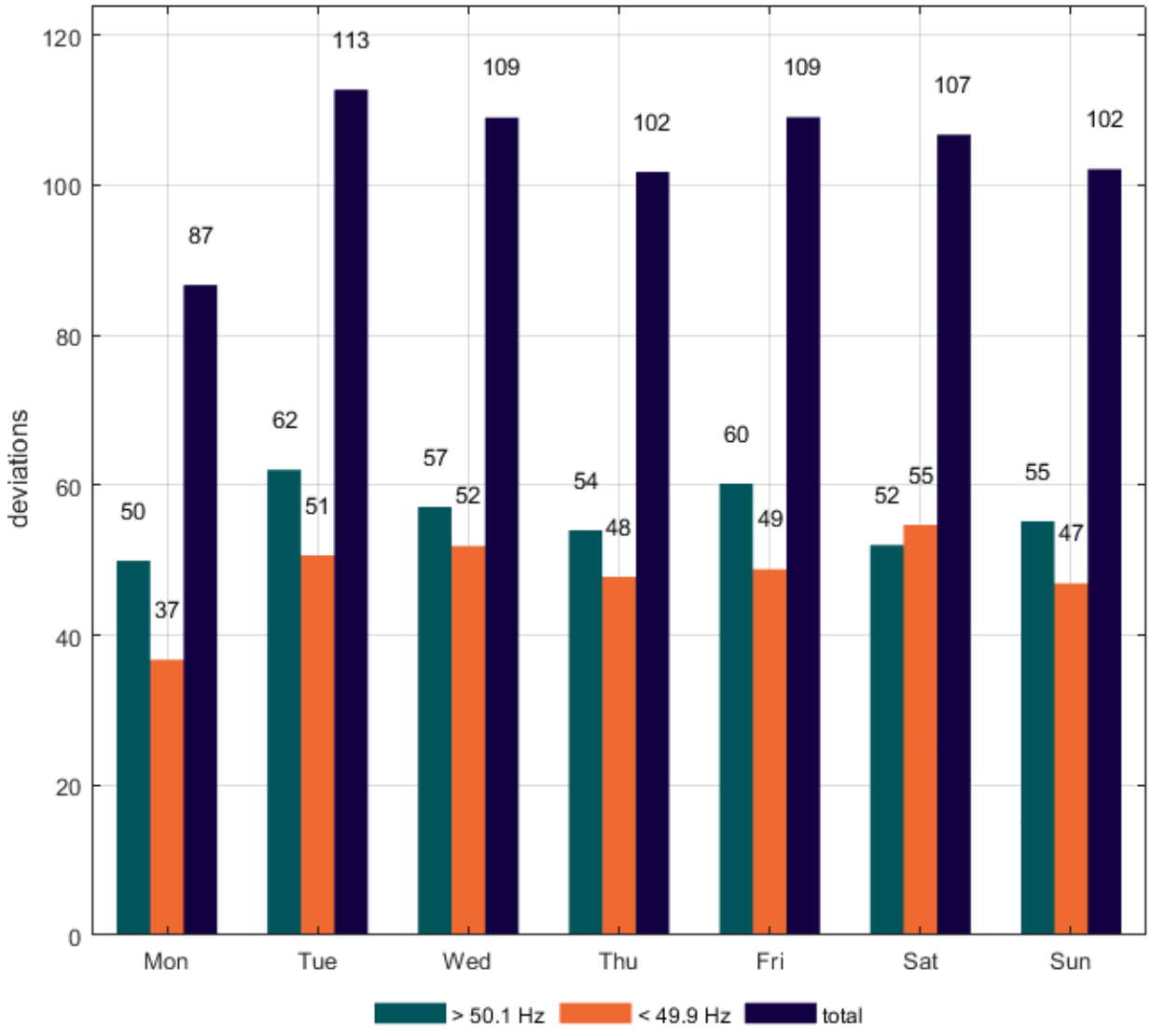


Figure 3.46 shows the number of threshold crossings for each day of the week in 2021. The number of crossings has been highest on Tuesdays and lowest on Mondays.

Figure 3.46**. **Daily average number of threshold crossings for every day of the week in 2021



The hourly number of threshold crossings inside an average day is presented in Figure 3.47. The smallest number of threshold crossings has occurred at 9 am. The most crossings were experienced at 7 in the morning and in early afternoon.

Figure 3.47. Average number of threshold crossings for every hour of the day in 2021

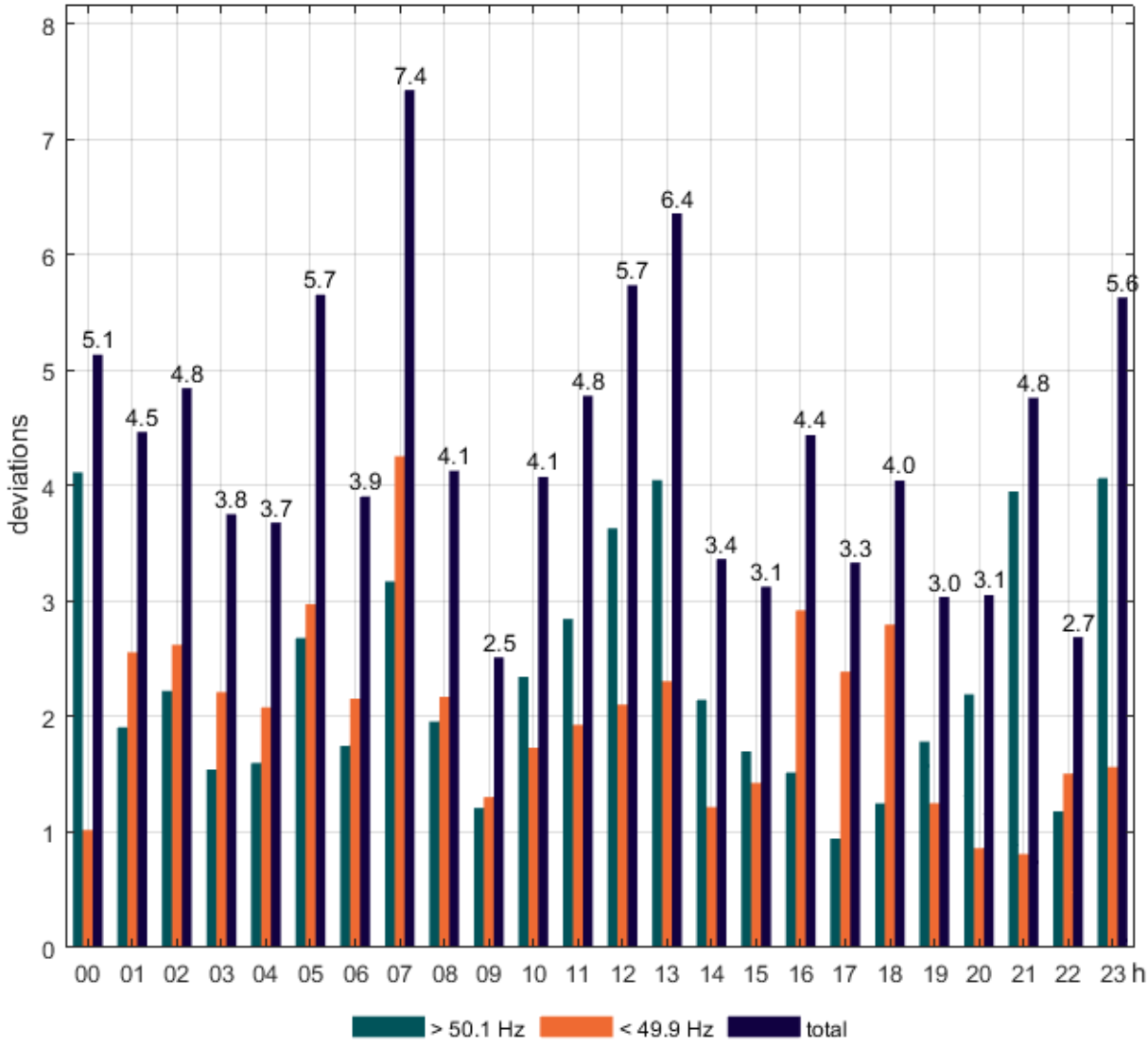
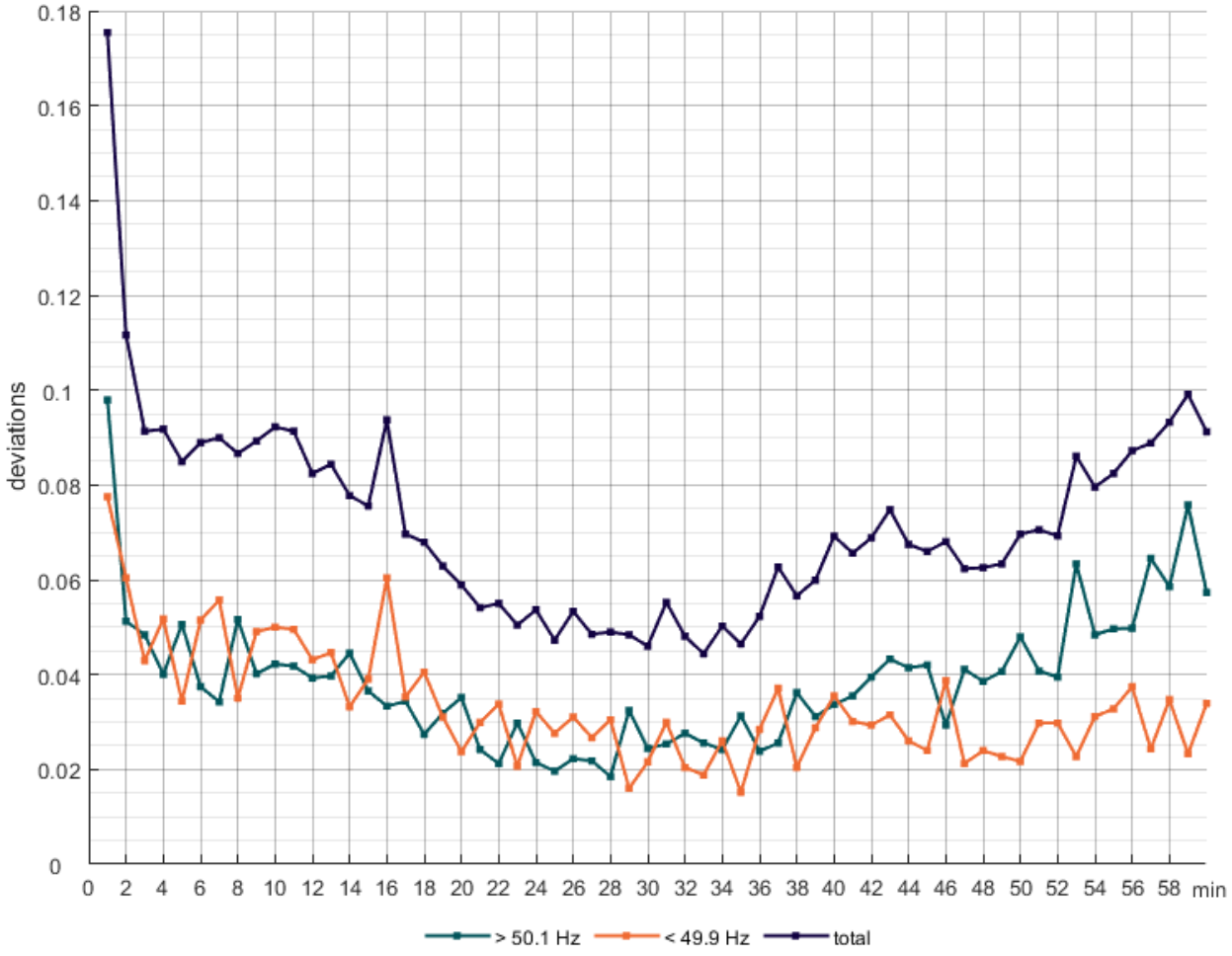


Figure 3.48 represents the average number of threshold crossings for every minute inside the hour. Most crossings have occurred in the first minutes of the hour. During the first 30 minutes of the hour, the frequency has crossed 49.9 Hz more often, whereas more crossings of 50.1 Hz have taken place in the latter part of the hour.

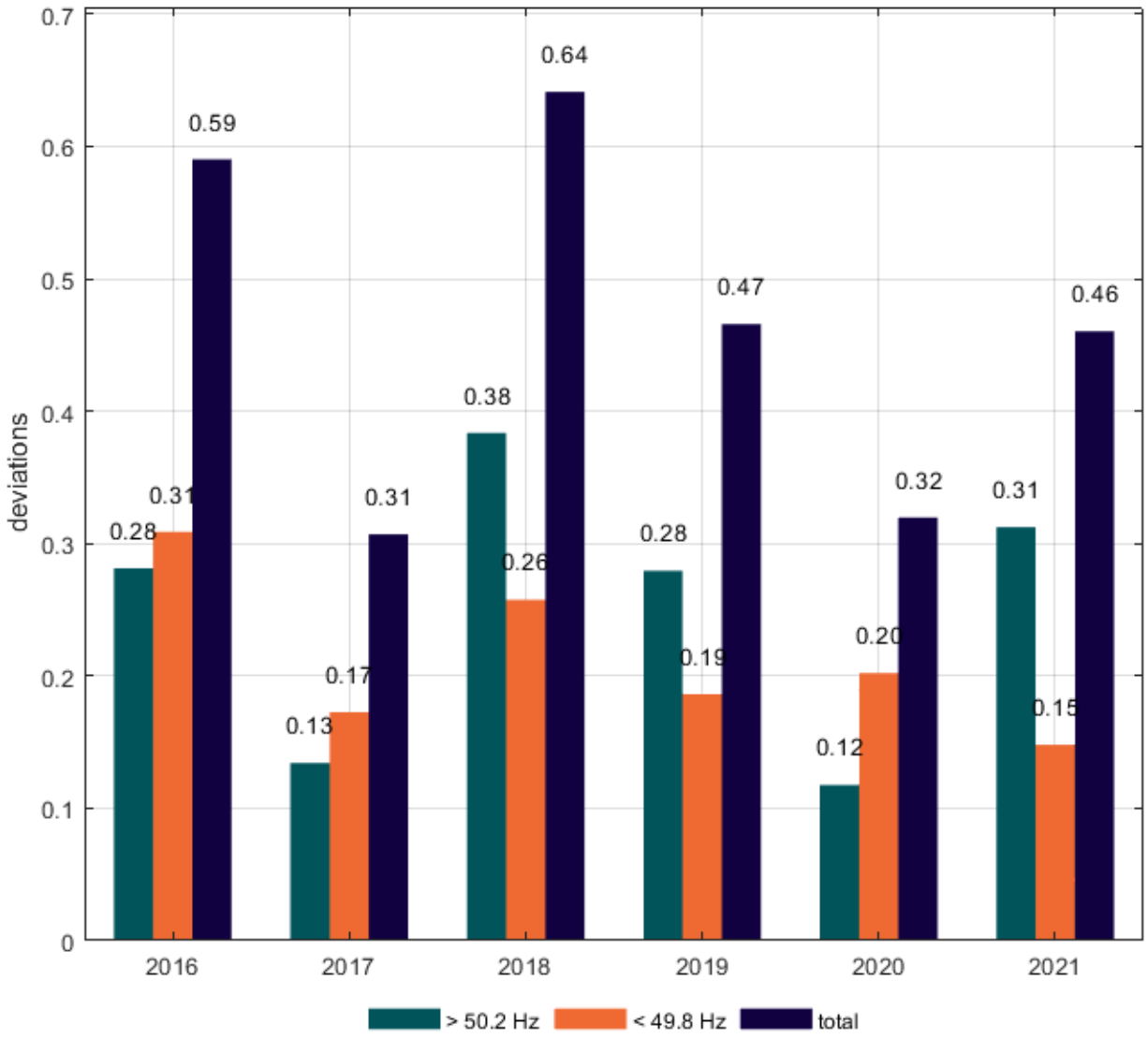
Figure 3.48. Average number of threshold crossings for every minute of the hour in 2021



3.6.2 Number of 49.8-50.2 Hz crossings

Figure 3.49 represents the average number of frequency deviations per day that exceeded ±200 mHz. In 2021, the number of deviations incresed significantly from year 2020.

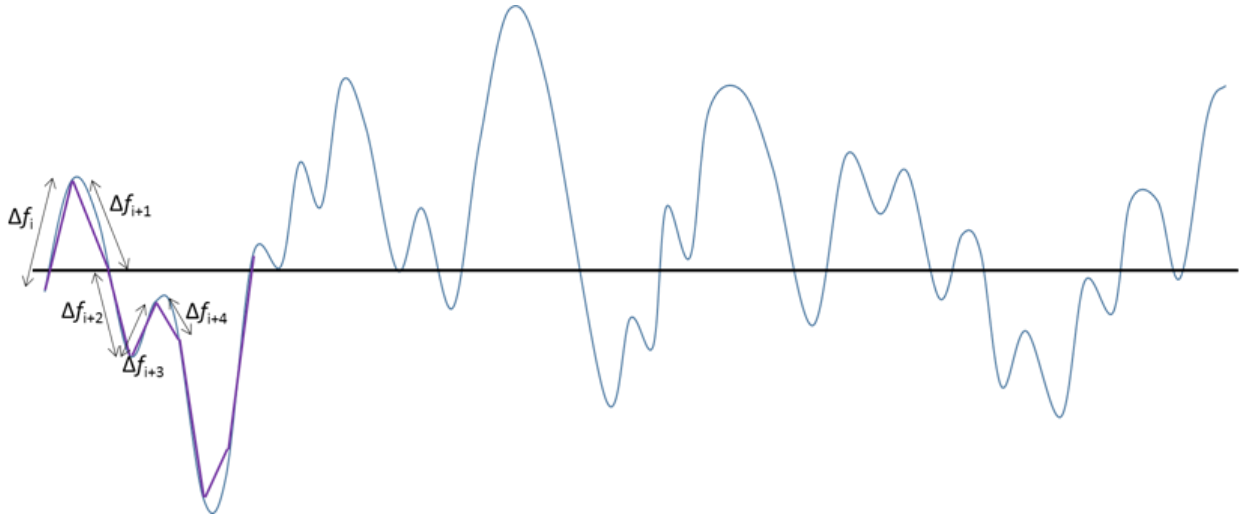
Figure 3.49. Daily average number of frequency deviations larger than ±200 mHz for years 2016-2021



3.7 Length of frequency path

The length of the path that frequency takes shows how much the frequency travels around the 50.0 Hz, as can be seen from 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).

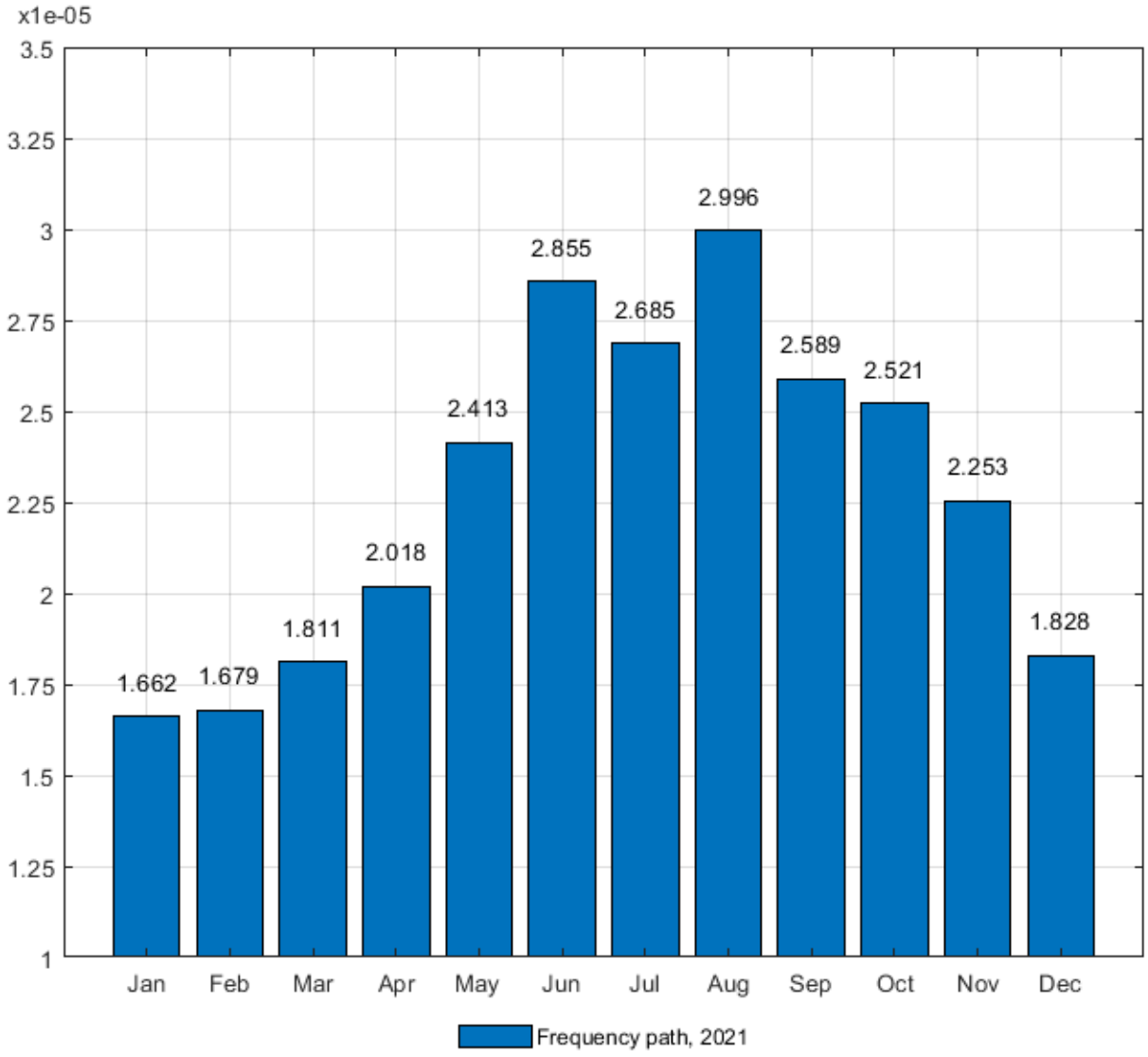
Figure 3.50. Frequency quality index: Length of the frequency path [8]



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

Figure 3.51 represents the frequency path for each month in 2021. The path lenght has steadily increased from February to June. In August the frequency path achieves its peak value, after which it starts to reduce towards end of the year. The peak value of frequency path have increased by nearly 28 % from 2020 value.

Figure 3.51. Length of the frequency path month by month in 2021



The frequency path for every day of the week shows 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 on the weekends than on the weekdays.

Figure 3.52. Length of the frequency path for every day of the week in 2021

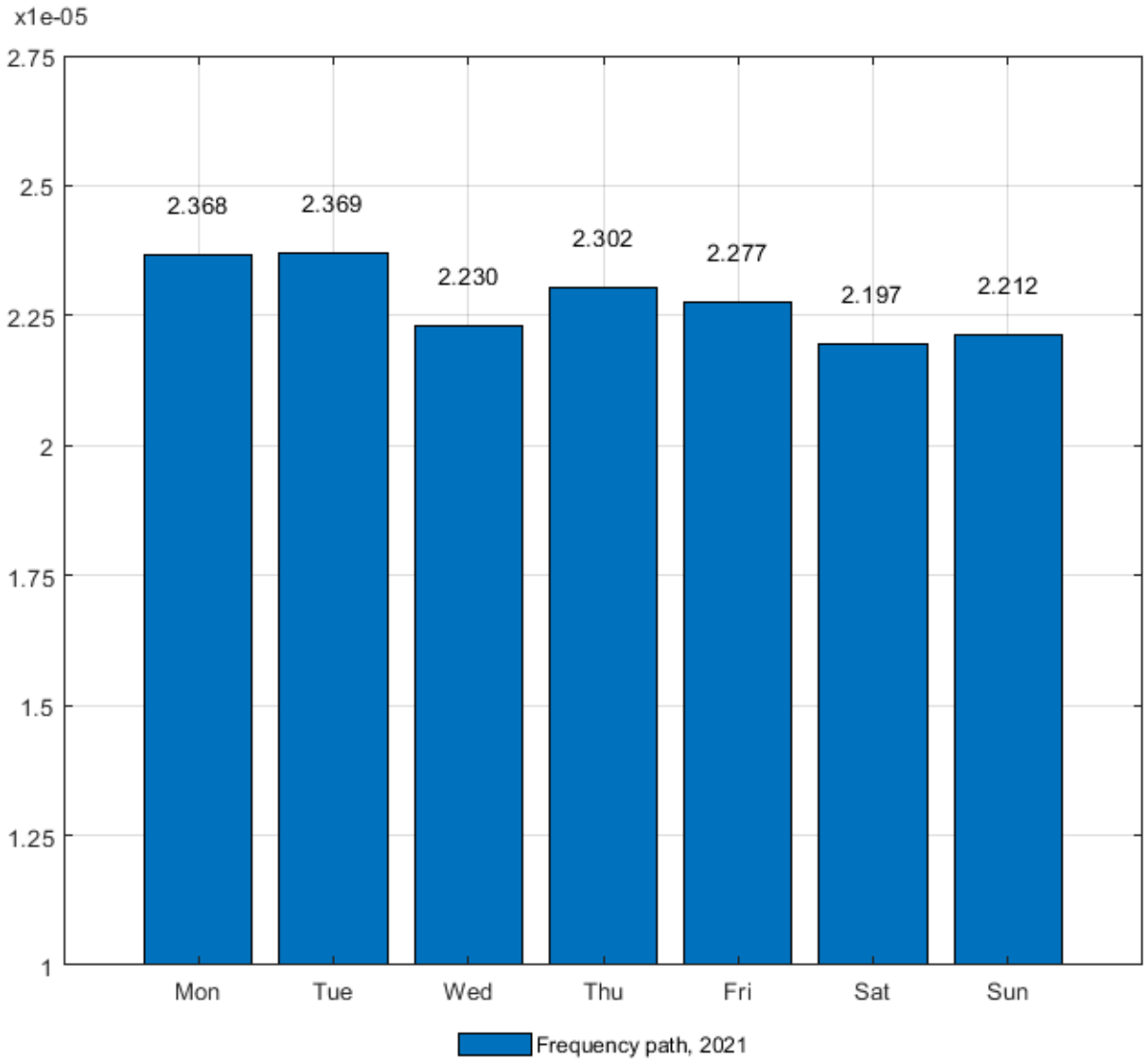


Figure 3.53 shows the frequency path during the day. The frequency path have stayed relatively constant throughout the day if few hours after midnight and one afternoon hour is exluded from the analysis.

Figure 3.53. Length of the frequency path for every hour of the day in 2021

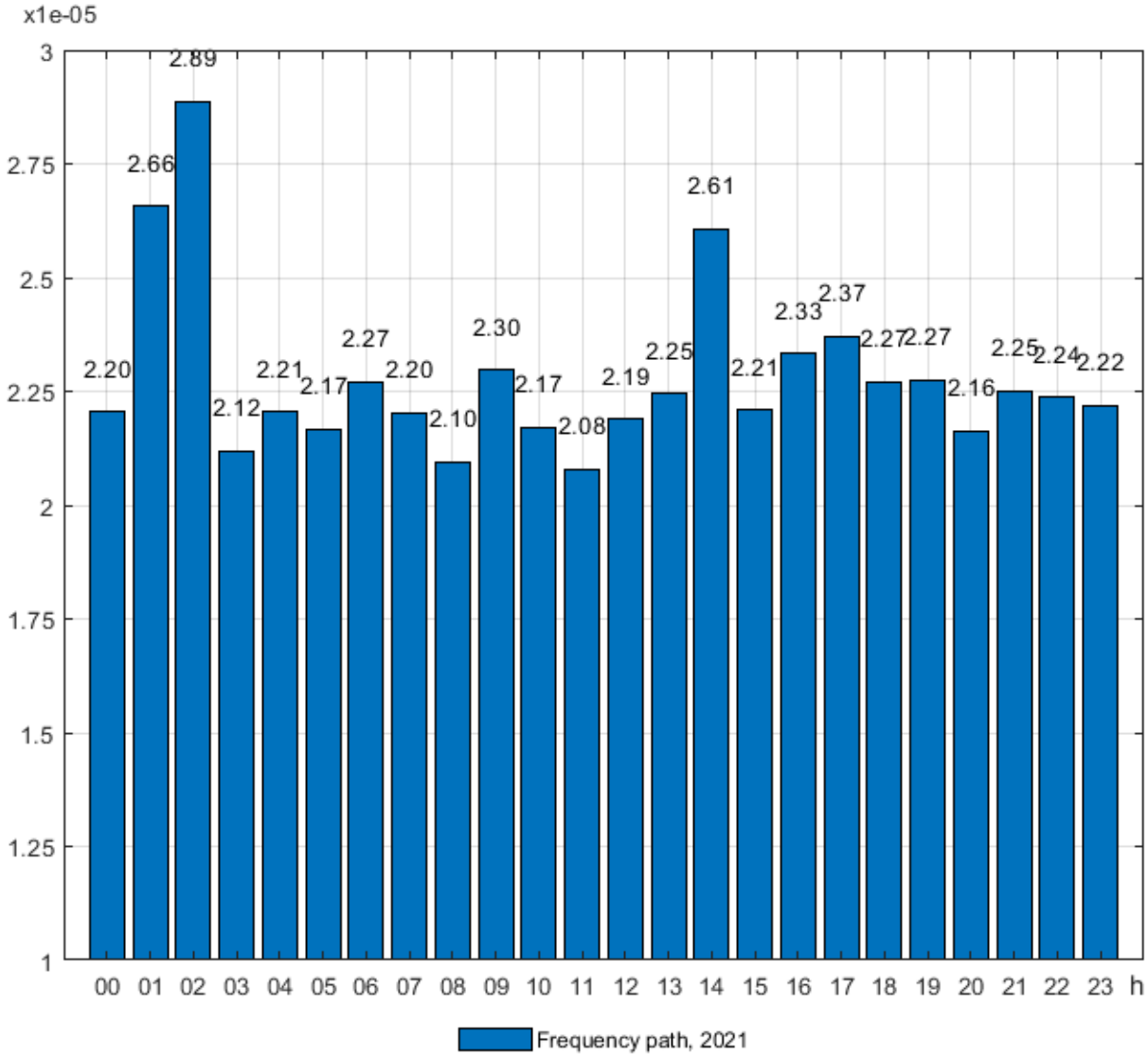
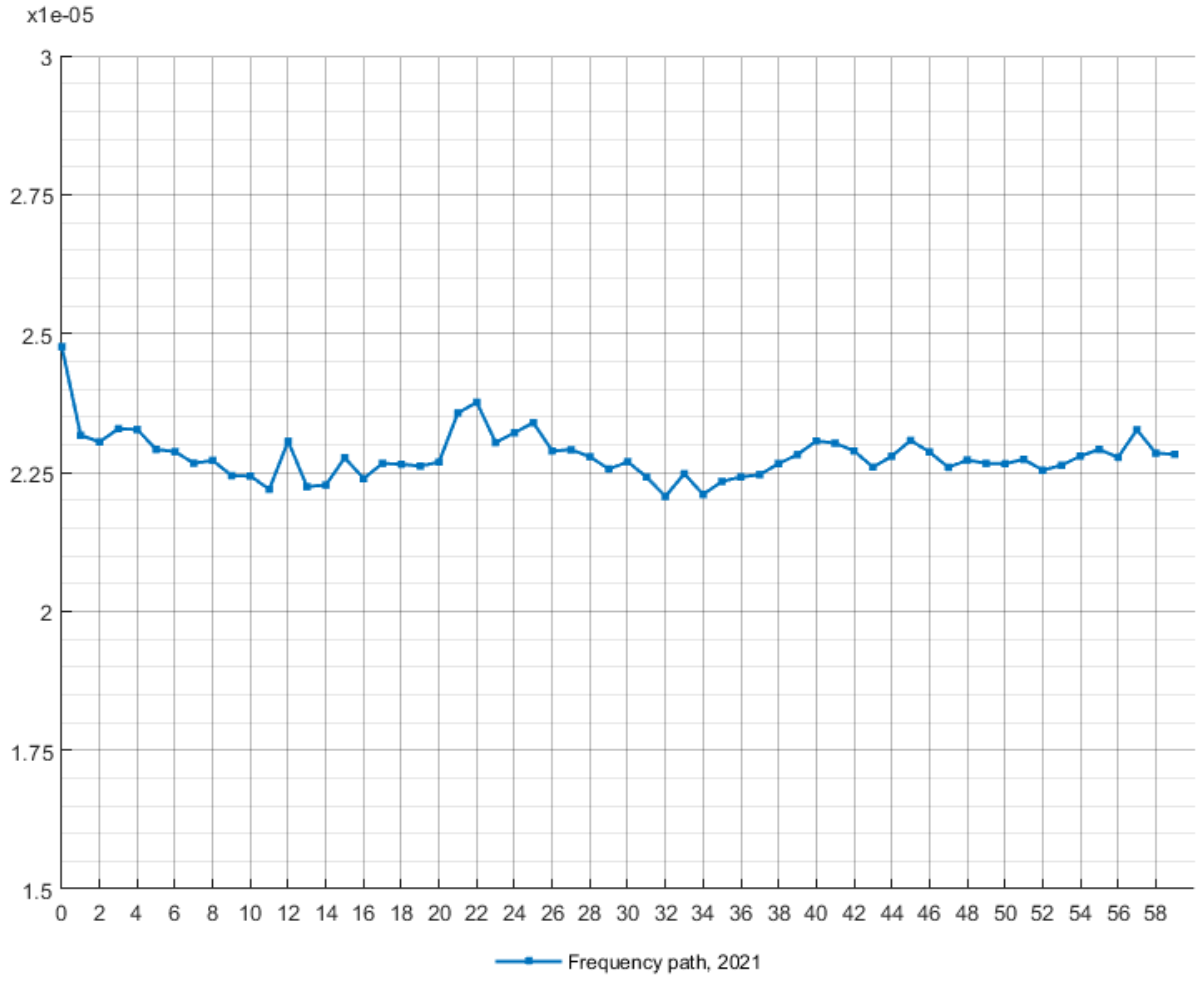


Figure 3.54 represents the average frequency path for every minute inside the hour. The amount of variation inside the hour has increased while comparin year 2021 to 2020, although both years peak within hour shift.

Figure 3.54. Length of the frequency path for every minute of the hour in 2021



3.8 Amount of frequency oscillation

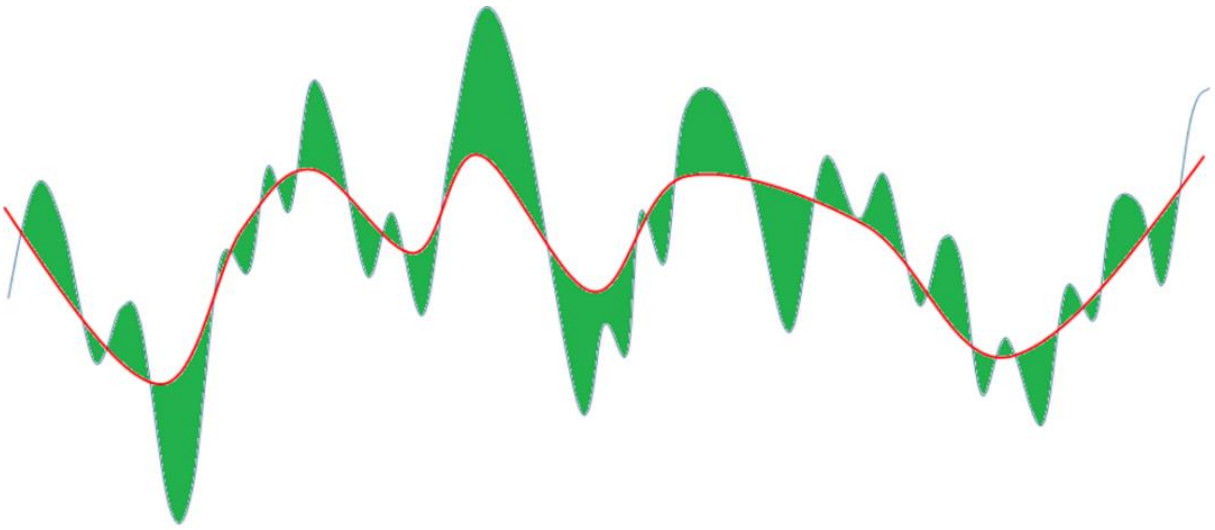
Frequency of the Nordic synchronous system oscillates constantly. Time period of the oscillation is approximately 40 to 90 seconds. This behavior is a natural characteristic of the system but it can be influenced through adequate settings of system reserves. Oscillation has an increasing effect on the 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 Fourier transform which can be used to decompose time series signals such as frequency measurements into sinusoidal frequency components. In other words, 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 time domain representation of the modified signal. [9]

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 [2,3,4,5,6,7], the frequency components were removed. Area between the filtered frequency signal and the original signal is used to represent the amount of oscillation. The approach is shown in Figure 3.55.

Figure 3.55. Frequency quality index: Amount of frequency oscillation [8]



Filtering band used in all studies was 30-240 s. Choice is based on comparison between different bands in the 2011 and 2012 oscillation analysis [9]. 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, Fourier transform was calculated for time intervals of one hour. The actually 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 measurement frequency had to stay at least at 4 Hz. If these requirements were not fulfilled that hour was skipped and removed from the calculations.

Figure 3.56. Frequency spectrum representing first 20 minutes of December 2012 (UTC+2). Green line corresponds to 40-90 s band and red line corresponds to 30-240 s band [9]

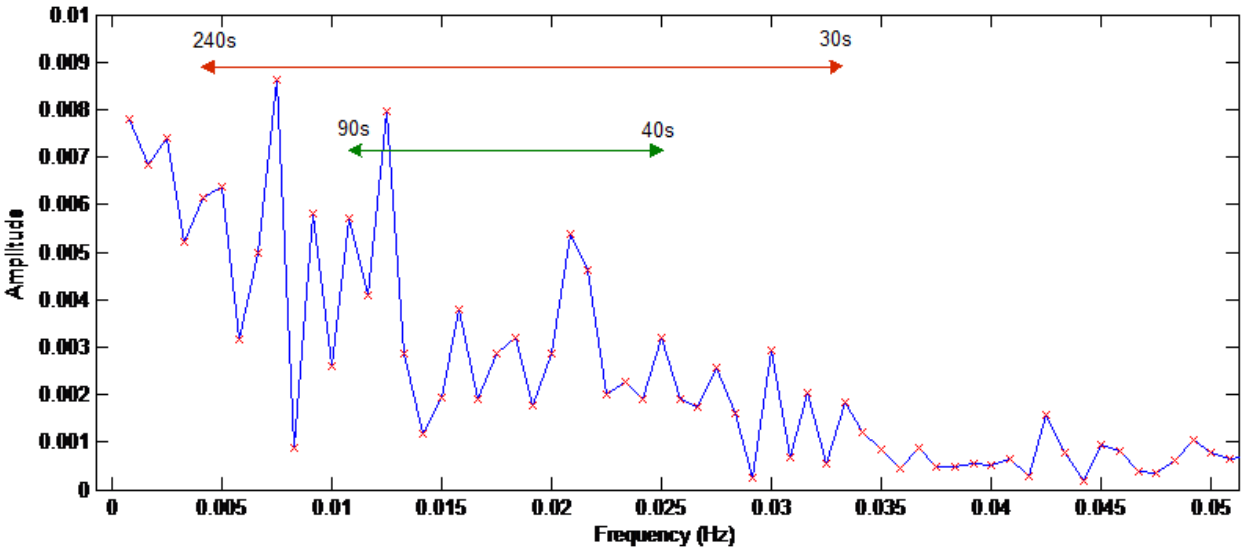
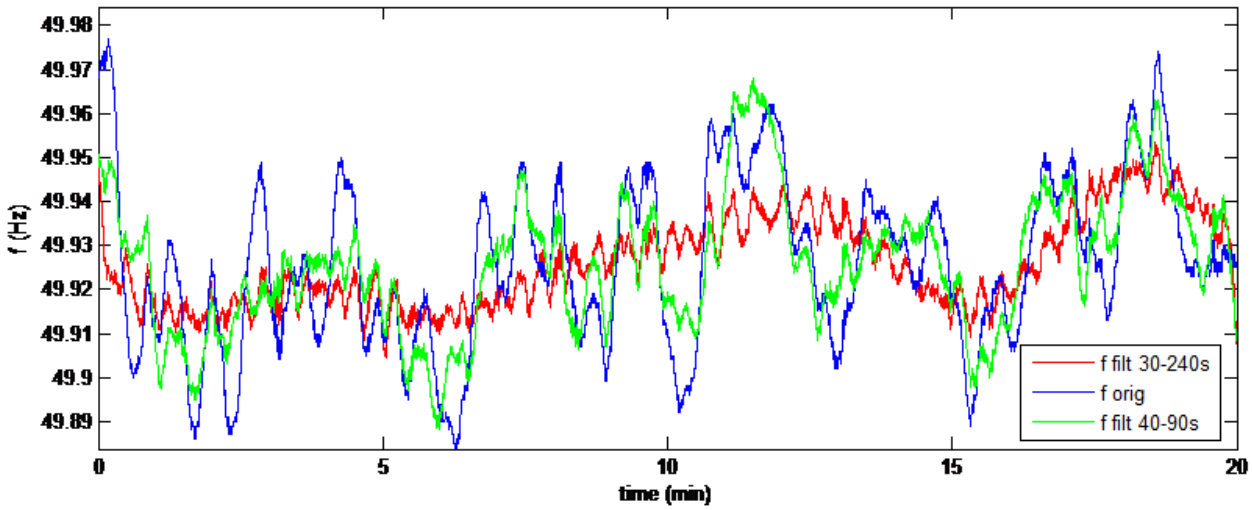


Figure 3.57. Original frequency (blue), frequency with 40-90 s band filtered (green) and frequency with 30-240 s band filtered (red). First 20 minutes of December 2012 are shown (UTC+2) [9]



3.8.2 Amount of oscillation

Figure 3.58 shows hourly values and 24 hour moving averages for the amount of oscillation in 2021. The 24 hour moving averages were calculated if there was enough eligible data for at least 12 hours in the frame of 24 hours.

Gaps in the following curves indicate that there were not enough eligible data for the calculations.

The 24 h moving average has had the highest values in end of the August. There is a visible increase in the average of the moving average between February and mid June. There is also a clear descending trend on the average of the moving average between August and November. Both of these trends differ from year 2020, where the value of moving average of oscillation stayed around 60 Hzs troughout the whole year. The amount of frequency oscillation has increased substantially from the previous years.

Figures 3.59 and 3.60 contain the previously mentioned 24 hour moving averages for years 2016-2018 and 2019-2021, respectively. In calculations of years 2016-2021, 12 hours of eligible data was required.

Figure 3.58. Amount of oscillation in 2021

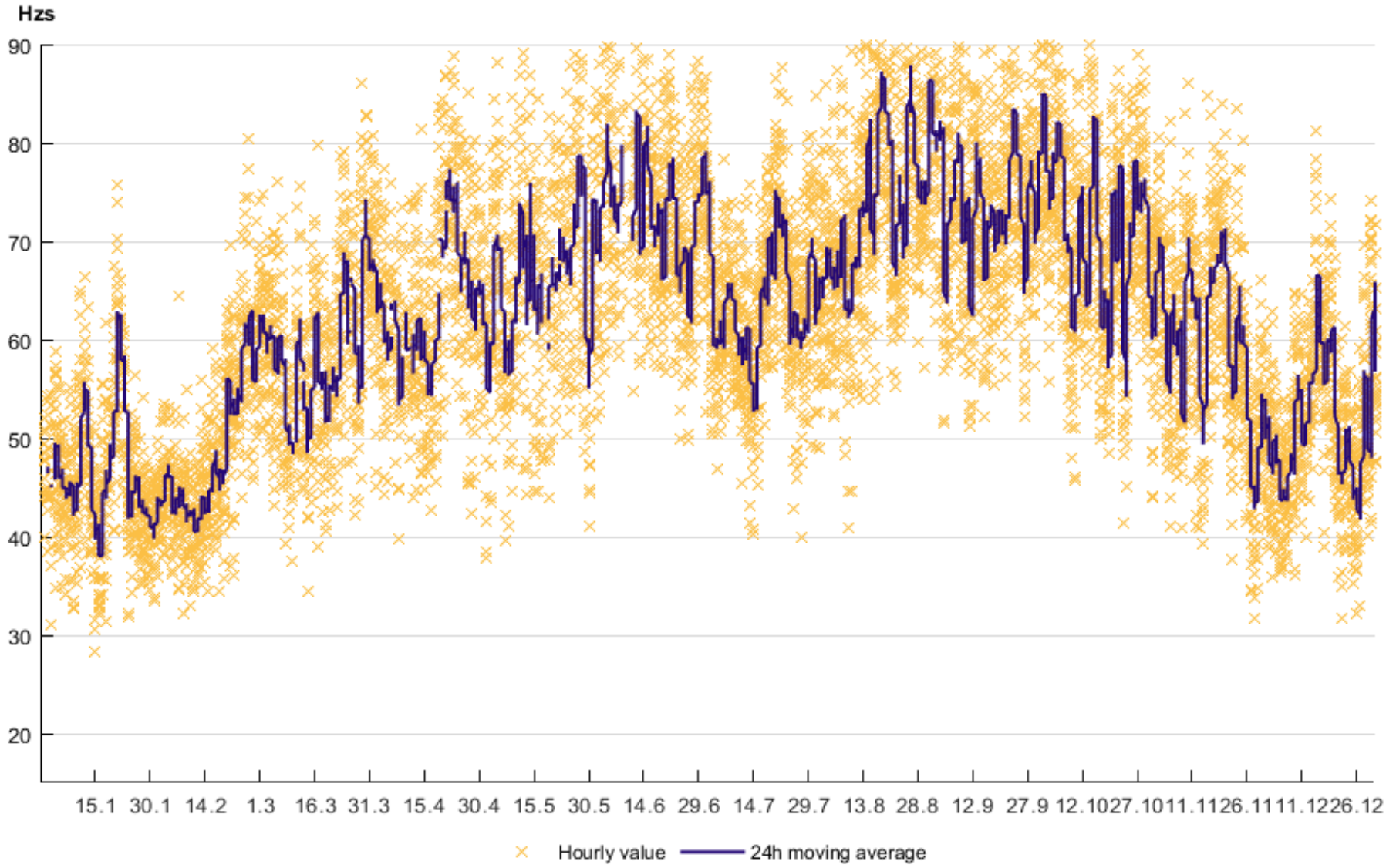


Figure 3.59. Amount of oscillation in 2016-2018

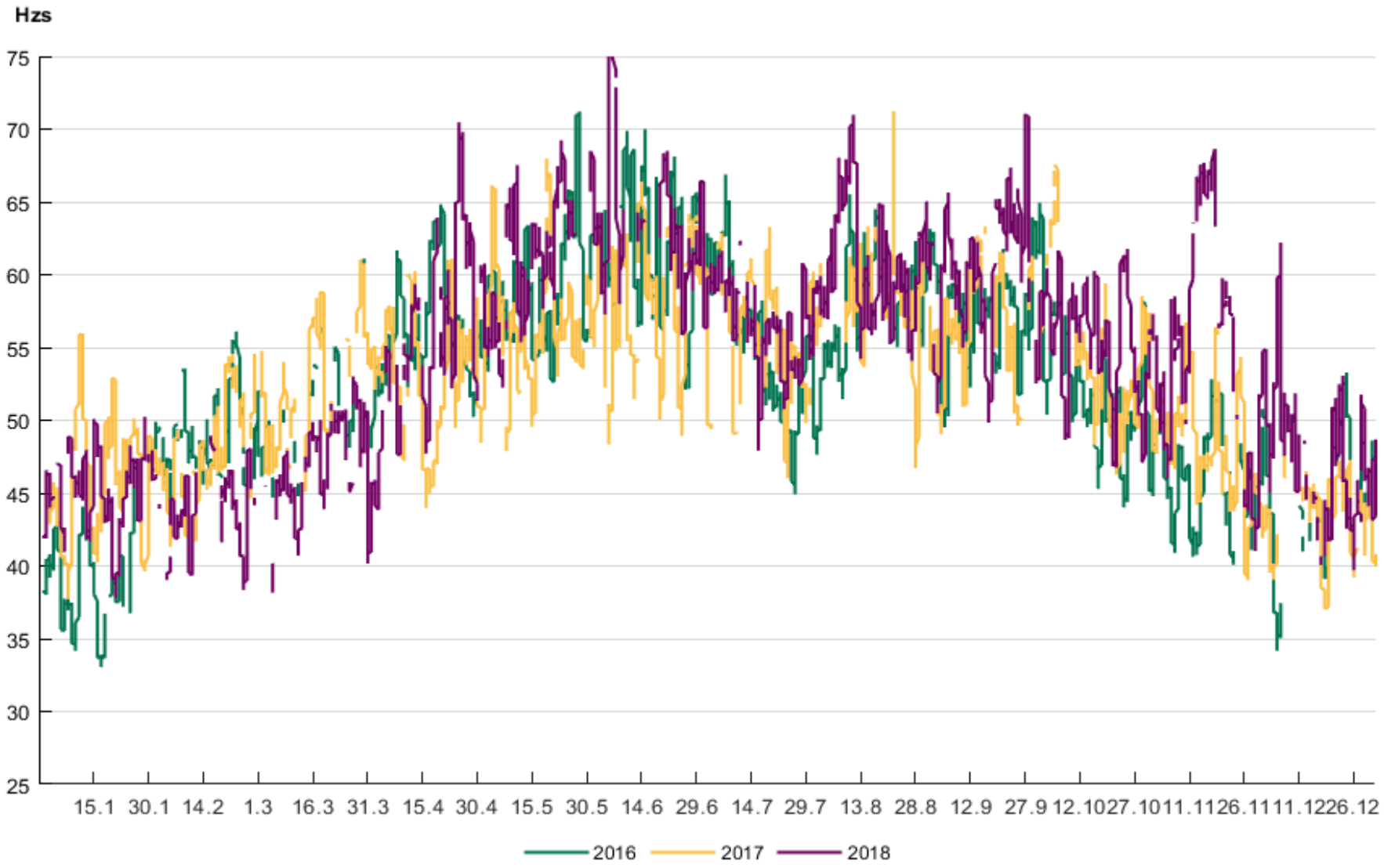
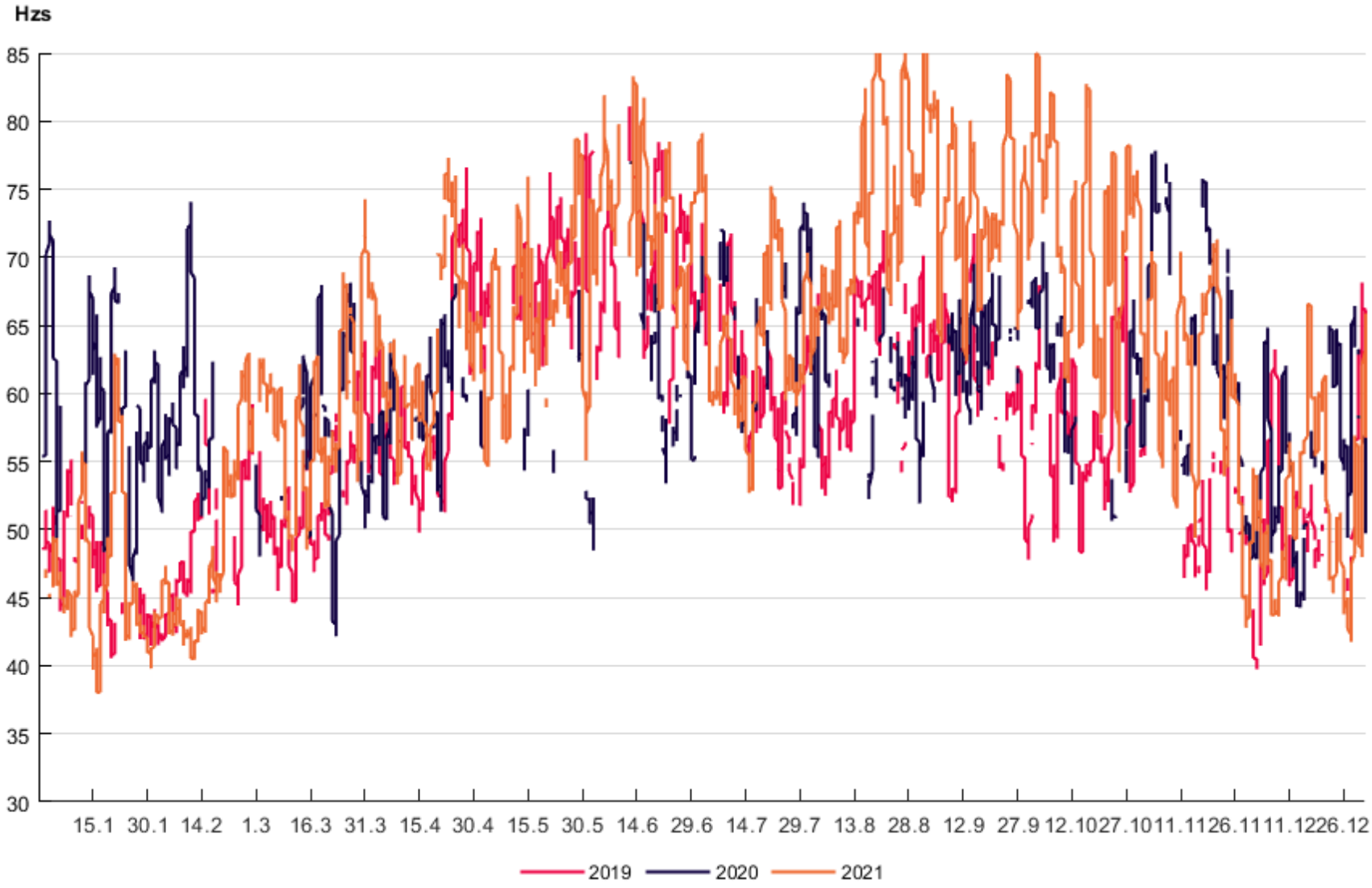


Figure 3.60. Amount of oscillation in 2019-2021



Mean value of the oscillation and standard deviation for each month from 2016 to 2021 are shown in Table 3.22 and 3.23. Figure 3.61 represents the same information in a visual form. The frequency has oscillated the most in June and from August to October. Frequency oscillated significantly more in 2021 in comparison to the previous years. The last three years have been among the worst years in terms of oscillation.

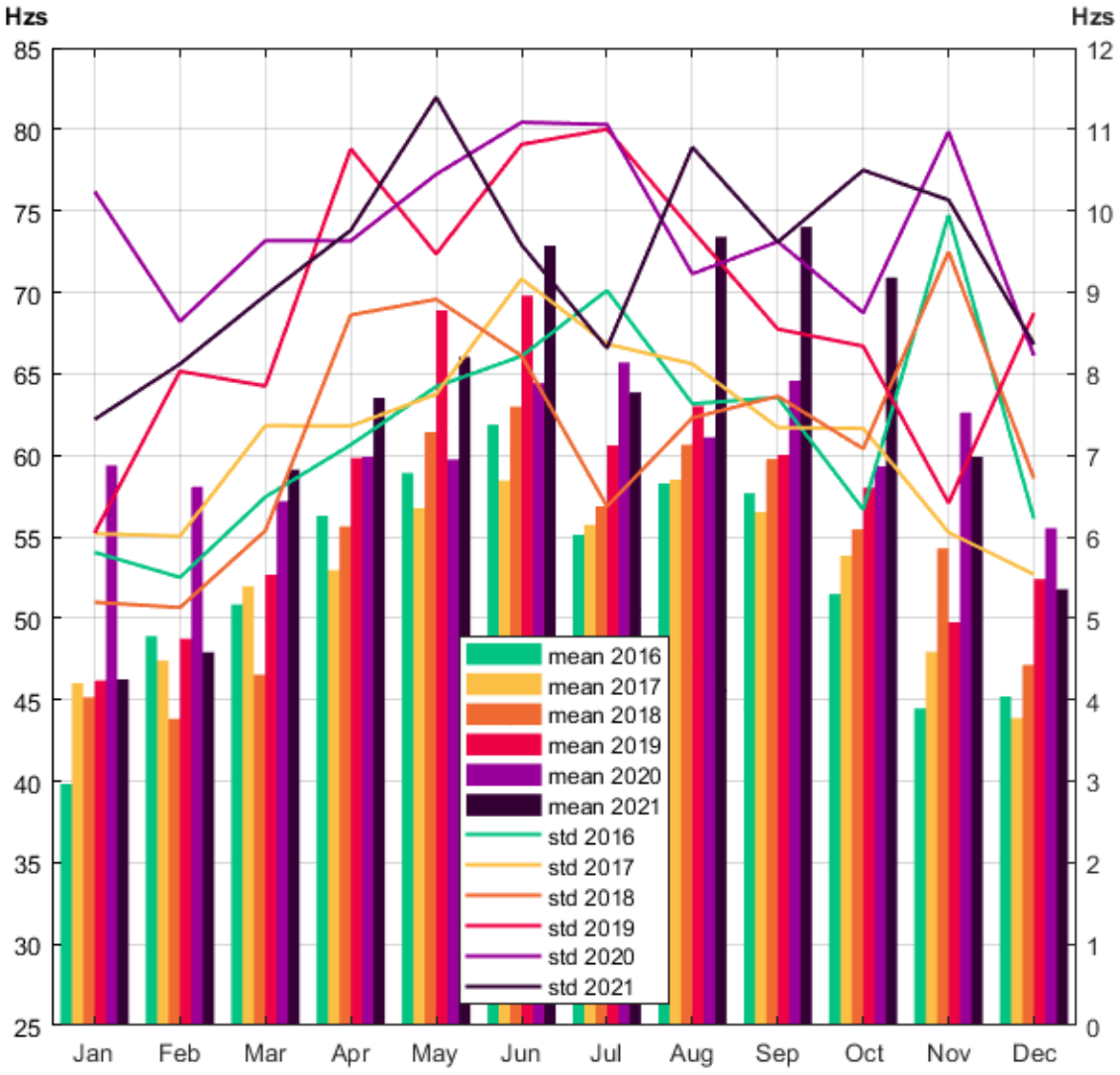
Table 3.22. Mean values and standard deviations for oscillation in years 2016-2018

	Mean value (Hzs)			**Standard deviation (Hzs)**		
Month	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**
January	39.8	46.0	45.1	5.8	6.0	5.2
February	48.9	47.4	43.8	5.5	6.0	5.1
March	50.8	52.0	46.5	6.5	7.4	6.1
April	56.3	52.9	55.6	7.1	7.4	8.7
May	58.9	56.8	61.4	7.8	7.7	8.9
June	61.9	58.4	63.0	8.2	9.2	8.2
July	55.1	55.7	56.9	9.0	8.4	6.4
August	58.3	58.5	60.6	7.6	8.1	7.5
September	57.7	56.5	59.8	7.7	7.3	7.7
October	51.5	53.8	55.4	6.3	7.3	7.1
November	44.5	47.9	54.3	9.9	6.1	9.5
December	45.2	43.9	47.1	6.2	5.5	6.7
Entire year	**52.4**	**52.5**	**54.1**	**7.3**	**7.2**	**7.3**

Table 3.23. Mean values and standard deviations for oscillation in years 2019-2021

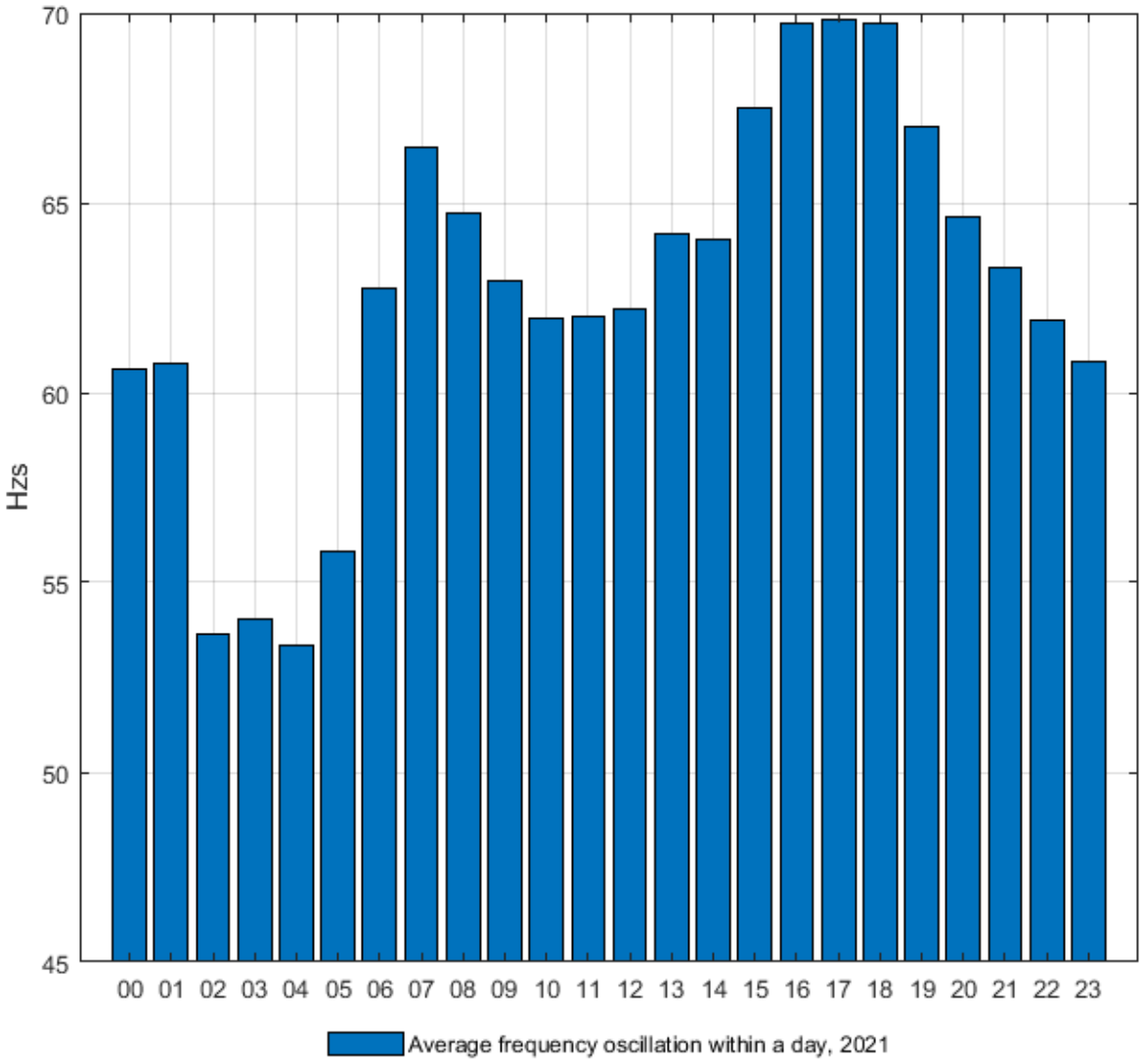
	Mean value (Hzs)			Standard deviation (Hzs)		
Month	**2019**	**2020**	**2021**	**2019**	**2020**	**2021**
January	46.2	59.4	46.2	6.0	10.2	7.4
February	48.7	58.1	47.9	8.0	8.6	8.1
March	52.7	57.2	59.1	7.8	9.6	9.0
April	59.8	59.9	63.5	10.8	9.6	9.8
May	68.9	59.7	66.0	9.5	10.4	11.4
June	69.8	64.4	72.9	10.8	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**

Figure 3.61. Mean values (left y-axis) and standard deviations (right y-axis) for oscillation in years 2016-2021



Average oscillation within a day in 2021 can be seen in fig 3.62. The amount of oscillation has peaked in the late afternoon. Least oscillation was experienced in the night from 2 am to 5 am.

Figure 3.62**. **Average frequency oscillation within a day in 2021

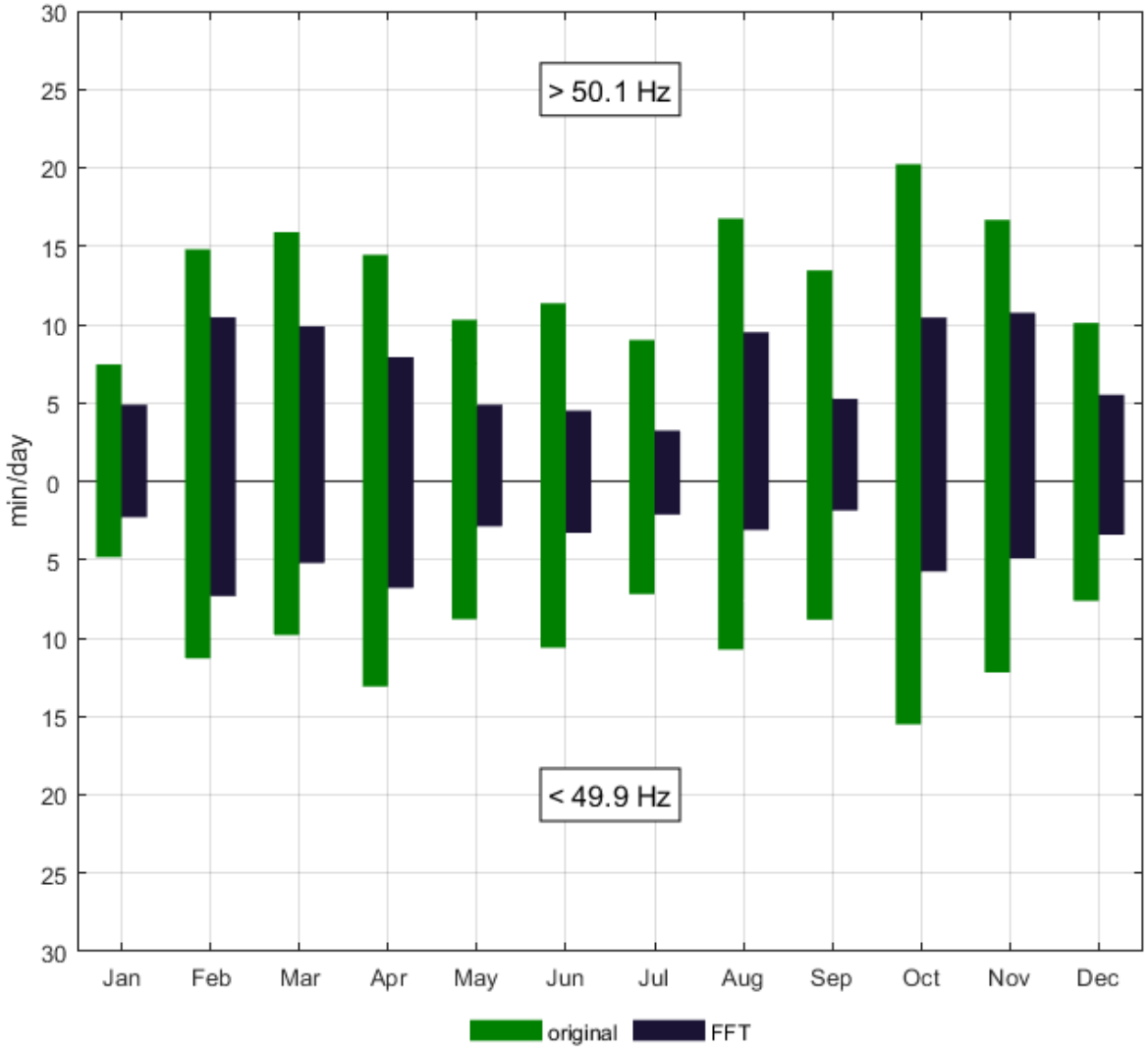


3.8.3 Influence of oscillation on frequency variations

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 2021 without filtering and after applying FFT-filtering. Figure 3.63 shows the average only for minutes per day outside the standard frequency range that had enough consecutive samples for one hour periods for the FFT-algorithm.

Figure 3.63. Average time per day outside the standard frequency range in 2021



In Figure 3.64, the reduction of time outside the standard frequency range through filtering is presented as percentages of the original values. The results show that filtering leads to significant reduction in time outside the standard frequency range. For September, the reduction of time outside the standard frequency range is close to 80 % with under frequencies. For summer months from June to August, the reduction of under frequencies is close 70 %.

Figure 3.64. Reduction in time per month outside the standard frequency range after filtering in 2021

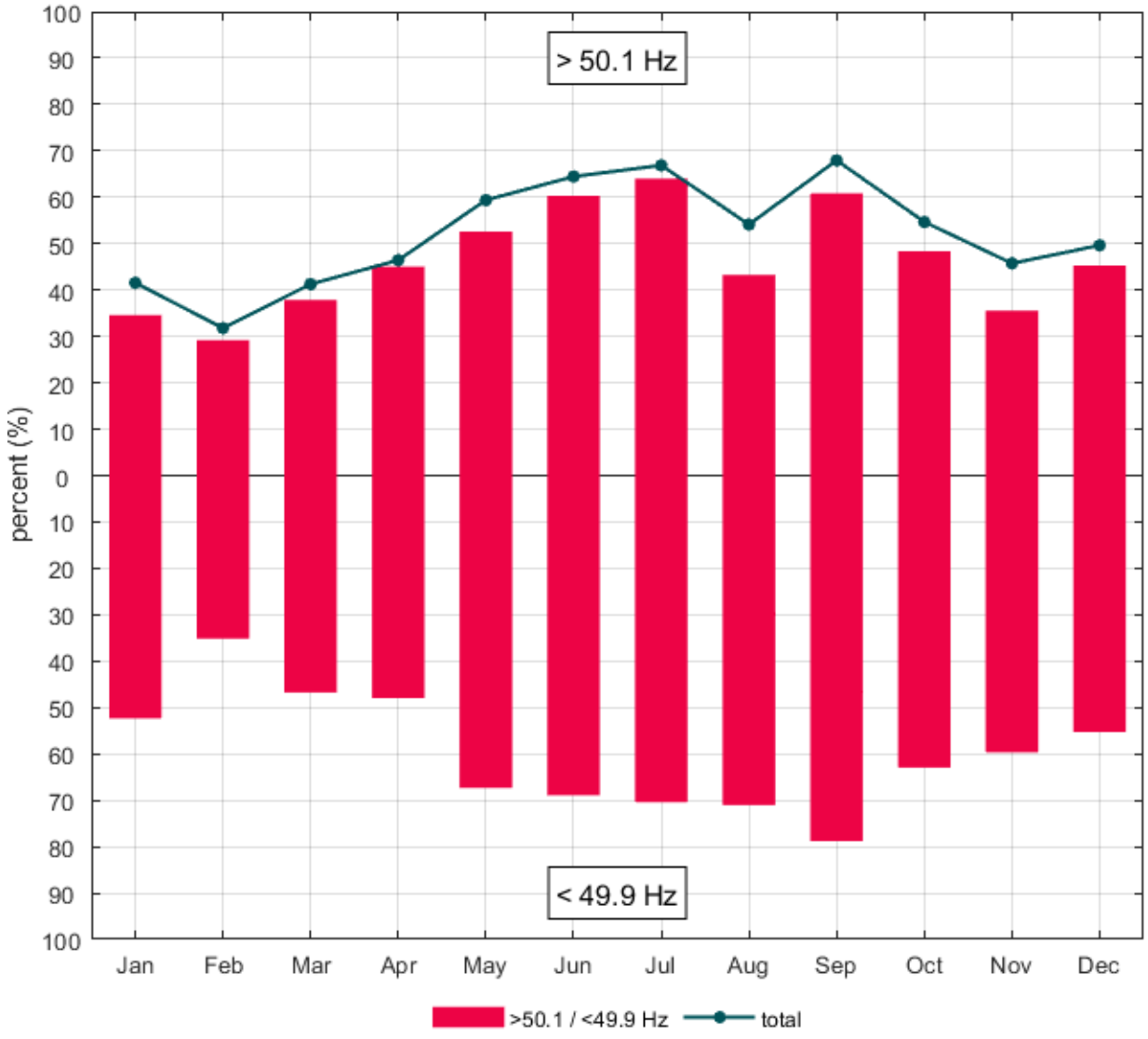
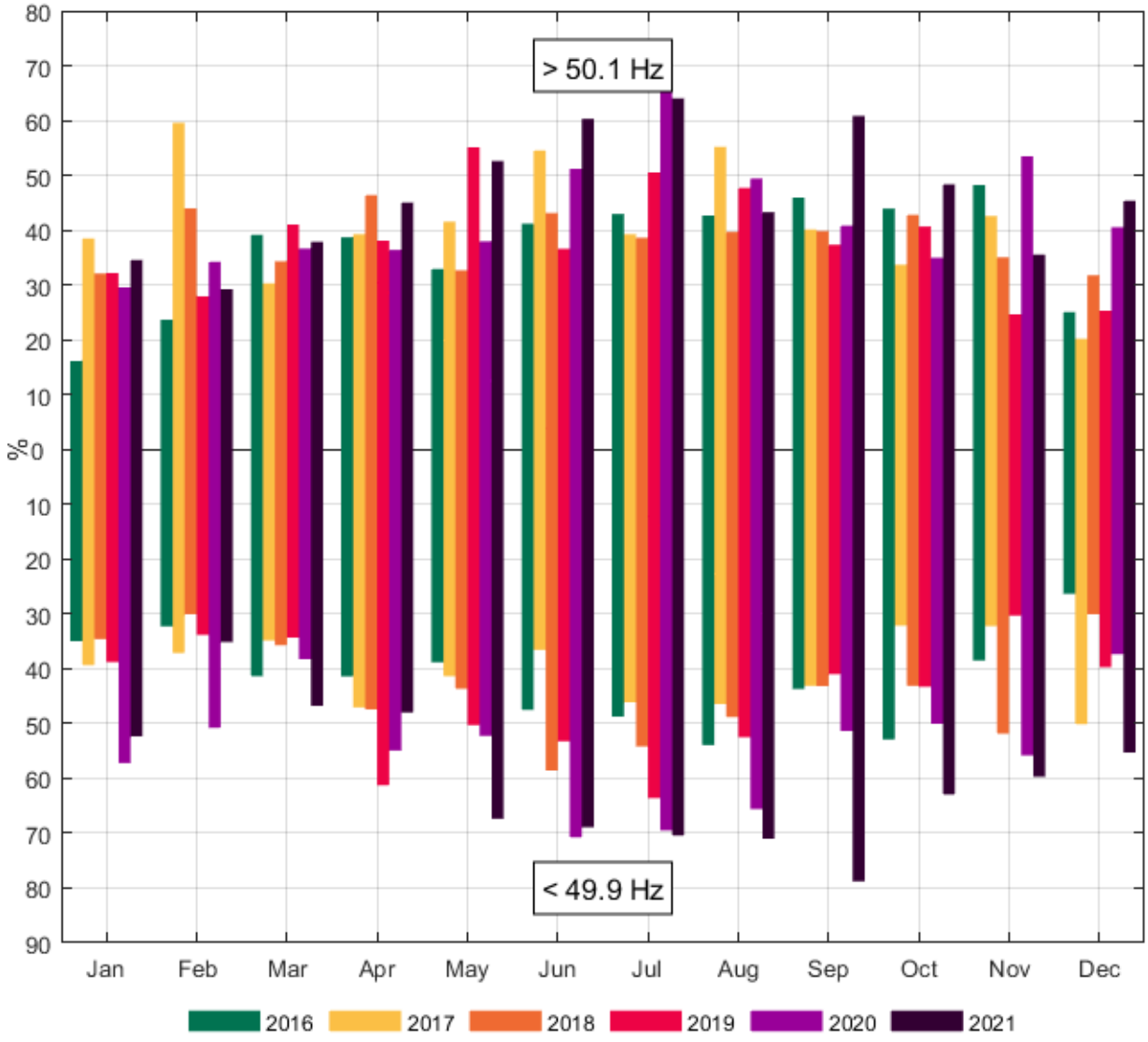


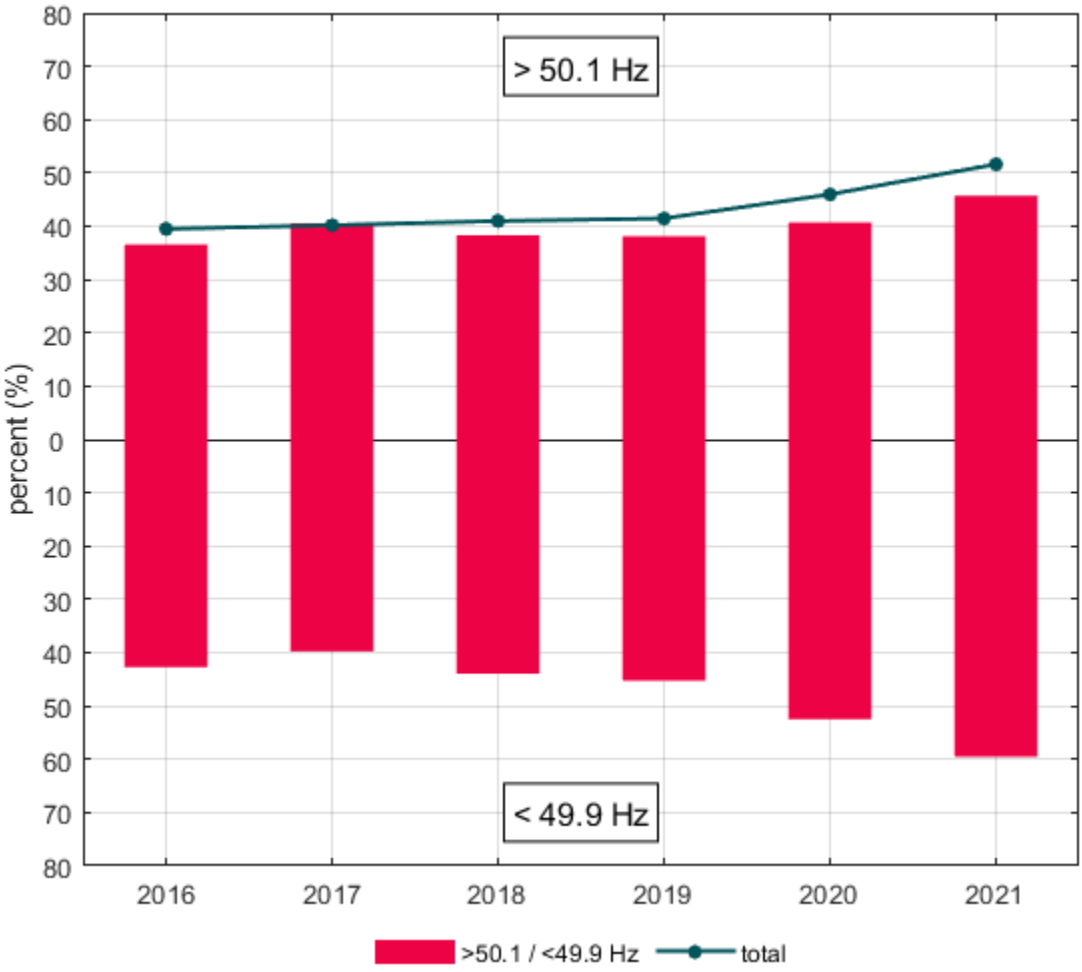
Figure 3.65 represents the reduction in time outside the standard frequency range in percentages month by month for years 2016 to 2021.

Figure 3.65. Reduction in time per month outside the standard frequency range after filtering in years 2016-2021



In addition to the monthly values presented in the previous figure, results for the entire year in 2016-2021 are shown below in Figure 3.66. Filtering the oscillation reduces duration of frequency deviations around 50 % in year 2021. Slight yearly growth in reduction can bee seen from 2016 onwards. The reduction is about 15% more for under frequency deviations in year 2021, which has increased from the previous years.

Figure 3.66. Reduction in time outside the standard frequency range after filtering for years 2016-2021



3.9 Frequency step around the hour shift

The frequency step around the hour shift is defined by the difference between the highest and the 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 2021. Of the total samples in a period, the 1st, 5th, 10th, 50th, 90th, 95th and 99th percentile 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 [8]

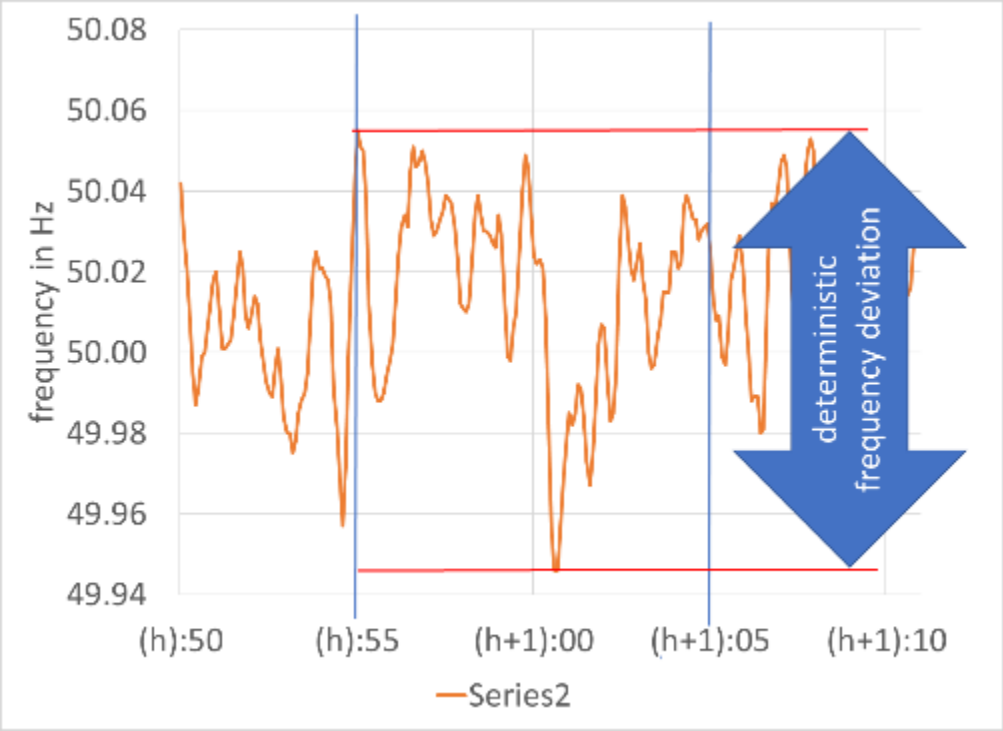


Figure 3.68 represents the deterministic frequency deviation per month in 2021. The 50th percentile stays below zero for the entire year, which indicates that the highest frequency took place before the lowest in more than half of the hour shifts.

***Figure 3.68**. The 1st, 5th, 10th, 50th, 90th, 95th, and 99th percentile of deterministic frequency deviation for every month in 2021*

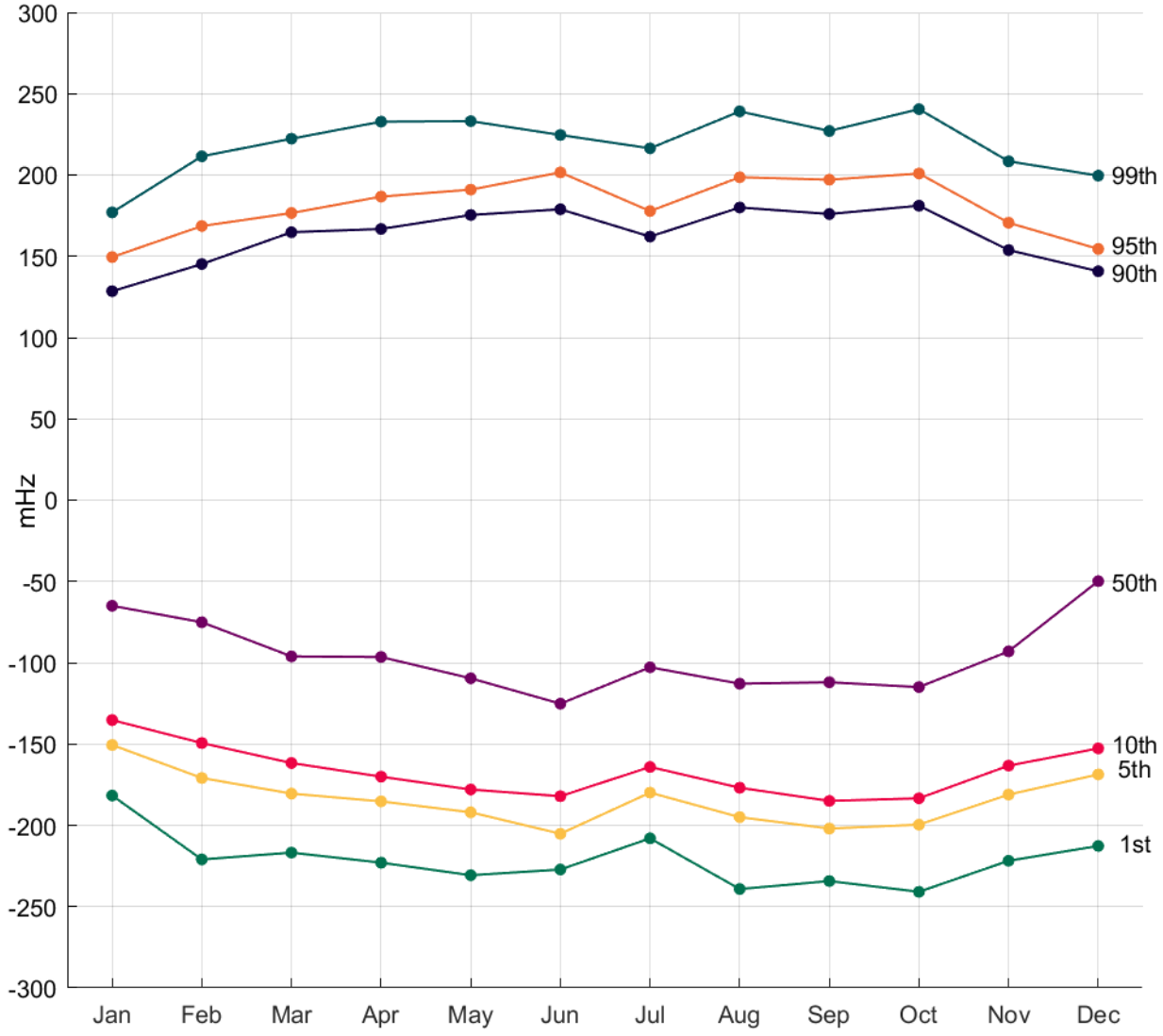
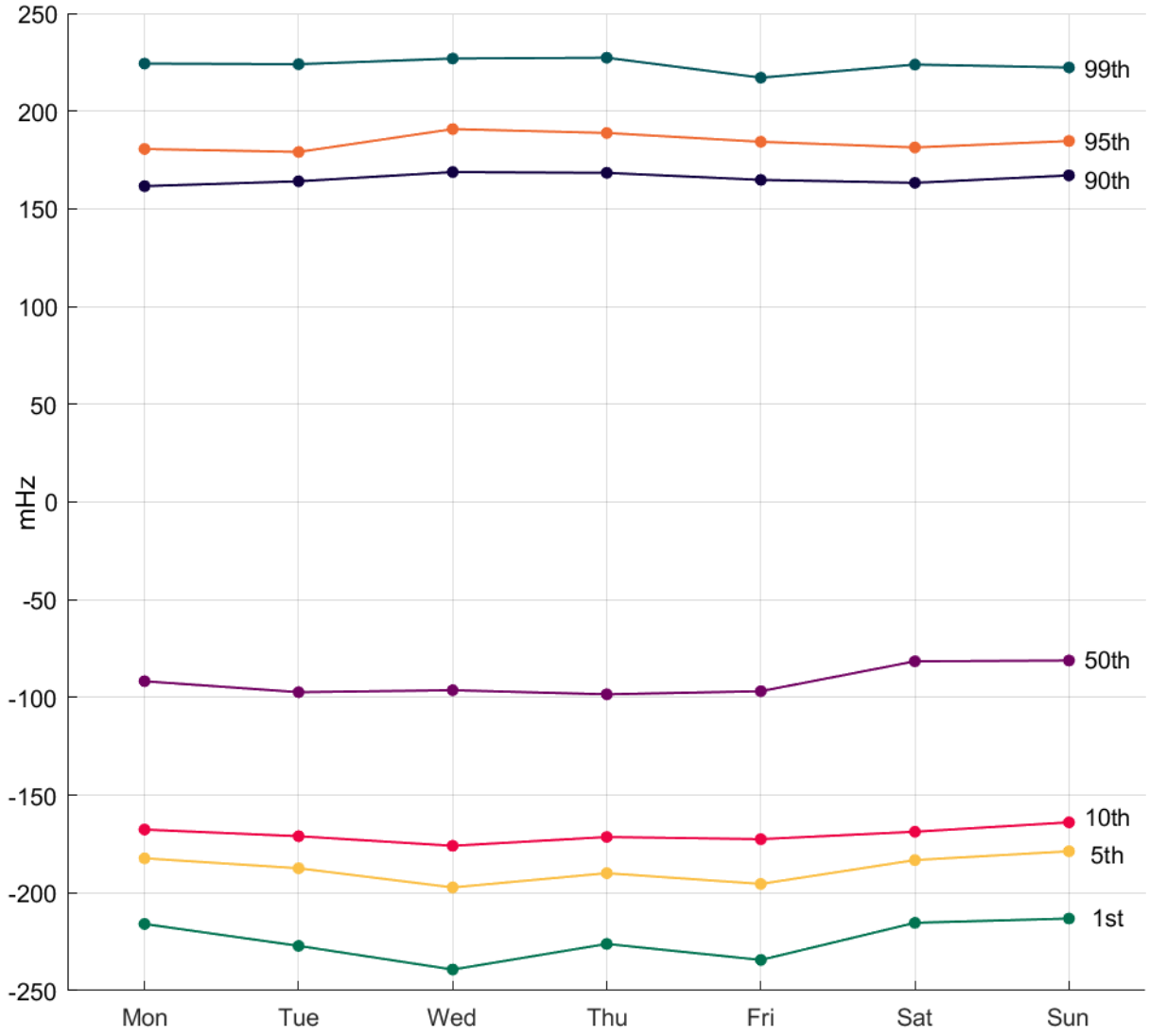


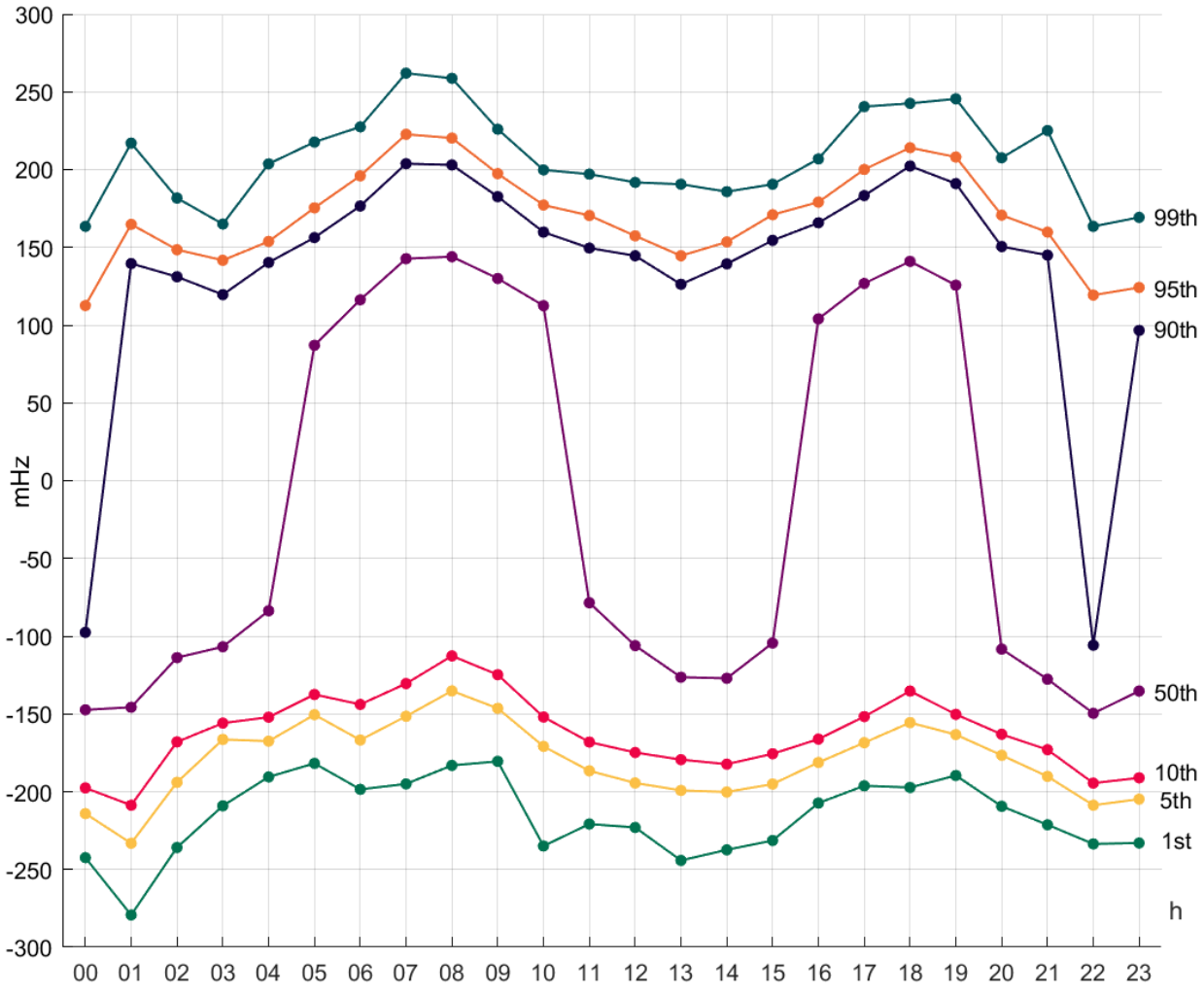
Figure 3.69 shows the percentiles around the hour shift for every day of the week in 2021. The 1st, 5th and 50th percentile have been slightly higher on the weekends.

***Figure 3.69**. The 1st, 5th, 10th, 50th, 90th, 95th, and 99th percentile of deterministic frequency deviation for every day of the week in 2021*



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 morning hours from 5 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 those hours.

***Figure 3.70**. The 1st, 5th, 10th, 50th, 90th, 95th, and 99th percentile of deterministic frequency deviation for every hour of the day in 2021*



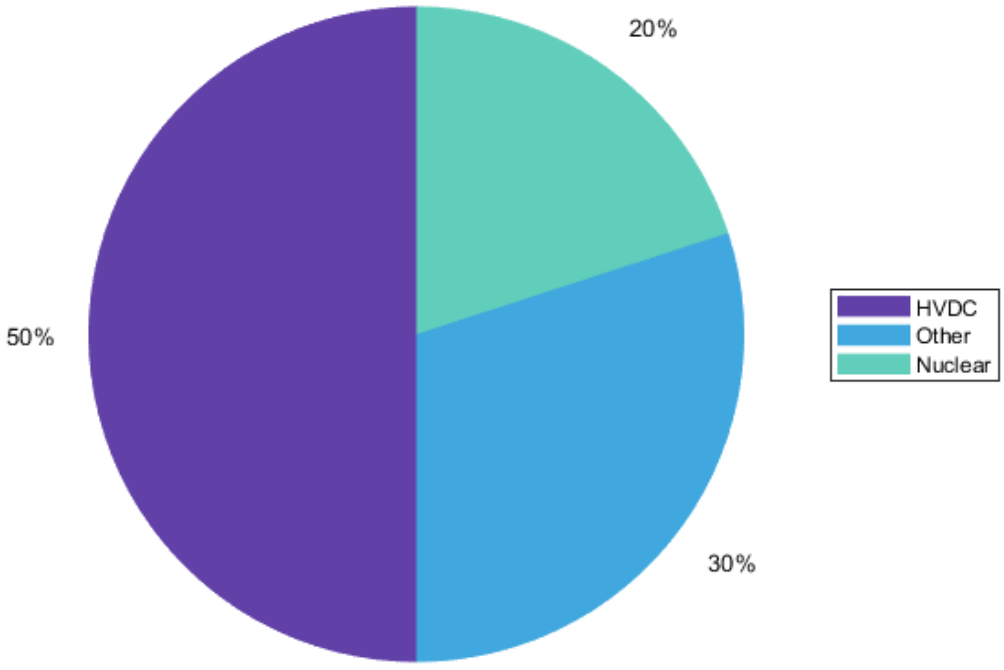
Chapter 4. Frequency disturbances exceeding 300 mHz frequency deviation

This chapter offers information of the major frequency disturbances in the Nordic synchronous system in the year 2021. Over 300 mHz frequency deviations are included.

Measurement data used for this study is from Fingrid's PMU located in Kangasala. Measurement frequency for the PMU was 10 Hz. This data describes at a fair accuracy frequency of the whole Nordic system.

Five of the over ±300 mHz disturbances were caused by failures in HVDC links, two by nuclear power plants and rest of them by other reasons. Figure 4.1 represents the share of factors causing over 300 mHz deviations. In 2021 the number of 300 mHz deviations doubled from the previous year.

Figure 4.1. Shares of factors causing over 300 mHz disturbances in the Nordic synchronous system in 2021



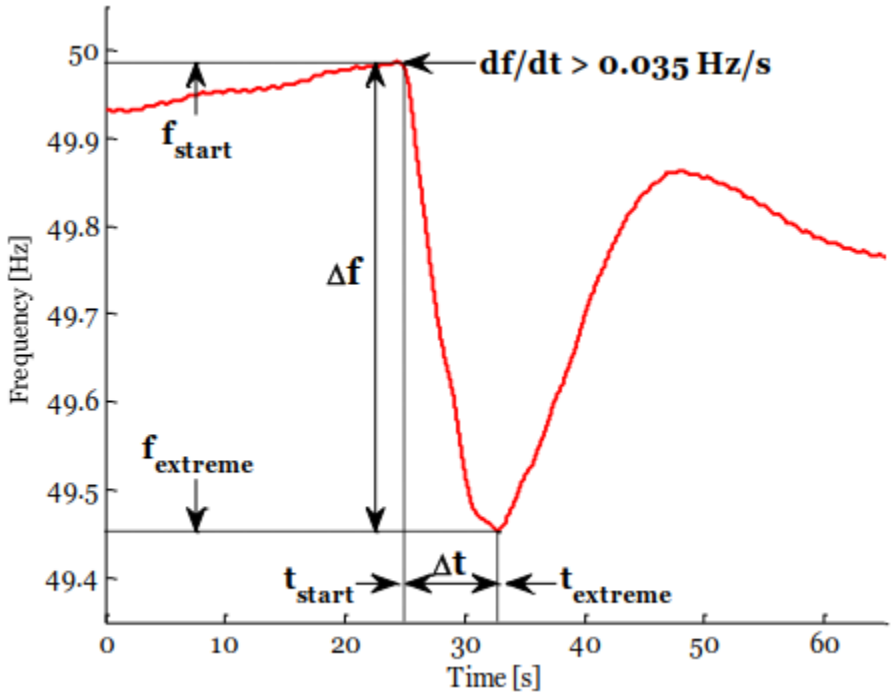
The largest over and under frequency deviations were caused by faults in HVDC links. First, an under frequency deviation of -0.444 Hz was reported on 2 September. The largest over frequency deviation occurred on 30 June and its amplitude was 0.376 Hz.

The following part of the chapter will go into more detail on every disturbance that took place in 2021. This will include figures of the frequency when the major disturbances have occurred and information about the disturbance in table form. Table 4.1 contains a short summary of the studied disturbances. Times presented are in the Finnish time (UTC+2 / UTC+3 in the summer). The information given are 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 frequency after disturbance = $| (f_{extreme3} - f_{extreme2}) / (f_{extreme2} - f_{extreme}) |$
- Frequency Bias Factor (FBF) = $\Delta P / \Delta f_{steady\ state}$

Frequency response indicators mentioned above are visually illustrated in Figure 4.2.

Figure 4.2. Graphical representation of frequency response indicators [10]



Some of the disturbances included have Δf-values below 300 mHz. Δf is defined to be the absolute value between f_{start} and $f_{extreme}$ as seen in Figure 4.2. In some cases there was a frequency deviation at a later moment that was higher than Δf and exceeded the ±300 mHz deviation. Those cases were included also. [11]

For a frequency disturbance to be reported as an over 300 mHz disturbance the frequency gradient (a momentary change in frequency divided by the change in time) must be over 0.035 Hz/s in the beginning of the disturbance as seen in Figure 4.2. In year 2021, one 300 mHz disturbance was excluded because of too small a gradient.

Kinetic energy (E_k) is an estimation of the rotation energy of synchronously connected generators in the Nordic synchronous system. Kinetic energy is related to the system inertia which describes the system's ability to oppose changes in frequency. Higher kinetic energy provides higher inertia and therefore better ability to oppose frequency deviations. [11] More detailed descriptions of the events listed in Table 4.1 are presented afterwards in Figures 4.3-12 and Tables 4.2-11.

Table 4.1. List of disturbance events in 2021

Event date	Δf (Hz)	ΔP (MW)	Δt (s)	E_k (GWs)	Cause	Page
07-Feb-2021 08:55:13	-0.368	1399	8.6	210	HVDC	105
07-Jun-2021 16:24:01	-0.300	539	9.0	174	Other	106
19-Jun-2021 11:16:19	-0.325	809	10.7	182	Nuclear	107
30-Jun-2021 18:41:12	0.376	683	8.2	188	HVDC	108
04-Jul-2021 09:13:45	-0.416	1250	7.1	174	Other	109
04-Jul-2021 14:49:31	-0.298	850	9.6	173	Other	110
17-Jul-2021 16:13:39	-0.311	639	6.2	135	HVDC	111
02-Sep-2021 13:04:14	-0.444	1234	6.2	165	HVDC	112
16-Oct-2021 22:27:22	0.322	695	8.3	184	HVDC	113
29-Dec-2021 19:14:21	-0.333	1168	7.4	240	Nuclear	114

Figure 4.3. Disturbance 07-Feb-2021 08:55:13

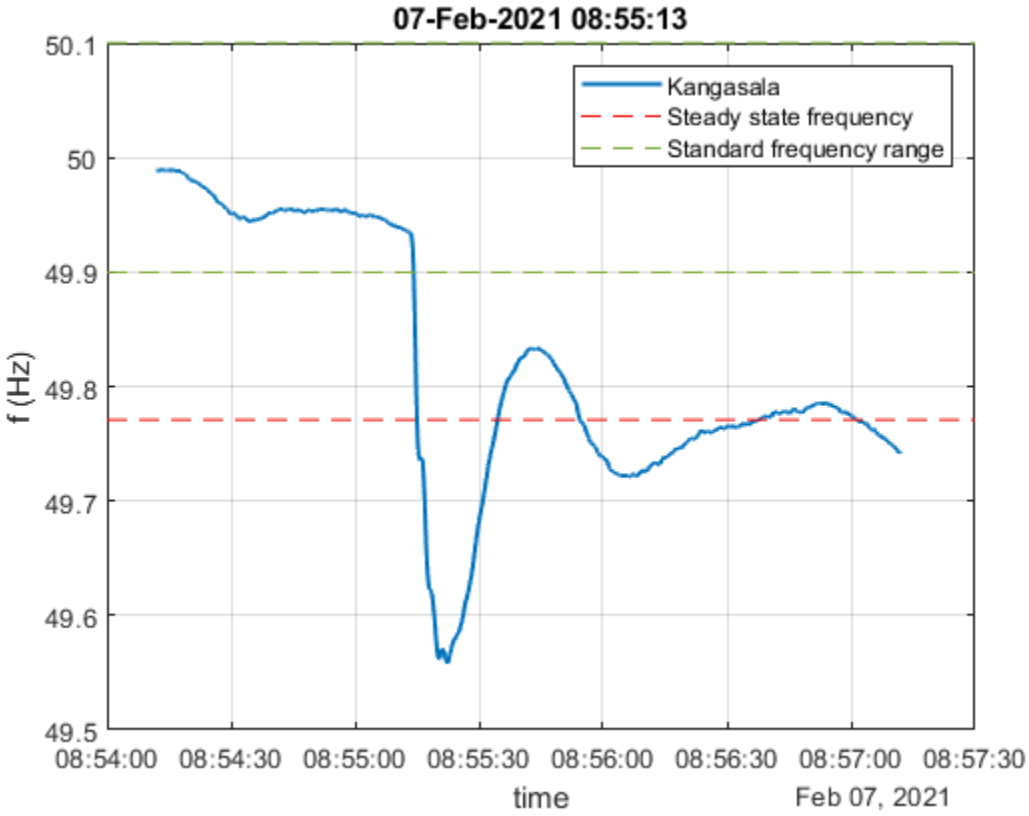


Table 4.2. Disturbance 07-Feb-2021 08:55:13

Date		**07-Feb-2021 08:55:13**	
f_{start}	49.927 Hz	$f_{steady\ state}$	49.771 Hz
$f_{extreme}$	49.559 Hz	$\Delta f_{steady\ state}$	0.156 Hz
Δf	-0.368 Hz	$f_{extreme2}$	49.833 Hz
Δt	8.6 s	$f_{extreme3}$	49.721 Hz
ΔP	1399 MW	damping	40.78 %
E_k	210 GWs	FBF	8954 MW/Hz
cause		HVDC	

Figure 4.4. Disturbance 07-Jun-2021 16:24:01

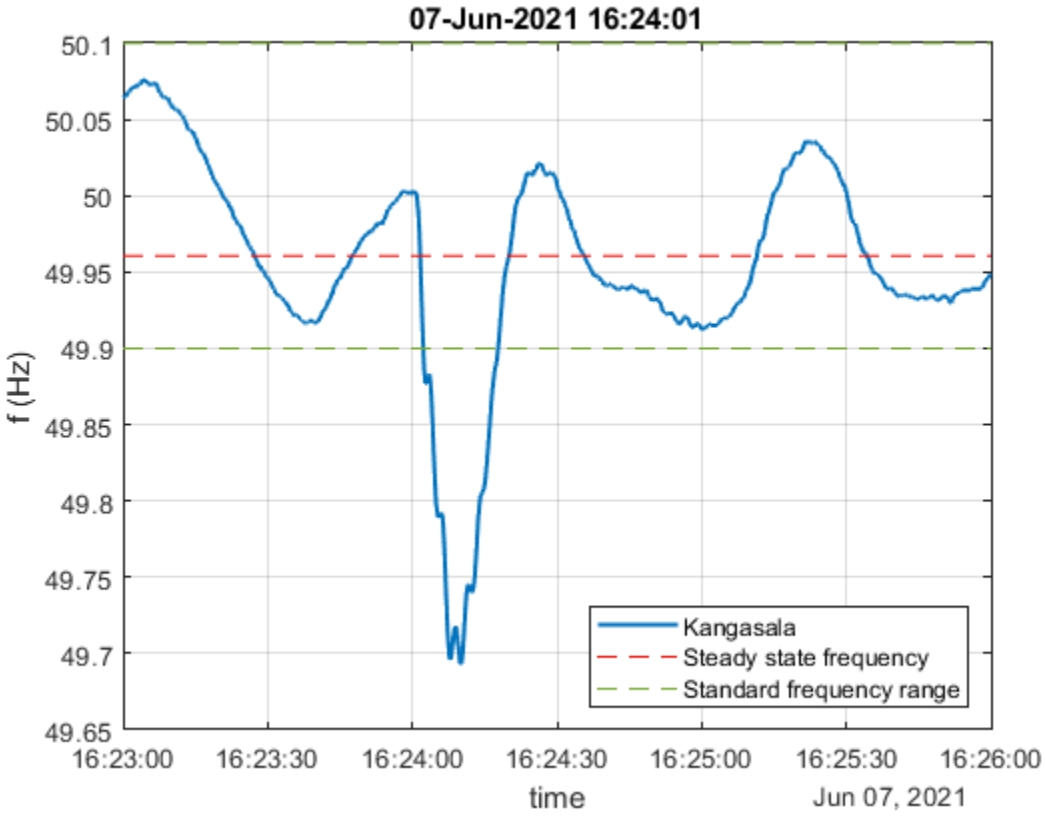


Table 4.3. Disturbance 07-Jun-2021 16:24:01

Date		**07-Jun-2021 16:24:01**	
f_{start}	49.994 Hz	$f_{steady\ state}$	49.961 Hz
$f_{extreme}$	49.694 Hz	$\Delta f_{steady\ state}$	0.033 Hz
Δf	-0.300 Hz	$f_{extreme2}$	50.021 Hz
Δt	9.0 s	$f_{extreme3}$	49.912 Hz
ΔP	539 MW	damping	33.23 %
E_k	174 GWs	FBF	16272 MW/Hz
cause		Other	

Figure 4.5. Disturbance 19-Jun-2021 11:16:19

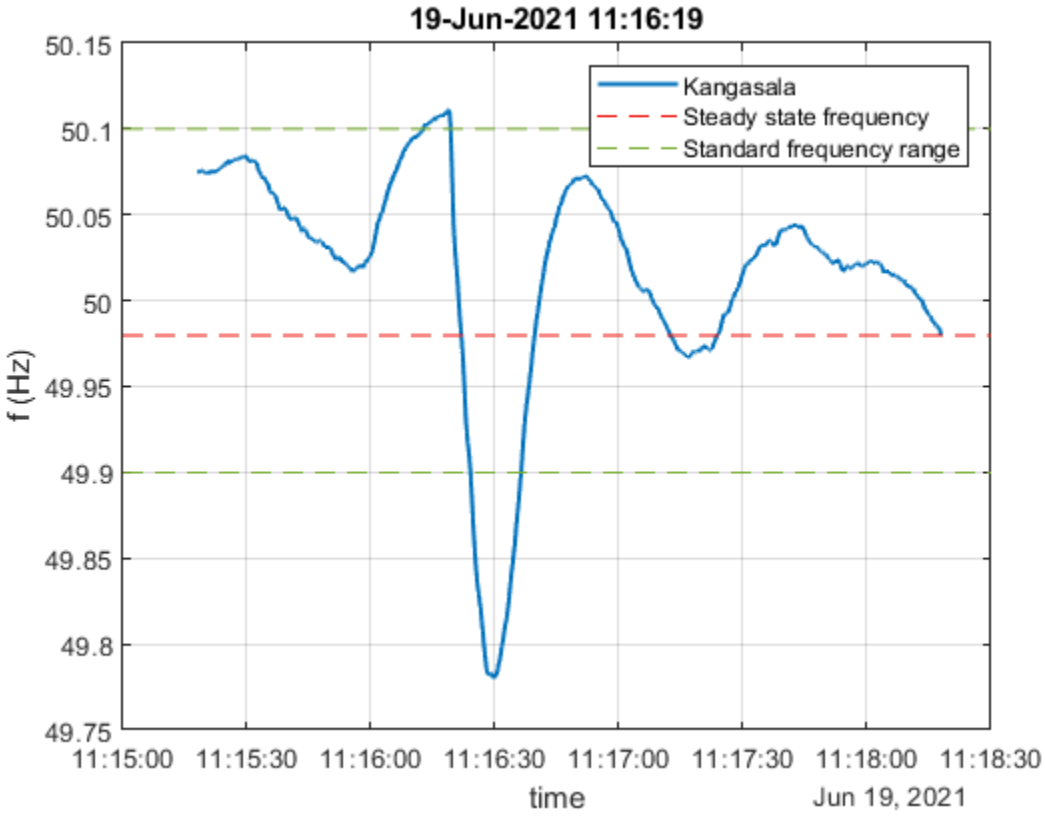


Table 4.4. Disturbance 19-Jun-2021 11:16:19

Date		**19-Jun-2021 11:16:19**	
f_{start}	50.106 Hz	$f_{steady\ state}$	49.980 Hz
$f_{extreme}$	49.780 Hz	$\Delta f_{steady\ state}$	0.126 Hz
Δf	-0.325 Hz	$f_{extreme2}$	50.073 Hz
Δt	10.7 s	$f_{extreme3}$	49.967 Hz
ΔP	809 MW	damping	36.16 %
E_k	182 GWs	FBF	6421 MW/Hz
cause		Nuclear	

Figure 4.6. Disturbance 30-Jun-2021 18:41:12

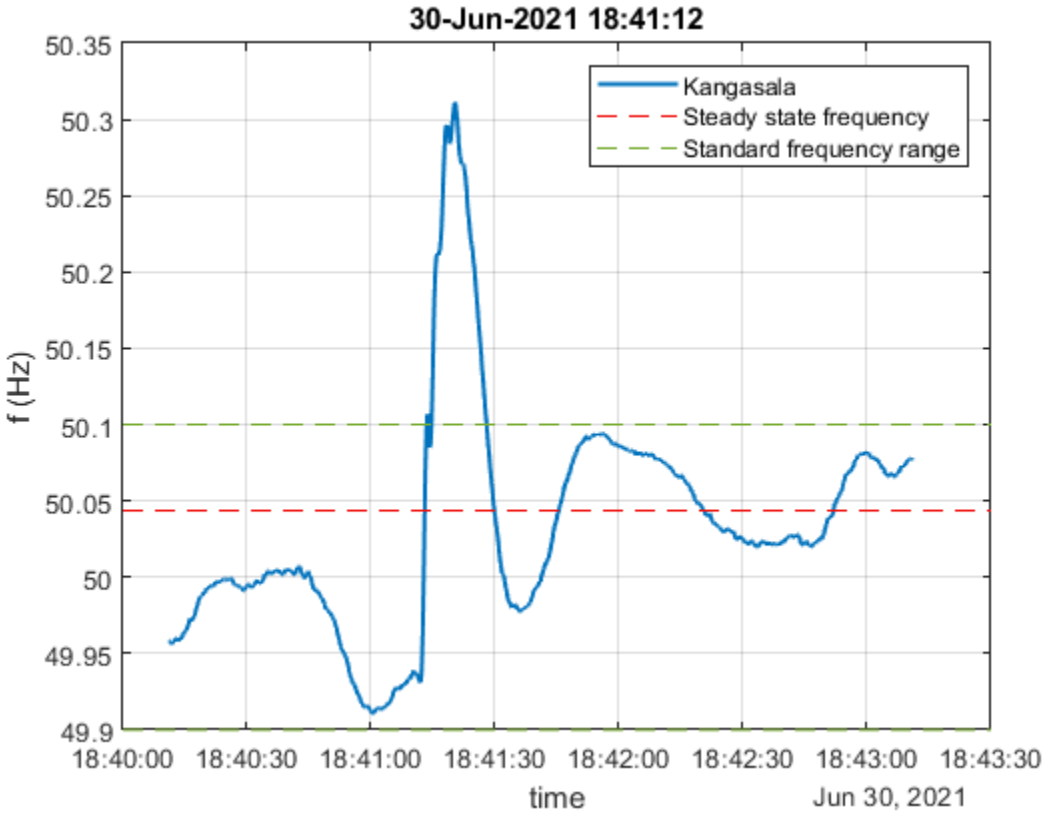


Table 4.5. Disturbance 30-Jun-2021 18:41:12

Date		**30-Jun-2021 18:41:12**	
f_{start}	49.934 Hz	$f_{steady\ state}$	50.044 Hz
$f_{extreme}$	50.310 Hz	$\Delta f_{steady\ state}$	0.110 Hz
Δf	0.376 Hz	$f_{extreme2}$	49.978 Hz
Δt	8.2 s	$f_{extreme3}$	50.094 Hz
ΔP	683 MW	damping	34.94 %
E_k	188 GWs	FBF	6231 MW/Hz
cause		HVDC	

Figure 4.7. Disturbance 04-Jul-2021 09:13:45

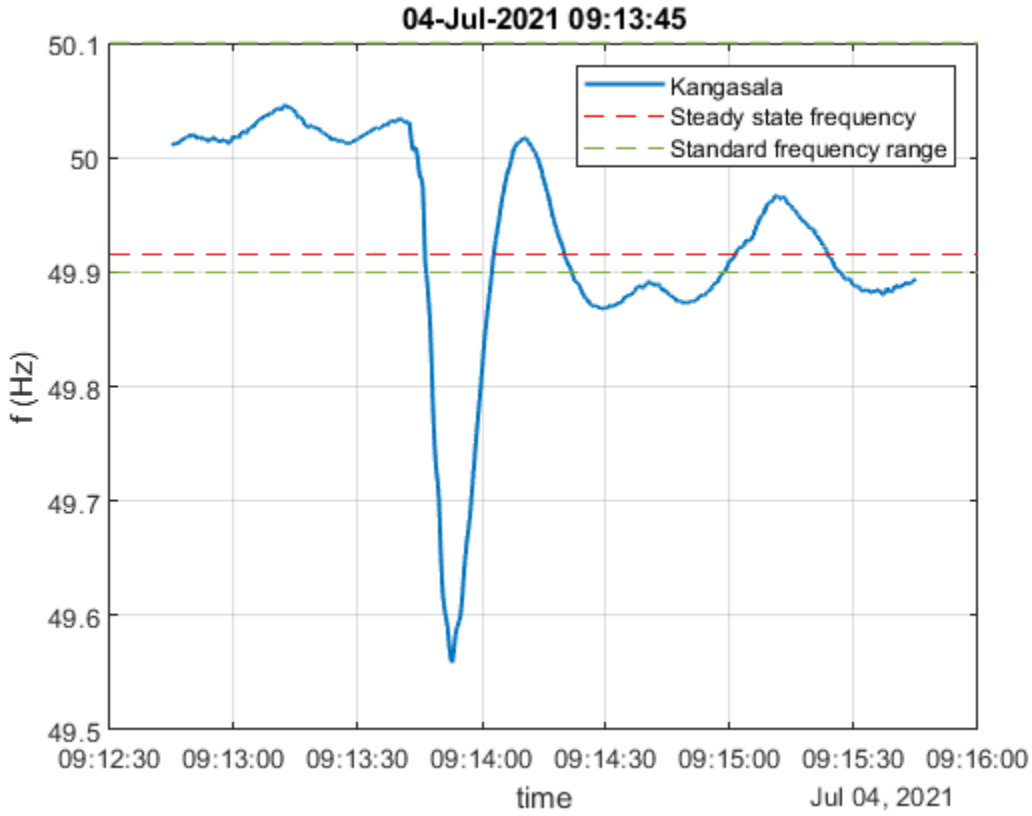


Table 4.6. Disturbance 04-Jul-2021 09:13:45

Date		**04-Jul-2021 09:13:45**	
f_{start}	49.975 Hz	$f_{steady\ state}$	49.916 Hz
$f_{extreme}$	49.560 Hz	$\Delta f_{steady\ state}$	0.060 Hz
Δf	-0.416 Hz	$f_{extreme2}$	50.017 Hz
Δt	7.1 s	$f_{extreme3}$	49.868 Hz
ΔP	1250 MW	damping	32.65 %
E_k	174 GWs	FBF	20937 MW/Hz
cause		Other	

Figure 4.8. Disturbance 04-Jul-2021 14:49:31

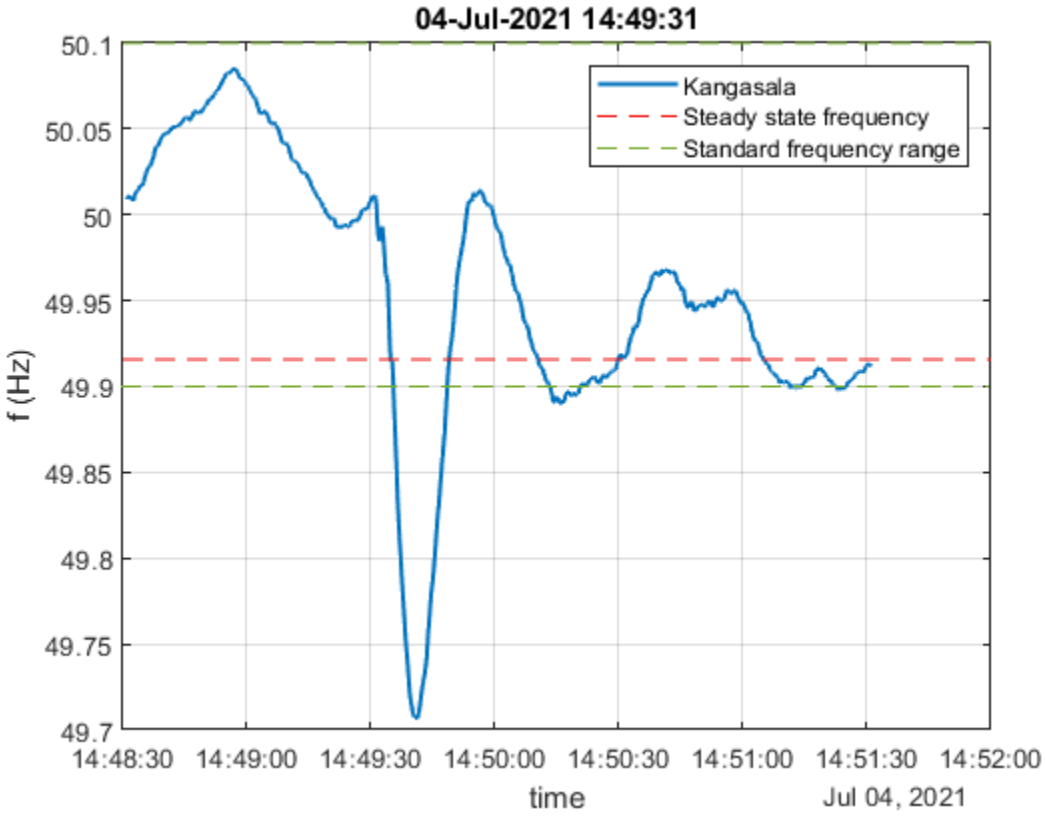


Table 4.7. Disturbance 04-Jul-2021 14:49:31

Date		**04-Jul-2021 14:49:31**	
f_{start}	50.005 Hz	$f_{steady\ state}$	49.916 Hz
$f_{extreme}$	49.707 Hz	$\Delta f_{steady\ state}$	0.089 Hz
Δf	-0.298 Hz	$f_{extreme2}$	50.014 Hz
Δt	9.6 s	$f_{extreme3}$	49.890 Hz
ΔP	850 MW	damping	40.32 %
E_k	173 GWs	FBF	9542 MW/Hz
cause		Other	

Figure 4.9. Disturbance 17-Jul-2021 16:13:39

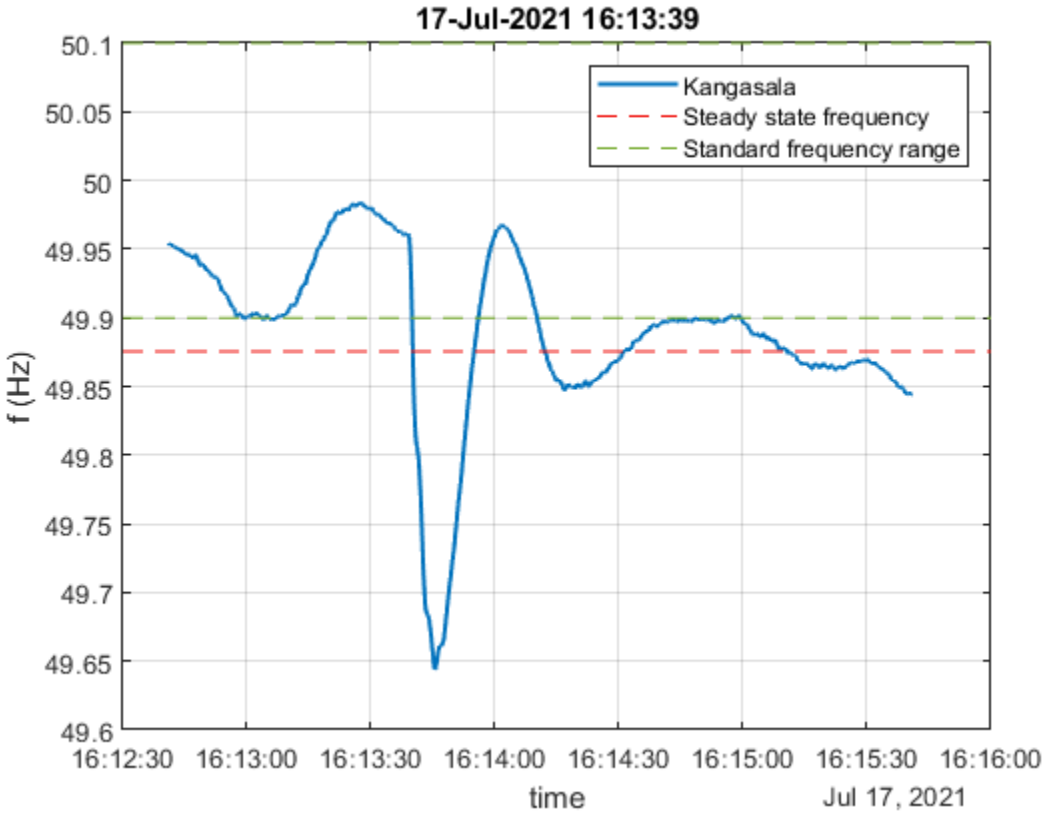


Table 4.8. Disturbance 17-Jul-2021 16:13:39

Date		**17-Jul-2021 16:13:39**	
f_{start}	49.956 Hz	$f_{steady\ state}$	49.876 Hz
$f_{extreme}$	49.644 Hz	$\Delta f_{steady\ state}$	0.080 Hz
Δf	-0.311 Hz	$f_{extreme2}$	49.967 Hz
Δt	6.2 s	$f_{extreme3}$	49.847 Hz
ΔP	639 MW	damping	37.12 %
E_k	135 GWs	FBF	7964 MW/Hz
cause		HVDC	

Figure 4.10. Disturbance 02-Sep-2021 13:04:14

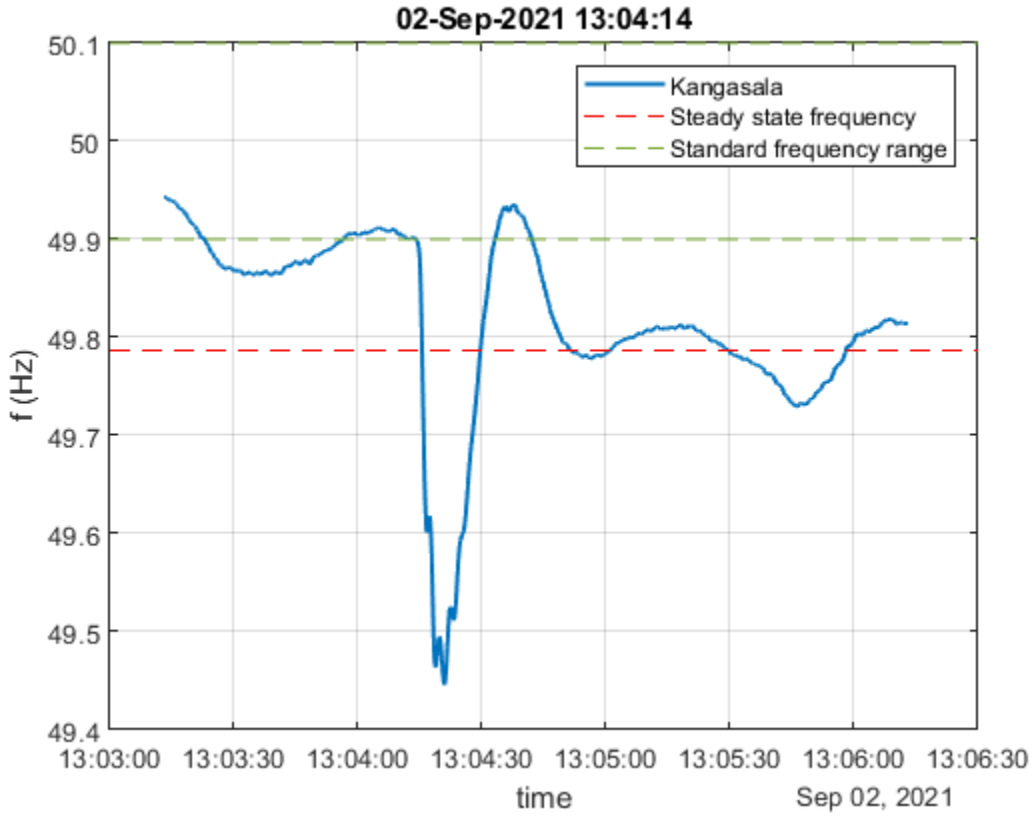


Table 4.9. Disturbance 02-Sep-2021 13:04:14

Date		**02-Sep-2021 13:04:14**	
f_{start}	49.891 Hz	$f_{steady\ state}$	49.787 Hz
$f_{extreme}$	49.447 Hz	$\Delta f_{steady\ state}$	0.104 Hz
Δf	-0.444 Hz	$f_{extreme2}$	49.935 Hz
Δt	6.2 s	$f_{extreme3}$	49.770 Hz
ΔP	1234 MW	damping	33.88 %
E_k	165 GWs	FBF	11860 MW/Hz
cause		HVDC	

Figure 4.11. Disturbance 16-Oct-2021 22:27:22

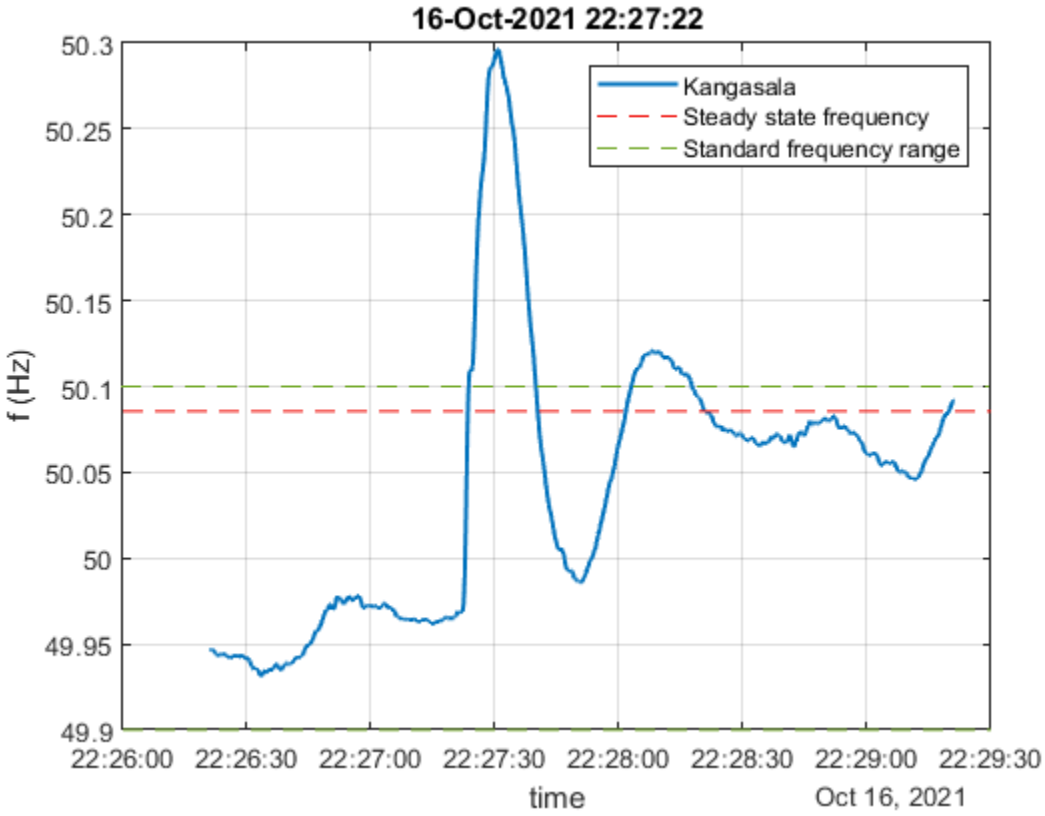


Table 4.10. Disturbance 16-Oct-2021 22:27:22

Date		**16-Oct-2021 22:27:22**	
f_{start}	49.974 Hz	$f_{steady\ state}$	50.086 Hz
$f_{extreme}$	50.296 Hz	$\Delta f_{steady\ state}$	0.111 Hz
Δf	0.322 Hz	$f_{extreme2}$	49.986 Hz
Δt	8.3 s	$f_{extreme3}$	50.121 Hz
ΔP	695 MW	damping	43.47 %
E_k	184 GWs	FBF	6253 MW/Hz
cause		HVDC	

Figure 4.12. Disturbance 29-Dec-2021 19:14:21

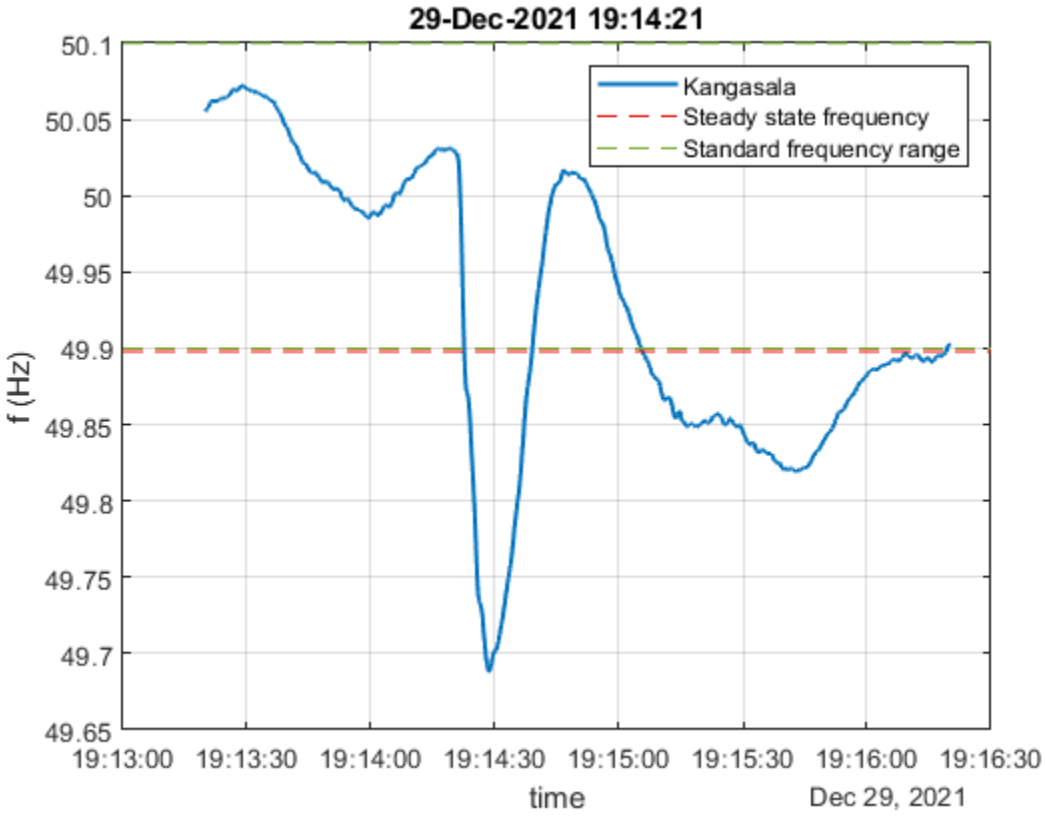


Table 4.11. Disturbance 29-Dec-2021 19:14:21

Date		**29-Dec-2021 19:14:21**	
f_{start}	50.021 Hz	$f_{steady\ state}$	49.898 Hz
$f_{extreme}$	49.688 Hz	$\Delta f_{steady\ state}$	0.123 Hz
Δf	-0.333 Hz	$f_{extreme2}$	50.017 Hz
Δt	7.4 s	$f_{extreme3}$	49.819 Hz
ΔP	1168 MW	damping	60.16 %
E_k	240 GWs	FBF	9481 MW/Hz
cause		Nuclear	

Chapter 5. Summary

The aim of this report was to analyse frequency variation and oscillation in the Nordic synchronous system in 2021. Various indices were used to assess frequency quality and the results were compared with the previous years. The overall quality of frequency was worse than in the previous year of 2020. In this comparison, however, it is good to note that the frequency quality of the year 2020 was exceptionally good in comparison with the previous years. For example when comparing the total time outside the standard frequency range of the year 2021 with years 2016-2019, year 2021 has the smallest amount of total time outside.

The average duration and the number of frequency deviations varies on monthly and daily basis. January, July and December were clearly the best months in terms of frequency quality although the average of frequency differed from 50 Hz during those months. In terms of time outside the standard frequency range, standard deviation and frequency area, the quality of the frequency was the worst in April and October. While comparing the days of the week, Monday was the best day of the week in terms of frequency quality and Tuesday the worst. For example, Monday had the lowest number of threshold crossings, standard deviation and daily average time that frequency was outside the standard frequency range, meanwhile Tuesday had the largest values in these categories.

In the hourly analysis, the highest number of threshold crossings, standard deviation and the longest time outside the standard frequency range occurred at 7 am. Inside an average hour, the quality of the frequency was worse closer the hour shift and especially at the beginning of the hour.

The amount of oscillation in 2021 has been higher than the levels of the previous years. The mean value of oscillation was the highest in September and the standard deviation in May and August. During the years from 2016 to 2019 the frequency has oscillated less during winter and more from spring to autumn. The year 2020 made an exception from this trend by staying close to 60 Hzs throughout the year, but the year 2021 continued to follow the trend of previous years. Removal of the oscillation by filtering the frequency data clearly reduces frequency deviations. The reduction is around 50 % with the FFT-filtering method. The reduction is generally higher for under frequency deviations.

The time outside 49.8-50.2 Hz and number of 200 mHz deviations increased from the previous year. There were 10 frequency disturbances, where the deviation exceeded 300 mHz. The most common source of these disturbances were faults in HVDC links. The number of 300 mHz disturbances doubled from year 2020.

Chapter 6. Sources

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

[2] Saukkonen M.: "Frequency quality analysis for year 2015", Fingrid Oyj, 16.8.2016

[3] Lindberg D.: "Frequency quality analysis for year 2016", Fingrid Oyj, 22.9.2017

[4] Lindberg D.: "Frequency quality analysis for year 2017", Fingrid Oyj, 28.8.2018

[5] Keskinen K.: "Frequency quality analysis for year 2018", Fingrid Oyj, 6.9.2019

[6] Valli V.: "Frequency quality analysis for year 2019", Fingrid Oyj, 17.9.2020

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

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

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

[10] Commission Regulation (EU) 2017/1485 of 2 August 2017 (System Operation Guideline), available at https://www.entsoe.eu/major-projects/network-code-development/system-operation

[11] Nordic report: Future system inertia, ENTSO-E, 2015, available at http://www.entsoe.eu