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Linderum Electricity Quality - Measurements and Analysis

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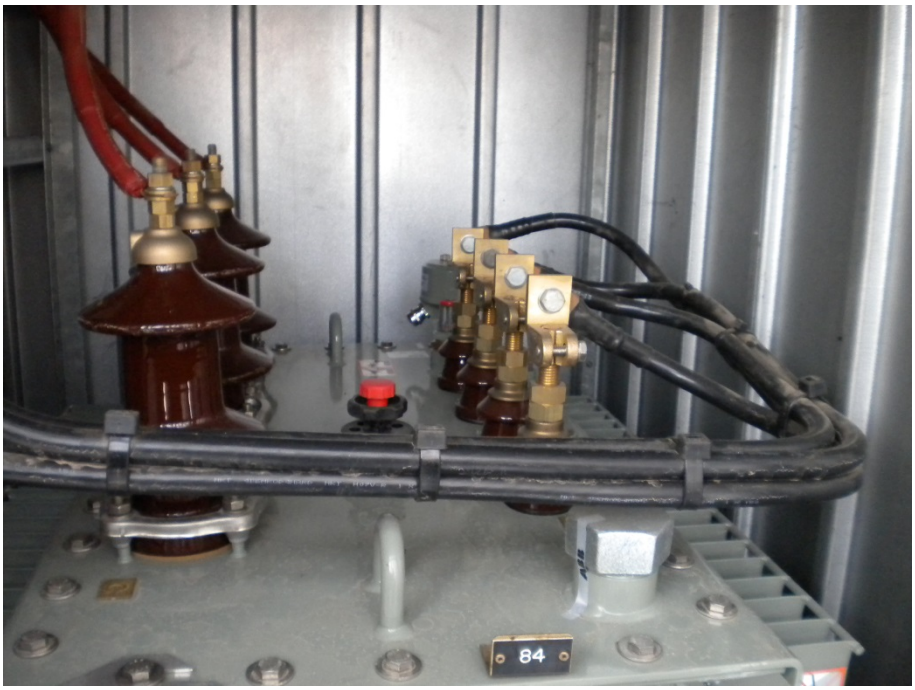
INSTITUTE OF ENERGY TECHNOLOGY – AALBORG UNIVERSITY

Linderum Electricity Quality

Measurements and Analysis

Filipe Miguel Faria da Silva and Claus Leth Bak

7/3/2013



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Objectives

- To measure the voltage and the current at two distinct locations. One of locations must be Linderum, more precisely the cables going to the houses with possible problems. The second location is semi-randomly chosen by the authors, being the selection limited by two constrains: it should not be distant from Linderum and it should serve residential loads.
- To acquire voltage and current waveforms at both locations at approximate the same time (in this case: Monday morning between 10am and 11am).
- To install a power analyser for one week (Monday to Monday), in two consecutive weeks at both locations.
- To compare and to analyse the results obtained for both locations, as well as to confirm that the values are inside/outside of the typical intervals.

Equipment

- Oscilloscope: DPO2014 with a sampling frequency of 200Mhz and capable of acquire 1 million points;
- Power Analyzer PPA5530 and laptop with the respective acquisition software;
- Voltage probes P5205A with a 100MHz bandwidth a 500x attenuation (for short-term measurements, not necessary for long measurements);
- Current probes:
    - TCP0150 with a minimum sensitivity of 5mA, 150A maximum current and a 1% maximum error (short-term measurements)
    - Voltech CL1000 with a 1000x attenuation, an 1% maximum error and a 45Hz-1kHz bandwidth (one week measurements)

Waveforms/Short Measurements

The voltage and current waveforms were both acquired on the 17th of June in a 1h interval.

Figure 1-Figure 3 show the obtained results[1]. The current waveforms were acquired twice in Linderum, because of the larger harmonic content.

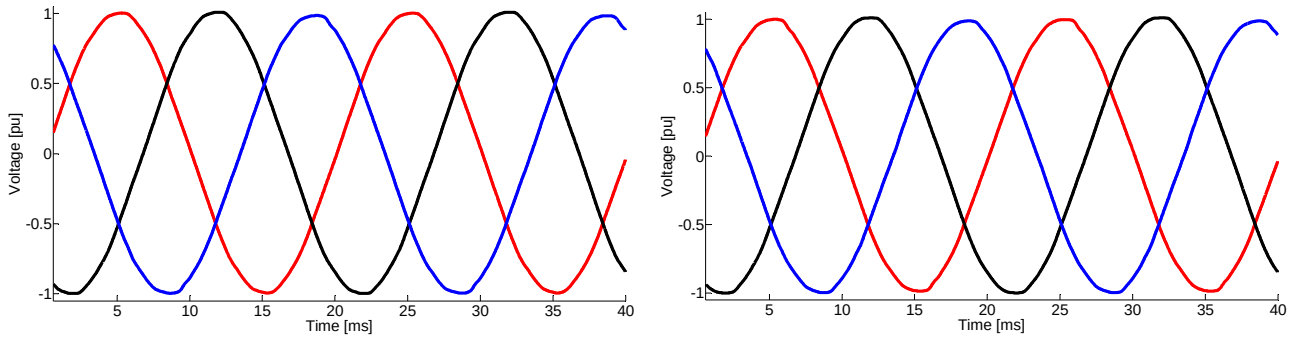


Figure 1 – Voltage waveforms in Linderum (left) and location 2 (right)

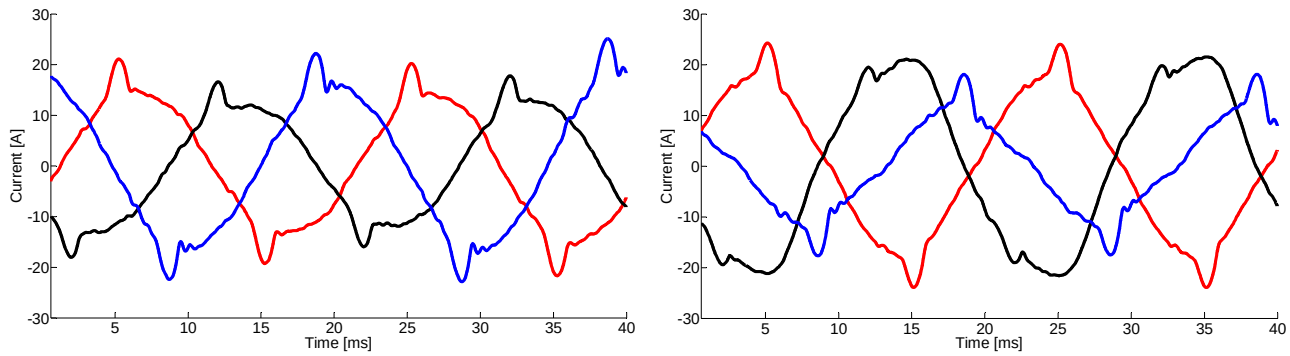


Figure 2 – Current waveforms in Linderum

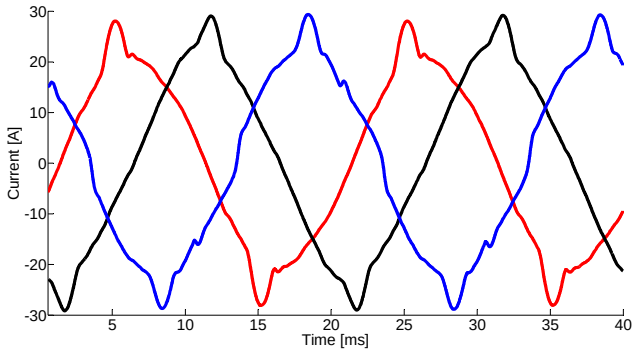


Figure 3 – Current waveforms in location 2

The analyse of the results shows that the voltage waveforms are close to perfect in both locations and that there it is a substantial harmonic distortion and unbalance on the current waveforms, being larger in

[1]The results were digitally filtered using a 2nr order Butterworth low-pass filter with a cutting frequency of 2kHz, in order to eliminate the high-frequency noise that is always associated to field measurements

Linderum. Thus, there was applied a FFT[2] (Fast Fourier Transform) to the results and there were obtained the different harmonic components.

Voltage

There are not shown the harmonics for the voltage as they were virtually non-existent. In the same way the THD (Total Harmonic Distortion) was below 1% at both locations. This reinforced at the one week simulations where the THD is always below the 3%, which is the limit for the distortion that can be provided by one harmonic at the IEEE standard.

The values from the IEC standard are more variable: 3rd - 4%; 5th – 5%; 7th – 4%; 9th - 1.2% and a maximum THD of 6.5%, but the measured values continue to be well inside of the interval[3].

Conclusion: The voltage at both locations has a high quality and it is well inside of the limits indicated by the standard.

Current

Figure 4 shows the harmonic currents in function of the fundamental for each phase. As expected, only odd harmonics are present and thus, only those are shown. Table 1 shows the current's THD for the different phases.

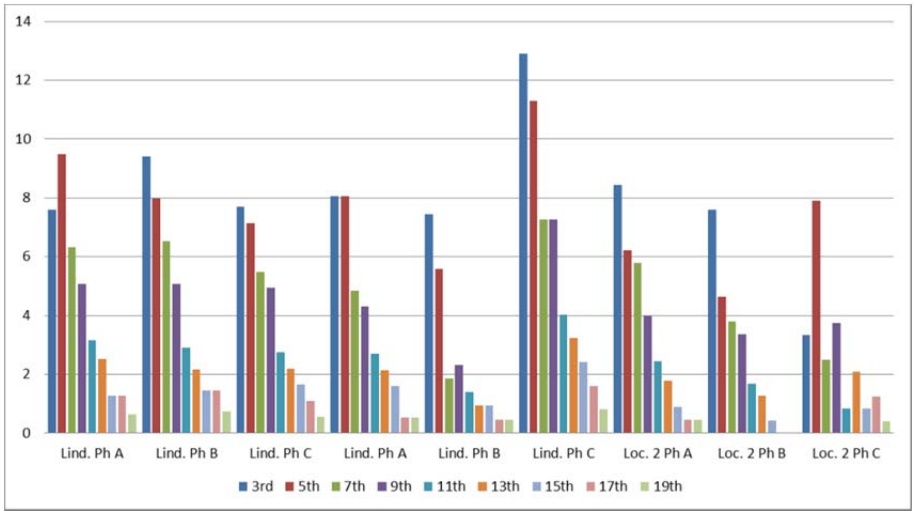


Figure 4 – Harmonic currents in percent of the fundamental

Table 1 – THD at the different locations

Linderum - Phase A	15.8
Linderum - Phase B	15.4
Linderum - Phase C	13.5
Linderum - Phase A (2nd test)	13.7
Linderum - Phase B (2nd test)	10
Linderum - Phase C (2nd test)	20.9
Location 2 – Phase A	13
Location 2 – Phase B	10.5
Location 2 – Phase C	10.1

[2] Due to mathematic constrains a FFT requires several periods of a signal in order to provide accurate results. Only two periods were acquired in the measurements, which it is not enough for having good results. In order to solve this issue it was considered that the measured signals were repeating themselves. This is just a mathematical "trick" that is required for a high accuracy and it does not introduce any error in the results.

[3] In theory it would be possible to have problems with the 9th harmonics, was in the one week measurements there were measured total THDs above 1.2%. However, considering the measured THD and the fact the main contributions are for the 3rd and 5th harmonic, it can be said with a high degree of certain that this is not issue.

For the currents more important than the THD is the TDD (Total Demand Distortion), which depends on the maximum load current. Ideally, there would be one year measurements and an average, but due to the existing limitations it is used the measured peak value of one week. In order to have a worst case scenario is also slightly lower the value of the peak current, which is considered as being approximately 40A at both locations. Figure 5 and Table 2 show the total TDD at the Linderum and location 2 for these conditions.

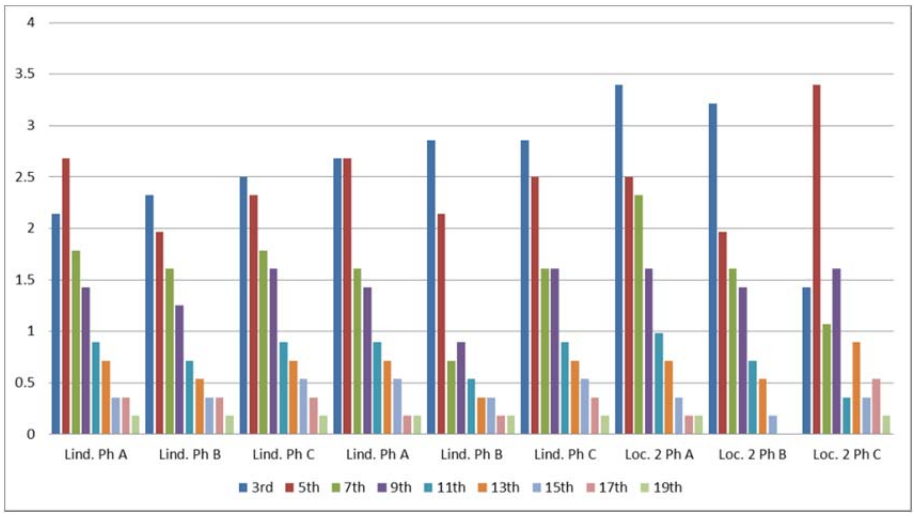


Figure 5 – TDD of the individual harmonics

Table 2 – Total TDD at the different locations

Linderum - Phase A	4.3
Linderum - Phase B	3.8
Linderum - Phase C	4.4
Linderum - Phase A (2nd test)	4.5
Linderum - Phase B (2nd test)	3.8
Linderum - Phase C (2nd test)	4.6
Location 2 – Phase A	5.2
Location 2 – Phase B	4.4
Location 2 – Phase C	4.3

Table 3 shows the standard current harmonic limits according to IEEE and IEC. The value is I_L is considered equal to 40A, as previously explained. The short-circuit current is unknown (IEEE standard), but the Danish network is very strong, thus, it is expected to be high.

For the short-term measurement the TDD is inside of the limits imposed by both standards and it is not an issue.

It is also important to notice that the DSO (Distribution System Operator) is only responsible for the voltage at the transformer, being the current dependent on how the costumers use the electricity. In the last decades with the increase of electronics in the households there was also an increase of current harmonics in the network, which can clearly be observed in this situation.

Table 3 – Harmonic current limits for distribution systems. Letf: IEEE; Right: IEC (MV systems)

Current Distortion Limits for General Distribution Systems
(120 V Through 69,000 V)

Maximum Harmonic Current Distortion in Percent of I_L						
Individual Harmonic Order (Odd Harmonics)						
I_{SC}/I_L	<11	11≤h<17	17≤h<23	23≤h<35	35≤h	TDD
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Where:
I_{SC} = maximum short-circuit current at PCC.
I_L = maximum demand load current (fundamental frequency component) at PCC.

Harmonic Number, h	5	7	11	13	>13
I_h/I_L	5	5	3	3	$500/h^2$

The measurements show also an unbalance on the phases, which can be explained by the reduced number of households connected to the link. Together with the use of single-phase appliances this will naturally result in a current unbalance.
In theory this could be a problem as there is a return current flowing from the houses to the transformer (see Figure 6). However, there is a neutral conductor between the transformer and the houses. As a result, practically all the return current flows in the return current and there is not a risk for humans [4].

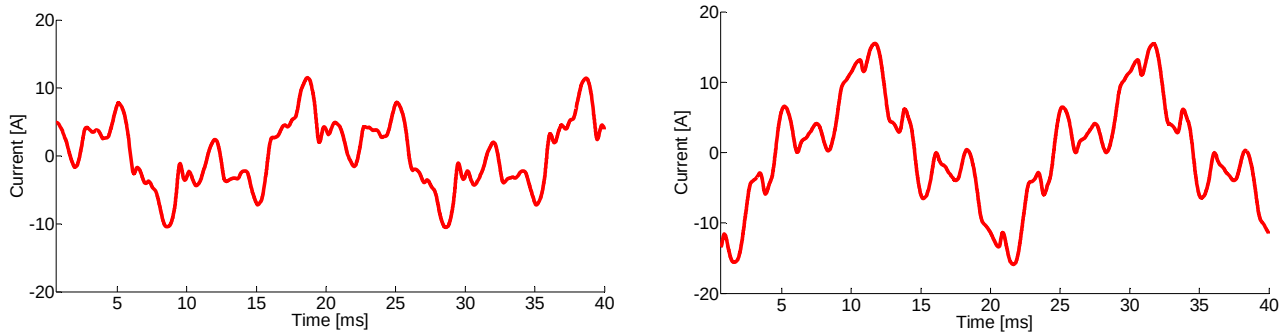


Figure 6 – Return current in Linderum (left) and location 2 (right)

One Week Measurements

Note: All the results described below are available in the appendices.

Frequency: The Danish power system must operate at a frequency between 49.5Hz and 50.5Hz at continuous operation. The measure values are well inside this interval for both locations.

RMS Voltage: The voltage should be between 0.95 and 1.05 pu. The measure values are well inside this interval for both locations.

RMS Current: Depends on the costumers and their use of electricity. The variations of the values are normal, with the peak of consume being those typically associated to residential loads (late afternoon and evening).

Harmonic Voltage: The measured values are very low at both locations and they are not an issue.

[4] Assuming that the electrical installation in the houses is properly done and that all the sub-circuits are connected to the neutral conductor. The existence of circuits not connected to the neutral conductor could arise some problems as there would be currents in the ground, however, the habitants would have notice electrical shocks. Moreover, this would be their responsibility, as Nord Energi is not responsible for the electrical installation in the households.

Harmonic Current: The harmonic currents seem to be rather large when compared with the RMS currents, which indicated the presence of harmonics that are too high. This topic is developed below in the *THD Current* and *TDD Current* sections.

Peak Voltage: It should correspond to the RMS voltage multiply by square root of two for all the measuring instants. The measured values show a maximum difference inferior to 2% (Linderum) and 0.5% (location 2), reinforcing the conclusion that the voltage is close to ideal.
In Linderum there is a decrease of the peak voltage from middle Tuesday to middle Thursday. At the same time there is an increase of the THD, meaning that the harmonic content was larger during this period. However, the variation is small and both values are still inside of the typical operational range.

Peak Current: It should correspond to the RMS current multiply by square root of two for all the measuring instants. The measured values show that there is often a difference of more than 100% at both locations, reinforcing the conclusion that there is a large current harmonic content.

THD Voltage: The measured values are very low at both locations and well inside of the standards limits.

THD Current: The THD currents are rather high and at some points larger than 50%. The individual harmonic contribution was not measured, but using the results from Figure 4 and Table 1 it can be said with a very high degree of certain that some of the harmonics are rather high.
Example: The short-term measurements show at Linderum an 8-10% harmonic content for the 3rd and 5th harmonics for a THD of 16%. The registered peak values of the THD are the triple of the 16% obtained in the short-term measurements, thus, it is expected that the harmonic content, in percentage, of the harmonics is also approximately the triple [5].
Table 4 shows the one-week average THD values at both locations. The values are in line with those of the short-term measurements, being slightly larger. Thus, the conclusions are alike to those made before.

Table 4 – Average THD during one week

	Ph A	Ph B	Ph C
Linderum	21%	18%	23%
Location 2	18%	19%	12%

TDD Current: As it was explained before the important parameter for currents is not the *THD*, but the *TDD*. The power analyser is not capable to provide this parameter, but it can still be obtained by manipulating the data of the THD Current. This was done and the results are shown in the appendices.
Like for the THD there can be used the results from Figure 5 and Table 2 to deduce more about the behaviour of the individual harmonics and then compare it with the standards.
Similar to the THD the maximum TDD is three times larger than the one obtained in the short-time measurements[6]. Thus, an approximation is to say that the TDD of the individual harmonics is also three times larger, using the reasoning also applied to the THD current. In this case the values will still fulfil the demands of the IEEE standard (assuming a strong network), but they would be slightly over the threshold for the IEC standard.
Thus, one could say that there is ground for a problem here. However, there are some points that have to be considered before doing that. First the IEC standard is considered as being conservative, second the analysis is being made for a worst case scenario considering a peak demand current lower than it really is, third these

[5] The THD is calculated using $THD = \sqrt{\sum_{h=2}^{\infty} I_h^2} / \sqrt{I_1^2}$, thus, the only way of having a 50% THD is if the harmonic currents increase, when compared with the fundamental. The best case scenario, would be to have a relative increase of the current equal for all the harmonics, as in this case none of them would have a higher increase.
[6] Such similarity is expected as the formulas used are very alike

values are for the peak TDD which happened very few times, fourth the TDD is worse and location 2 than in Linderum and there were not complains from this second location.
As a result, considering that the results are just above the limit and that the analysis was made for worst-case scenario using values that are worse than in reality, it cannot be said that this is a problem.
Table 5 shows the one-week average TDD values at both locations. The values are in line with those of the short-term measurements, being slightly larger. Thus, the conclusions are alike to those made before.

Table 5 – Average TDD during one week

	Ph A	Ph B	Ph C
Linderum	5%	4%	7.5%
Location 2	6%	5%	3.5%

Conclusions

The main conclusions are that:

- *The voltage is very stable, with a high quality and well inside the intervals stated by the standard at both locations;*
- *The current shows a large harmonic content, which is larger than desirable, but still tolerable;*
- *There are non-noticeable differences between the two locations where measurements were performed;*

A DSO, in this case Nord Energi, is only responsible by the voltage at the secondary side of the transformer, which the measurements show to be well inside of the standard values.
The high harmonic currents are responsibility of the costumers and depend on the electrical equipment that is use in households.

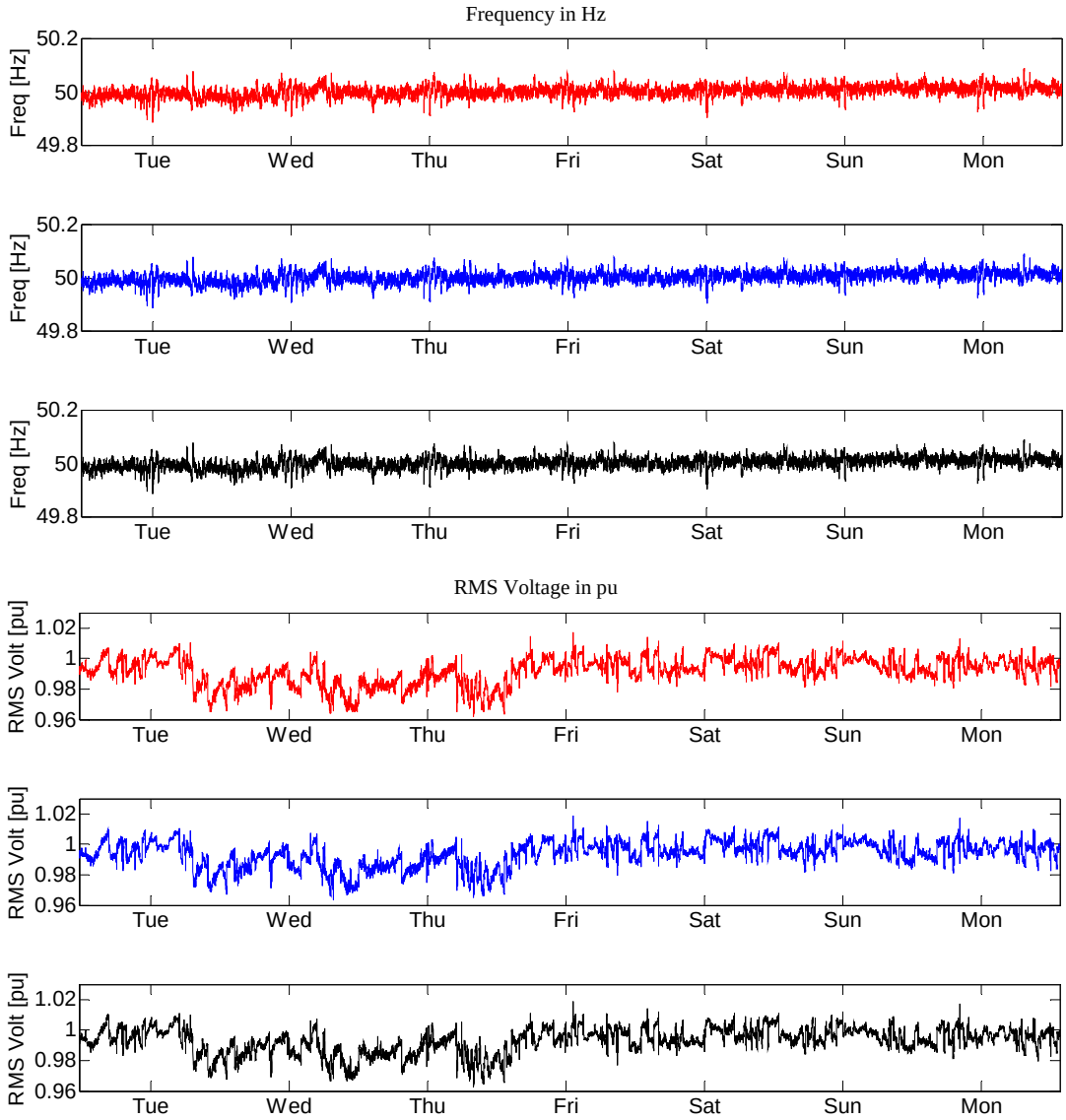
As a result, it is our opinion that the electricity provided by Nord Energi fulfils the existing quality standards and it is not responsible for any possible health problems that may exist.

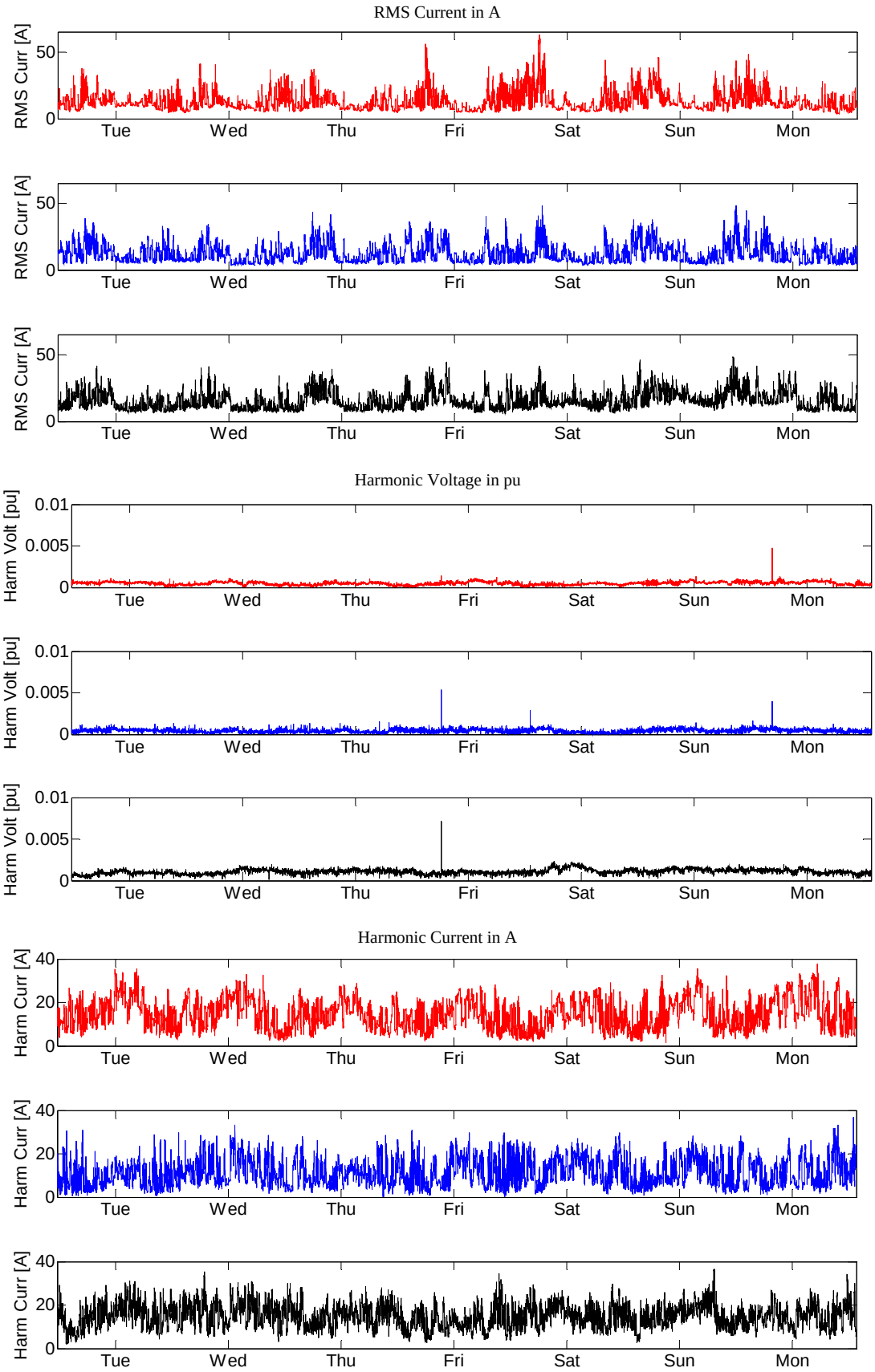
Advices

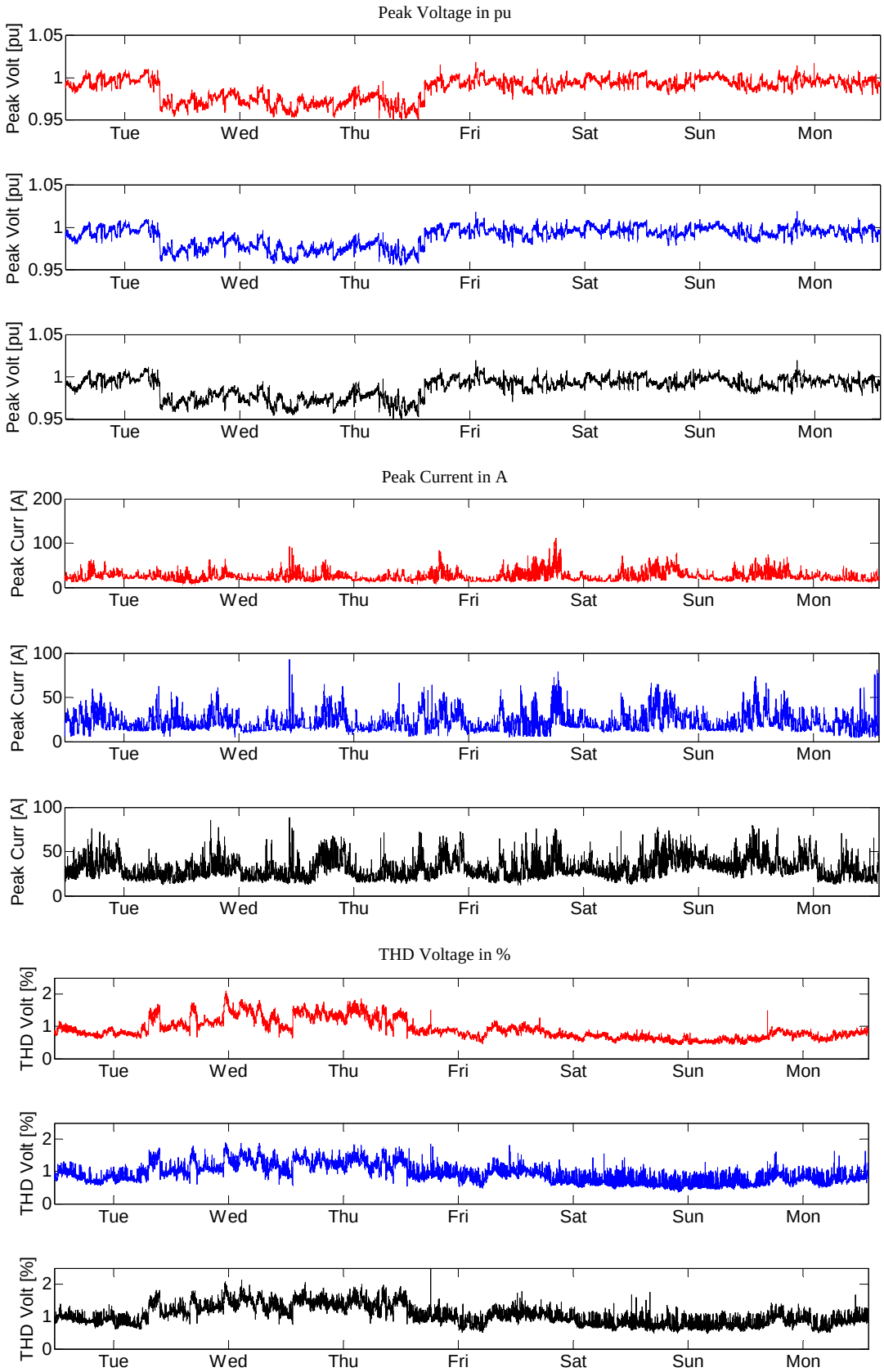
Health problems in humans and animals due to electricity is a topic many times raised by the media, but, with some exceptions, is has yet to be shown a clear correlation between both.
As an example, exceptions to this are the flowing of currents through the body, i.e., electrocution or electric shocks, or the effects of strong magnetic field in bees.
When observing the premises of this particular case, the only possible source of health problems that the authors can see is the presence of improper electrical installation in the houses, which would lead to currents flowing outside of the wires (e.g., some old houses used to have electricity flowing in water metal pipes). Such situation is not expected.
The measurements reinforce the expectations, by not showing any relevant differences between Linderum and the second location.

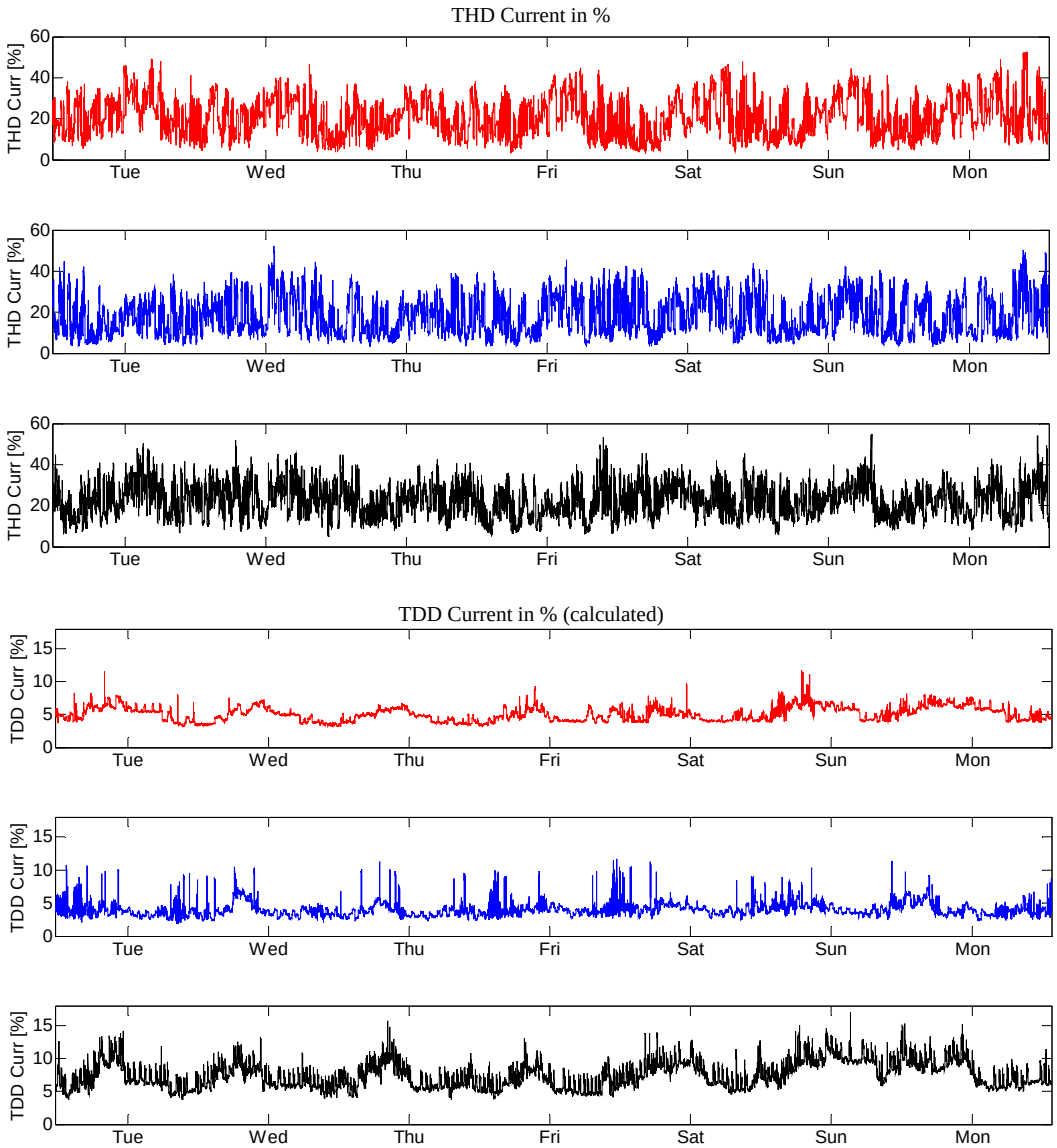
Appendix

Power Analyzer Results (Linderum)

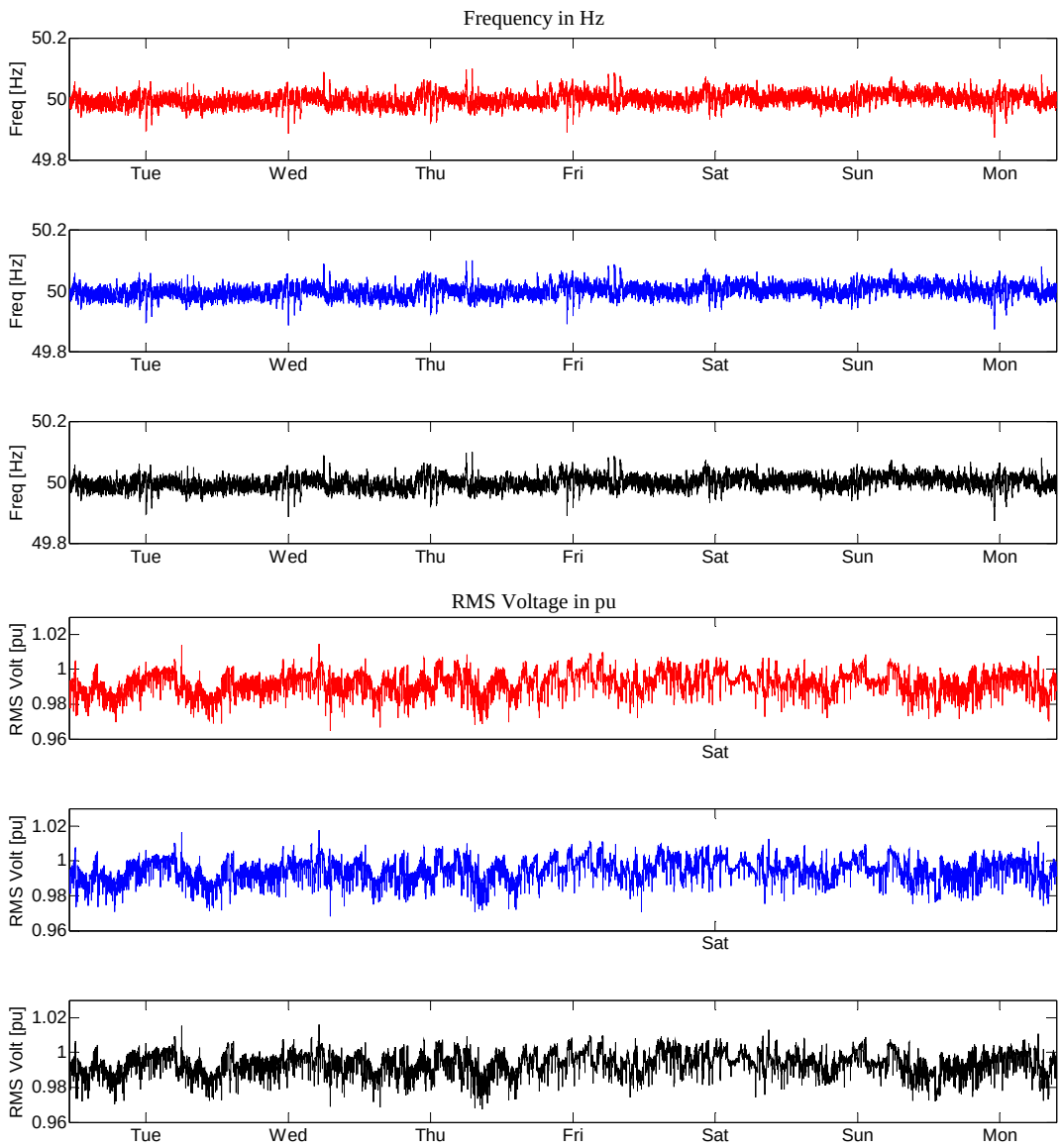


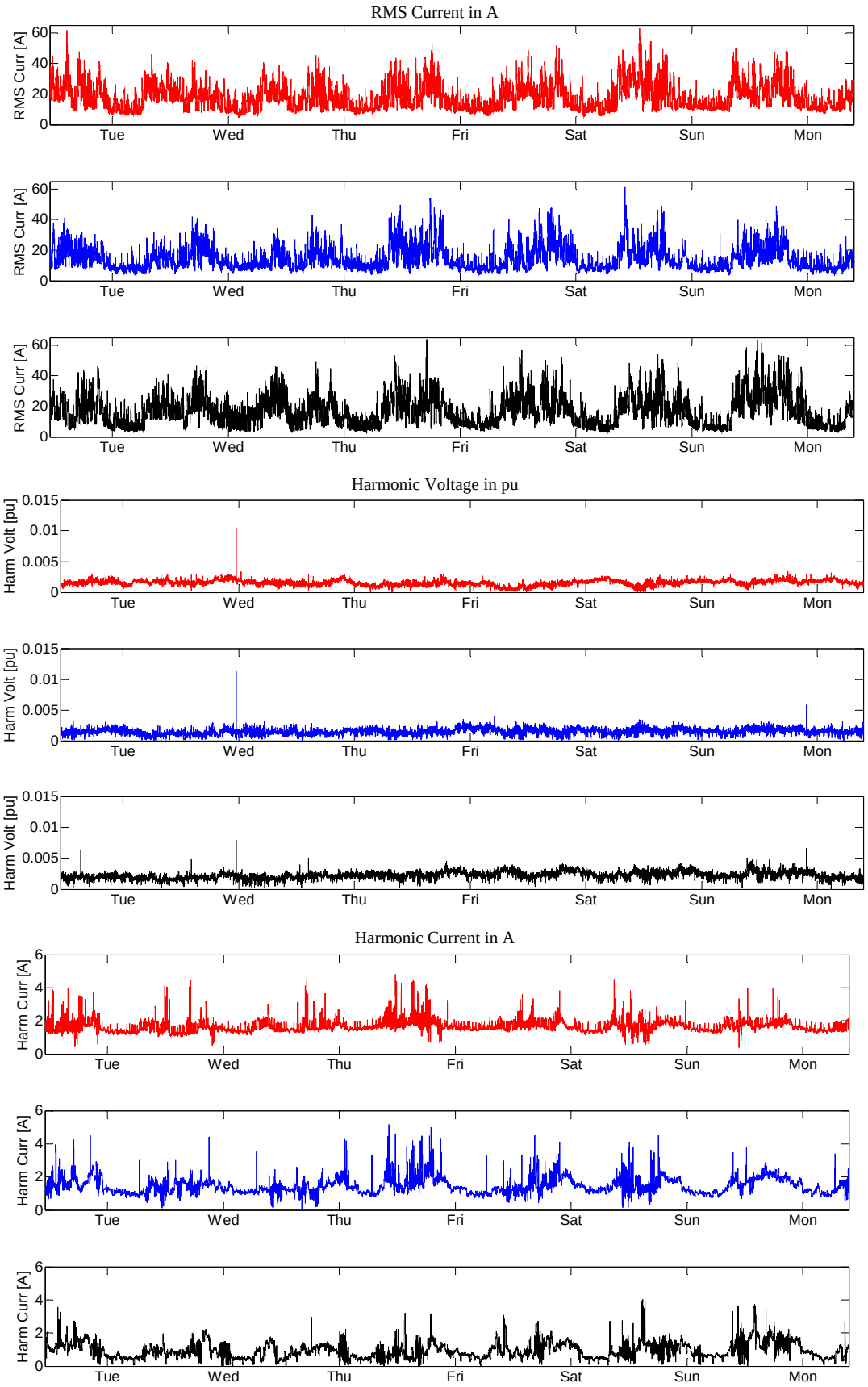

RMS Current in A
RMS Curr [A]
50
0
Tue
Wed
Thu
Fri
Sat
Sun
Mon
Harmonic Voltage in pu
Harm Volt [pu]
0.01
0.005
0
Harmonic Current in A
Harm Curr [A]
40
20

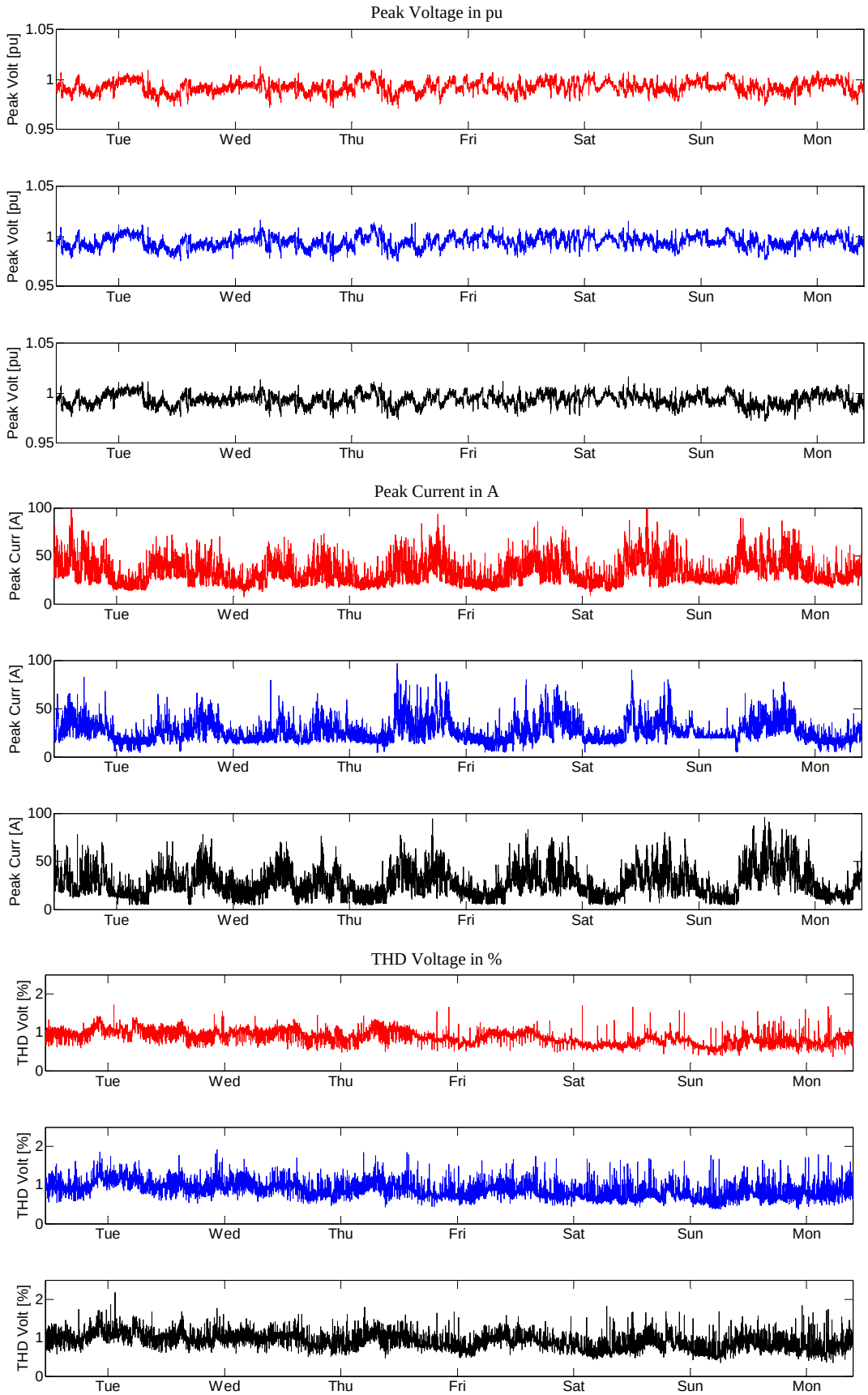

Peak Voltage in pu
Peak Volt [pu]
1.05
1
0.95
Tue
Wed
Thu
Fri
Sat
Sun
Mon
Peak Current in A
Peak Curr [A]
200
100
0
50
THD Voltage in %
THD Volt [%]
2
1

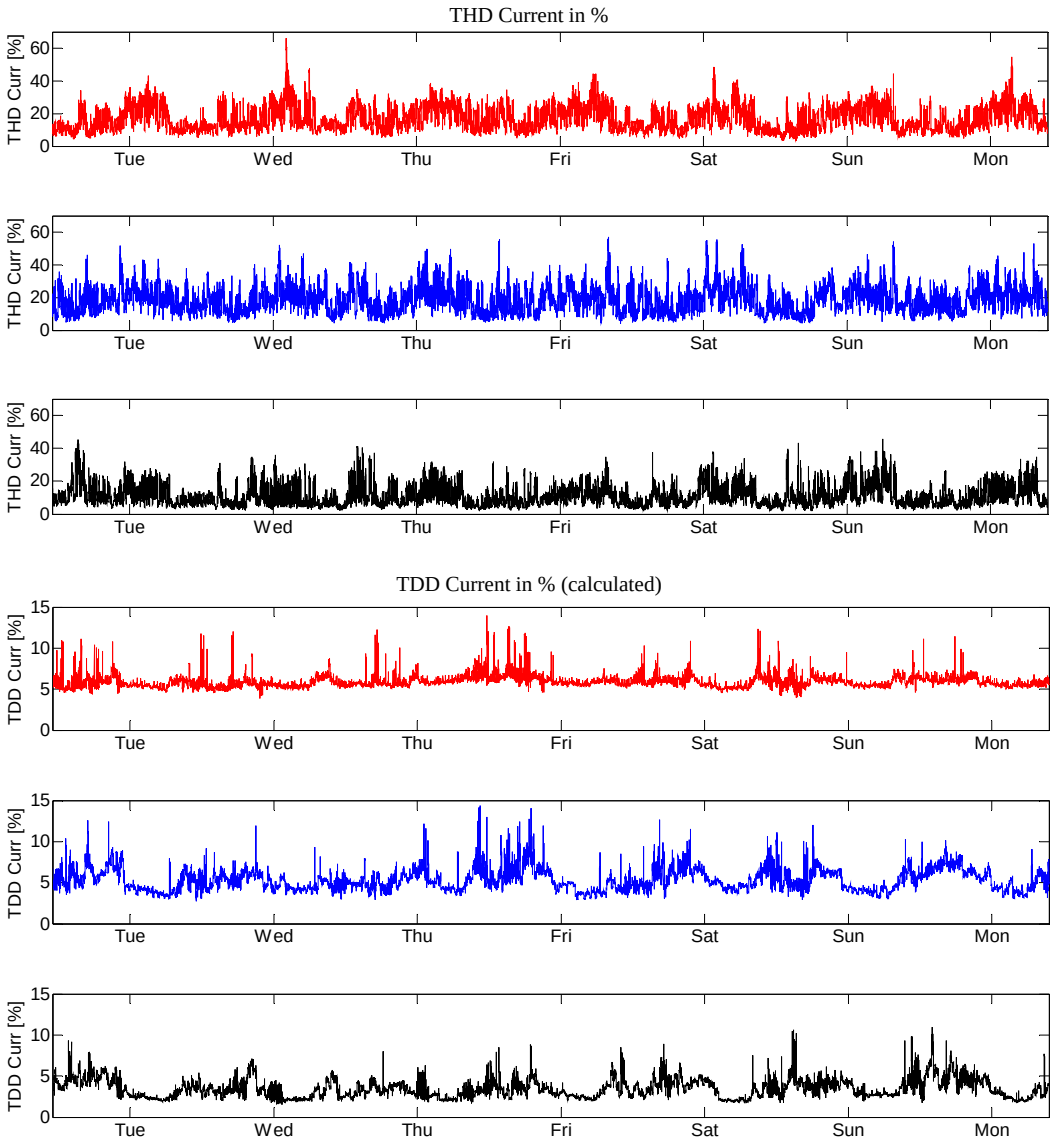

THD Current in %
THD Curr [%]
60
40
20
0
Tue
Wed
Thu
Fri
Sat
Sun
Mon
TDD Current in % (calculated)
TDD Curr [%]
15
10
5
0

Power Analyzer Results (location 2)




RMS Current in A
RMS Curr [A]
60
40
20
0
Tue
Wed
Thu
Fri
Sat
Sun
Mon
Harmonic Voltage in pu
Harm Volt [pu]
0.015
0.01
0.005
0
Harmonic Current in A
Harm Curr [A]
6
4
2
0


Peak Voltage in pu
Peak Volt [pu]
1.05
1
0.95
Tue
Wed
Thu
Fri
Sat
Sun
Mon
Peak Current in A
Peak Curr [A]
100
50
0
THD Voltage in %
THD Volt [%]
2
1
0


THD Current in %
THD Curr [%]
60
40
20
0
Tue
Wed
Thu
Fri
Sat
Sun
Mon
TDD Current in % (calculated)
TDD Curr [%]
15
10
5