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SECTOR A

Paper A02

CATHODIC PROTECTION REMOTE MONITORING SYSTEM DESIGNED FOR SPECIFIC NEEDS OF PIPELINES OPERATORS

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Abstract
Cathodic Protection (CP) of pipelines relies on several types of tools (rectifiers, drainage diodes…) installed along the buried metallic structures. Whatever the on-line measurements are, everybody will agree that a reliable CP system needs those tools to function correctly and continuously.
For this purpose, the CP department of Fluxys has developed a Remote Monitoring System (RMS) which like many other system classically allows to watch the good functioning of tools and since electrical situation varies in time, to detect anomalies occurring on the CP system.. In addition to averages, standard deviations, minima, maxima, and alarm signals counters have been added to show how often signals were measured in certain voltage ranges.
But this RMS was developed keeping in mind specificities of pipelines operators: reasonable investment cost, low maintenance cost and long lifetime. One major factor of success appeared to be the limited energy consumption. To achieve this we calculated the optimal sampling frequency with regard to the cost of collecting data. Then we optimized the transmission cost of data, limiting it to 1 instant message (SMS) a day equipped with a Lithium battery, with a guaranteed autonomy of three years.

INTRODUCTION

Reliable Cathodic protection (CP) of buried metallic structures is strongly dependant on the equipment installed in its vicinity. This equipment includes rectifiers with impressed current anodes, drainage diodes, Mg-anodes… Other types of equipment, such as test posts, are also necessary to assess the good functioning of the CP.
A specific problem of pipeline operators is that the metallic structures are buried over a large area. E.g. Fluxys, the Belgian natural gas transport company, operates about 3800 km of pipelines, while the area of Belgium is approximately 30.000 km². Some equipment is placed in remote areas or in areas where power supply is not available.
In 2005 Fluxys has started the development of a Remote Monitoring System (RMS) in order to check the correct and continuous functioning of its CP equipment.
Fluxys focussed its development on several topics that each reflect a specific need of a pipeline operator:

1. The data transmission must be optimized. The quantity of transmitted data must be high enough in order to have a good idea of what is going on in the field. On the other hand, it is not feasible to check huge quantities of data. Therefore the data must somehow be “summarized”. Sending too much data is also very costly.
2. The aim of the RMS is to detect problems. These problems can be caused by interference from other structures, damaged/off-line rectifiers… Some problems can be detected easily, while some others will occur only at certain moments. This means that the sampling frequency must be high enough in order to detect all of these these problems.
3. The remote monitoring units (RMU) must work independently for long periods of time. When power supply is available, a backup system must ensure a correct functioning for several days. When power supply is not available, the RMU must be able to work for several years independently.
4. The user interface must be customized for the daily operational work.
5. The size of the RMU’s must be kept within certain boundaries. They must be small enough to fit into test posts, but they must be sturdy enough to resist the handling of them.
6. The electronic components must be protected again aggression from the environment. Humidity and dust are electronic component’s worst enemies.

The three first topics are discussed in this paper.

DATA TRANSMISSION OPTIMIZATION

Problem identification

In order to explain the need for data transmission optimization, a 4 channel RMU is assumed.
The sampling frequency is set to 1 Hz.
1 measurement is 2 bytes.
For every channel: 2 bytes/second * 60 seconds/minute * 60 minutes/hour * 24 hours/day * 7 days a week = 1209600 bytes/week ≈ 1,15 Mb/week
For the 4 channels this means approximately 4,6 Mb/week of data.
Assume 1000 units on the field, this will provide approximately 4,5 Gb of data every week (uncompressed, this means 6,5 CD-ROMS of 700 Mb).
From an operational point of view this huge quantity of data cannot be used (imagine someone who would have to check all this data). In order to store this data, even compressed and on DVD's, it will soon become a problem.

On the other hand the aim is to have a good idea of the situation in the field. Therefore, a minimal amount of parameters are necessary.

Parameters

During the first series of calculations real voltage measurements were used.
Following parameters were calculated:

- Minimum and maximum value,
- Average value,
- Standard deviation,

Besides that, 7 voltage zones were defined. For each zone the quantity of samples in the zone was counted. The longest uninterrupted period in a single zone was counted and the start of that period in time was identified.

The standard deviation is perhaps the most difficult parameter to calculate, but is necessary nonetheless since it gives you an idea of how much signal varies around its average. Short time peaks will not alter the standard deviation a lot, while a strong varying signal will have a significant standard deviation.

In order to calculate the "running" standard deviation following method is used (assuming the quantity of samples is high enough):

$\sigma^2 = 1/N * \Sigma (x_{avg} - x_n)^2 = 1/N * \Sigma (x_{avg}^2 -2 * x_{avg} * x_n + x_n^2)$
$= 1/N * (\Sigma x_{avg}^2 - 2 * \Sigma x_{avg} * x_n + \Sigma x_n^2)$
$= 1/N * (N x_{avg}^2 - 2 * x_{avg} * \Sigma x_n + \Sigma x_n^2)$
$= x_{avg}^2 - 2/N * x_{avg} * \Sigma x_n + 1/N *\Sigma x_n^2)$

$x_{avg} = 1/N * \Sigma x_n$

$\Rightarrow \sigma^2 = 1/N^2 * (\Sigma x_n)^2 - 2/N^2 * (\Sigma x_n)^2 + 1/N *\Sigma x_n^2$
$\Rightarrow \sigma^2 = 1/N * \Sigma x_n^2 - 1/N^2 * (\Sigma x_n)^2$
$\Rightarrow \sigma = 1/N * \sqrt{(N * \Sigma x_n^2 - (\Sigma x_n)^2)}$

Where σ = standard deviation
N = the quantity of samples
x_n = individual measurement
x_{avg} = average of all measurements

Simulations

2 simulations were performed with 2 different types of signals.

The zone limits were chosen as shown in table 1.

Table 1: Zone limits for the 2 simulations

Limit	Voltage / [V_{CSE}]
1	0
2	-0.83
3	-0.85
4	-0.95
5	-1.2
6	-2

Signal 1 (see picture 1) is a signal that is slightly disturbed in the first couple of seconds, but then stabilizes around ± -1 V. Table 2 shows the results of the analysis.

Table 2: Results of the analysis on signal 1

Parameter		
Time in zone 1	3 s	-
Time in zone 2	3 s	-
Time in zone 3	0 s	-
Longest period in zone 1	4 s	16 s
Longest period in zone 2	8 s	7 s
Longest period in zone 3	0 s	0 s
Longest period in zone 4	0 s	0 s
Longest period in zone 5	1 s	19 s
Longest period in zone 6	982 s	20 s
Longest period in zone 7	1 s	18 s
Maximum	0.74 V_{CSE}	
Minimum	-3.61 V_{CSE}	
Average / Standard deviation	-1.49 V_{CSE}	± 0.21 V_{CSE}

By looking at the results of the analysis only it is possible to conclude that there were some disturbances in the beginning of the recording (longest period in zone 1 3s out of a total of 4 during the entire recording, started after 16s of recording, similar results in zone 2), but after that the signal stayed in the same zone (982 s in zone 6 after 20 s). Minimum and maximum values are given. The average value of the signal is -1.49 V and doesn't vary a lot (in "average" the signal stays between -1.28 V and -1.60 V).
This coincides very well with original signal.

Signal 2 is a strongly varying signal (See picture 2). Table 3 shows the results of the analysis.

Table 3: Results of the analysis on signal 2

Parameter		
Time in zone 1	335 s	-
Time in zone 2	106 s	-
Time in zone 3	3 s	-
Longest period in zone 1 / start	5 s	820 s
Longest period in zone 2 / start	4 s	902 s
Longest period in zone 3 / start	3 s	784 s
Longest period in zone 4 / start	3 s	418 s
Longest period in zone 5 / start	3 s	383 s
Longest period in zone 6 / start	3 s	854 s
Longest period in zone 7 / start	4 s	470 s
Maximum	2.18 V_{CSE}	
Minimum	-4.54 V_{CSE}	
Average / Standard deviation	-0.93 V_{CSE}	± 1.93 V_{CSE}

By looking at the results of the analysis only it is possible to conclude that the signal varies a lot (the signal doesn't remain in the same zone more than 5 seconds). This is confirmed by the standard deviation. The signal is in "average" between 1 V and – 2.86 V.
Again, this coincides very well with the original signal.

Conclusion

The results of the tests have shown that it is possible to recreate a good image of the original signal by calculating only a couple of parameters.
Minimum, maximum and average are easily calculated and have a high added value, but the standard deviation must be calculated as well. This gives an idea of how strongly the signal varies around its average.
The different zones, along with their longest period and start moment have a smaller added value, but do help understanding better when certain occurrences have taken place and how long they lasted.

DETERMINATION OF THE SAMPLING FREQUENCY

Problem identification

“Measuring is knowing”. The higher the sampling frequency (the quantity of measurements per second), the more likely and/or the quicker problems will be detected.
On the other hand, every measurement costs money (every measurement uses a certain quantity of Ampere hours (Ah)). Batteries have a limited life span and replacing them is an even more costly activity (sending someone to on site to remove the battery and place a new one).
In its specifications, Fluxys has set a minimum life span of 3 years for the batteries, whenever a RMU is placed in a remote area where power supply is not available.
Whenever power supply is available, a back-up battery is used that must keep the RMU working for 7 days if power supply should be turned off.
During the development of the RMU’s extensive efforts were made to minimize the energy consumption of the units. This includes switching off most of the system’s components when they’re not being used, using low energy consuming components…
However, technically, it didn’t seem possible to have a RMU measure every second or more. Therefore, an additional study was performed by Fluxys to identify the minimal required sampling frequency in order not to lose too much information.

Measurements

In order to determine the minimal required sampling frequency, Fluxys has performed 18 recordings of 24 hrs with a sampling frequency of 1 Hz. Fluxys’ technicians were asked to perform such measurements in area’s they considered as being disturbed/under influence. The recordings were scattered over all provinces of Belgium (See pictures 3 to 20)
The time signals can be divided into 3 groups:

- Signals that vary strongly around a fixed average (Antwerpen, Luchtbal, Limburg 1 & 2, Gembloux),
- Signals that vary strongly with a very low frequent component (Rijkswacht & Schollestraat),
- Signals that are fairly constant but who experience high peaks (Hainaut 1 & 2, Chaudfontaine 1 & 2, Monsin, Floreffe, Namur, Oost-Vlaanderen 1 & 2, West-Vlaanderen 1 & 2),

Discussion - Calculations

For every signal the Fast Fourier Transform was calculated using a freeware called “SciLab”[1] (see pictures 21 to 38).
All FFT’s have similar characteristics, Low frequent components below 0.1 – 0.2 Hz are more or less significant while everything above this can be considered as noise.
The Signals that vary strongly around a fixed average are from a statistical point of view the “less” problematic. The peaks are very short in time, but will be detected in most cases. The standard deviation will probably be fairly high but this information is sufficient for the operator to decide whether further action is necessary or not.
This is translated by a very low signal to noise ratio (the noise level is very high in comparison to the frequency content that actually holds useful information).

[1] www.scilab.org

Only 2 signals (Limburg 1 & 2) have a small “high frequent” component. This means that the highest frequencies have a higher level than the noise level. Since Limburg 1 has a high noise level anyway, this is not relevant, while with Limburg 2 this high frequency component is relatively smaller.
The signals that vary strongly around a very low frequent component are slightly more difficult to handle. Except for the lowest frequencies that are significant, the signal to noise ratio is still low. However, since there is a very strong very low frequent component the other frequencies are relatively smaller on the FFT.
The signals that are fairly constant but who experience peaks are from a CP point of view the worst case scenario (DC-interference, AC-interference if AC is measured).
It is must more the shape of the overall signal rather the direction of the peaks that is relevant in this study. The FFT will not take into account DC-components (vertical shifts of the entire signal) as well as multiplication by -1 of the entire signal (mirroring of the signal). A multiplication of the entire signal by a (non-zero) factor will only enhance the amplitude of the FFT, but will not influence its shape as well.
In this case, the low-frequent part of the FFT is much bigger and the signal to noise ratio is much higher.
The signal-to-noise ratio was calculated for several signals from the third type, and the threshold for this ratio was set to 100. The lower the threshold, the more components are added that are partially noise and partially contain actual data.
For all signals it came out that the threshold was between 1/150 Hz and 1/200 Hz. This means that it is necessary to measure every 150 to 200 seconds in order to be certain to have most of the significant components of the signal.
Therefore the minimal sampling period was set to 2 minutes.

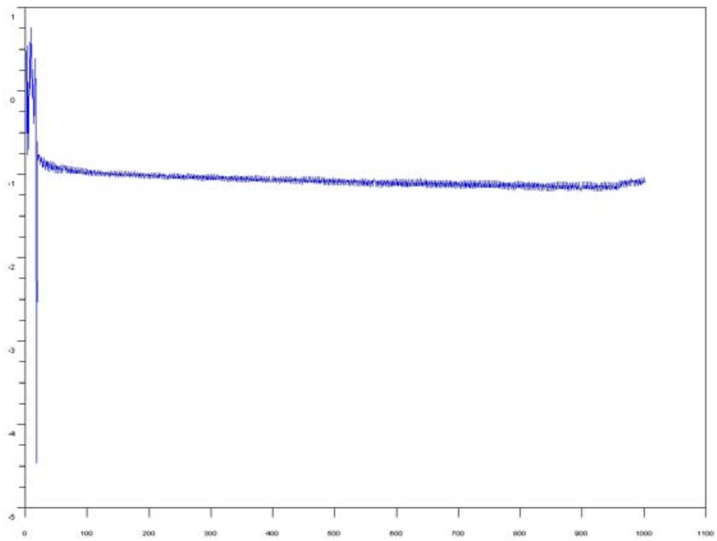
Conclusion

All signals have a frequency spectrum that is fairly similar. All signals are low frequent and all components above 0.2 Hz can be considered as noise.
Depending on the shape of the signal the overall signal-to-noise ratio will be different. The signals with peaks (such as the ones with DC-interference) have the highest overall signal-to-noise ratio.
The minimal sampling period was calculated to be 2 minutes in order to detect most problems and in order not to loose too much information by reducing the sampling frequency.

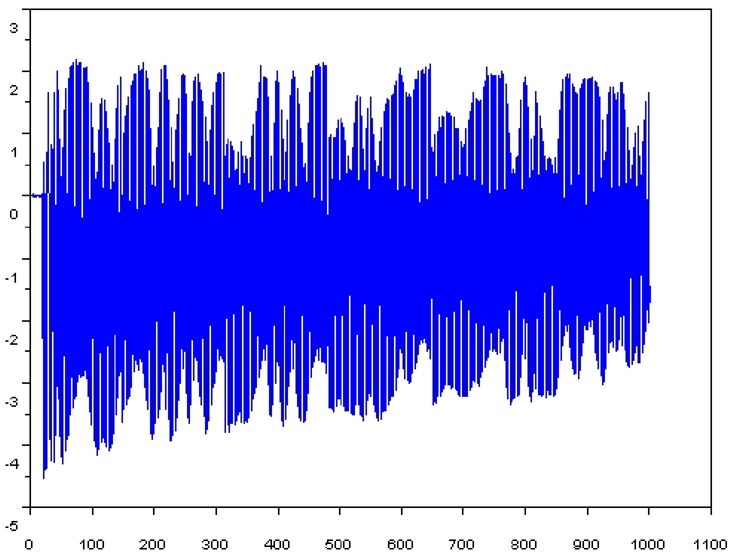
GENERAL CONCLUSIONS

Fluxys has identified specific needs for its Remote Monitoring System for Cathodic Protection.
During the development of this system a series of calculations were made were performed.
The first set of calculations showed that it is necessary to reduce the quantity of data transmitted. It was shown that it is sufficient to send minimum, maximum, average and standard deviation in order to have a good idea of the shape of the original signal, while using zones also brings an added value to that purpose.
The second set of calculations showed that a minimal sampling period of 2 to 3 minutes must be assumed to detect most disturbances on the network of Fluxys.
The modules have successfully been developed (see picture 39) and are now being installed over the entire network operated by Fluxys.

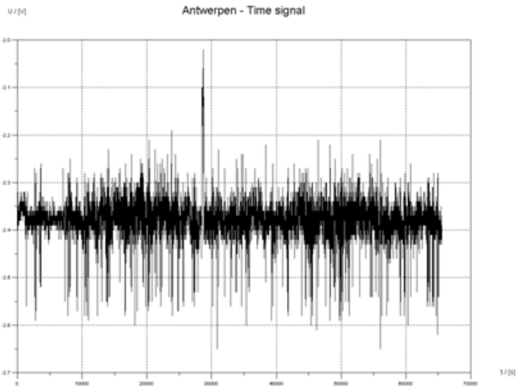
Picture 1: Simulation signal 1



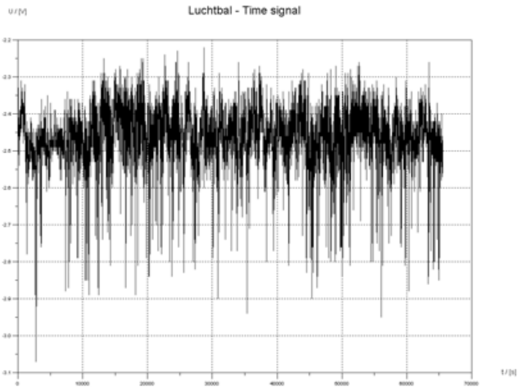
Picture 2: Simulation signal 2



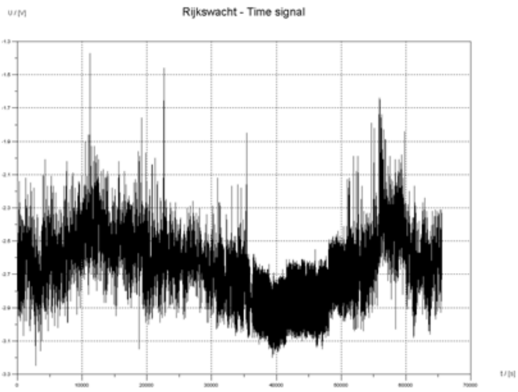
Picture 3: Recording 1 “Antwerpen”



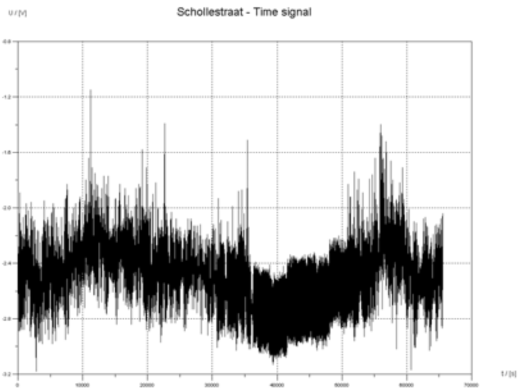
Picture 4: Recording 2 “Luchtbal”



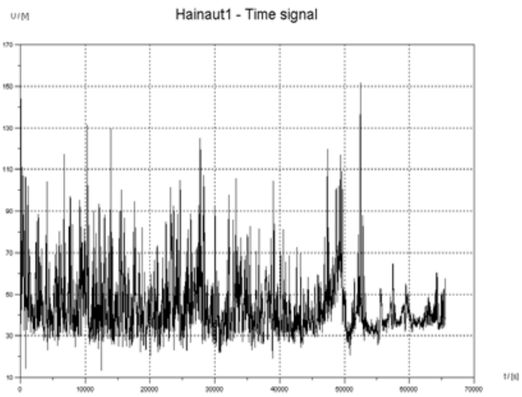
Picture 5: Recording 3 “Rijkswacht”



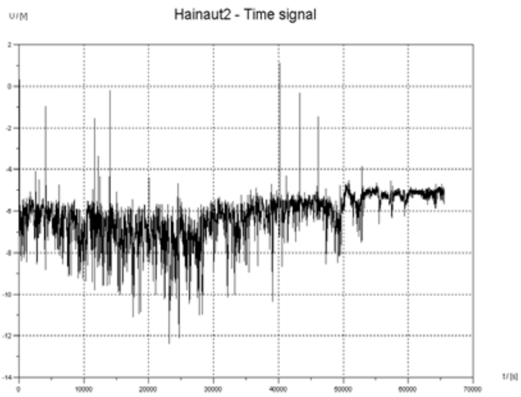
Picture 6: Recording 4 “Schollestraat”



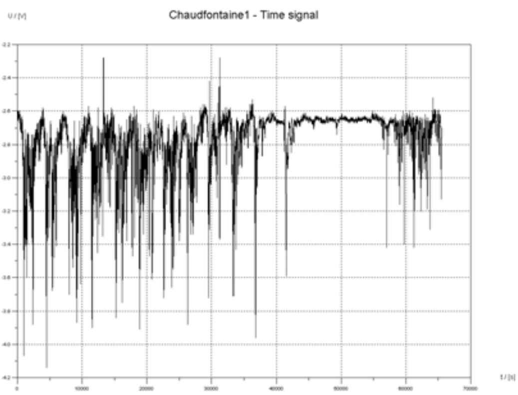
Picture 7: Recording 5 “Hainaut 1”



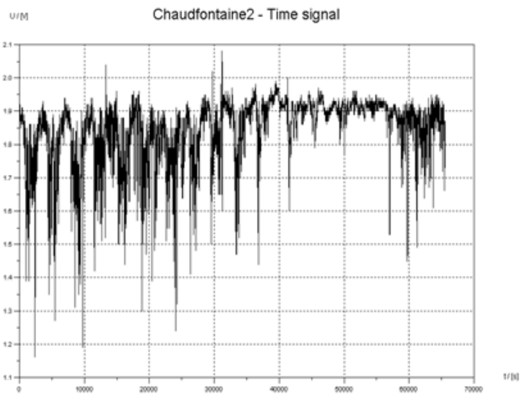
Picture 8: Recording 6 “Hainaut 2”



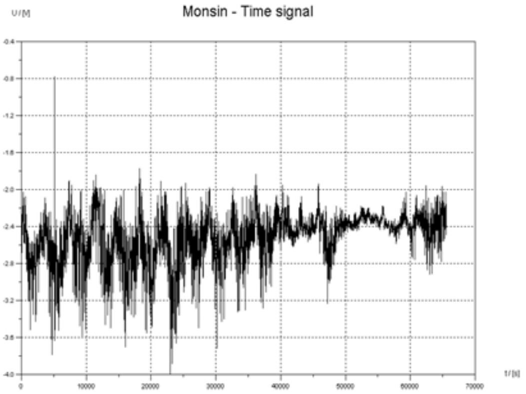
Picture 9: Recording 7 “Chaudfontaine 1”



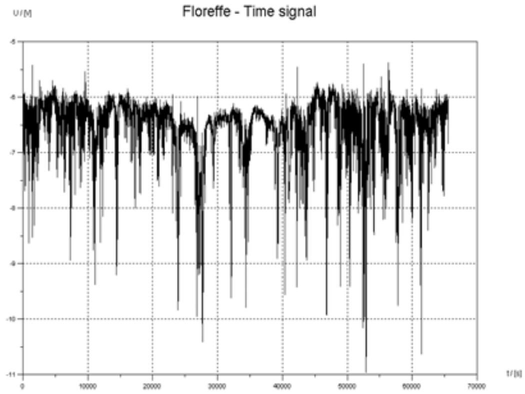
Picture 10: Recording 8 “Chaudfontaine 2”



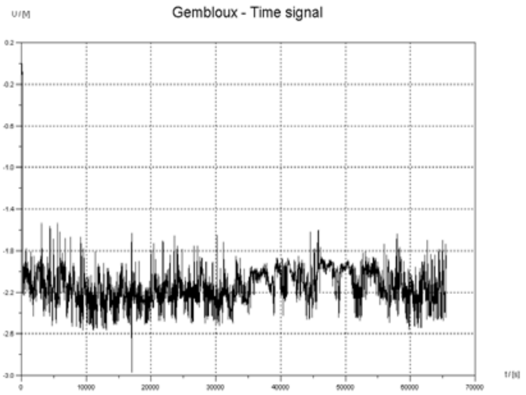
Picture 11: Recording 9 “Monsin”



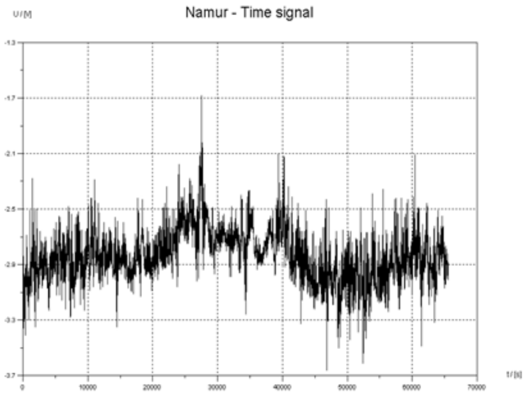
Picture 12: Recording 10 “Floreffe”



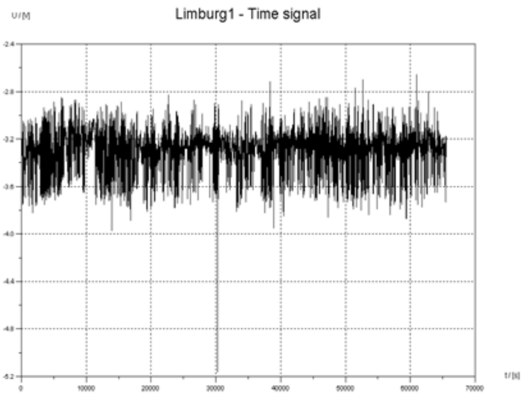
Picture 13: Recording 11 “Gembloux”



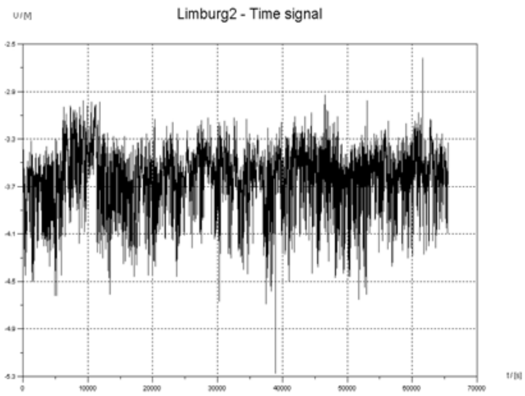
Picture 14: Recording 12 “Namur”



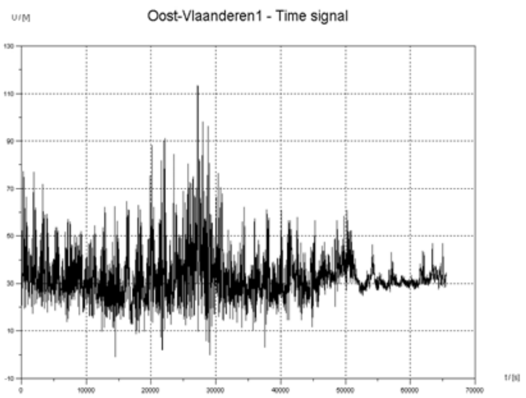
Picture 15: Recording 13 “Limburg 1”



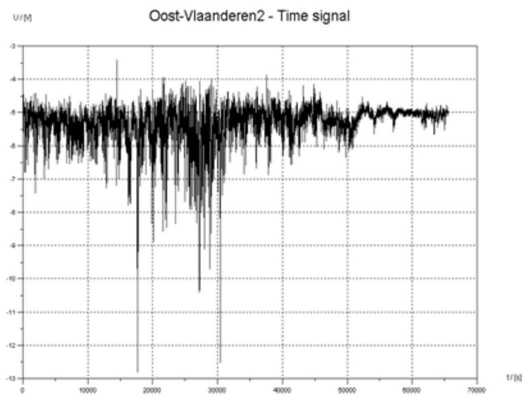
Picture 16: Recording 14 “Limburg 2”



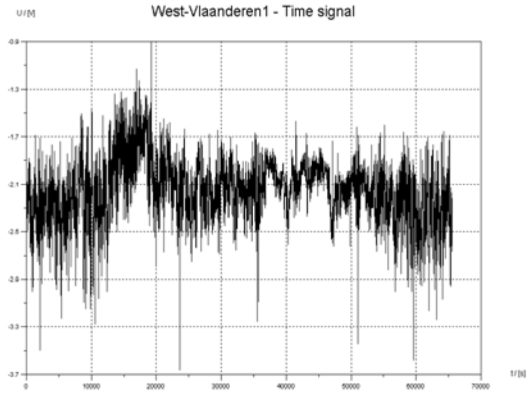
Picture 17: Recording 15 “Oost-Vlaanderen 1”



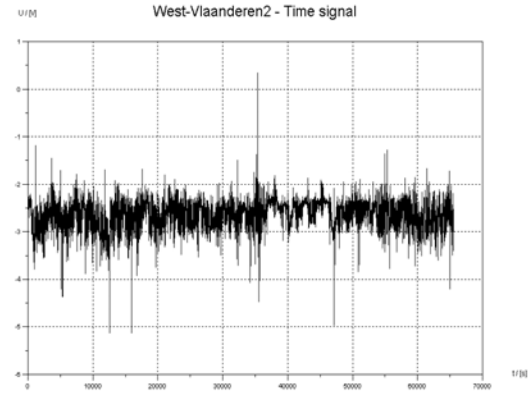
Picture 18: Recording 16 “Oost-Vlaanderen 2”



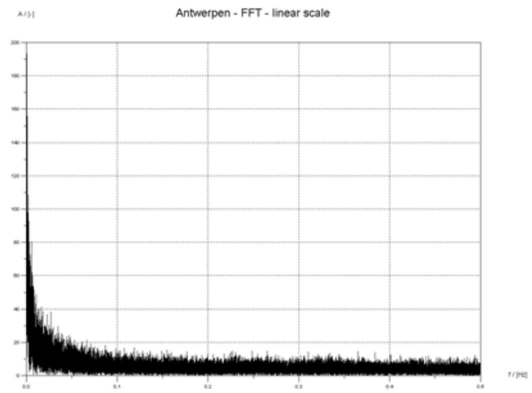
Picture 19: Recording 17 “West-Vlaanderen 1”



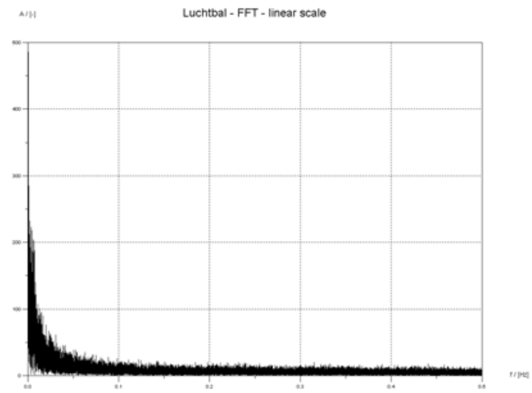
Picture 20: Recording 18 “West-Vlaanderen 2”



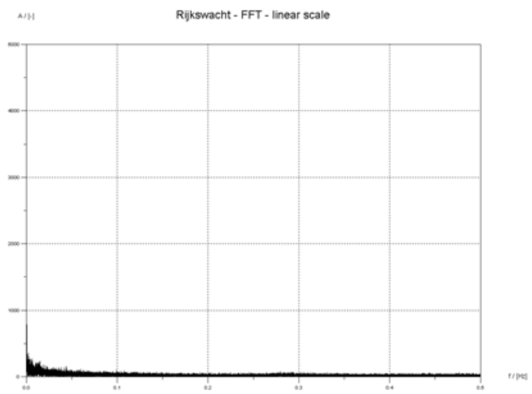
Picture 21: FFT 1 “Antwerpen”



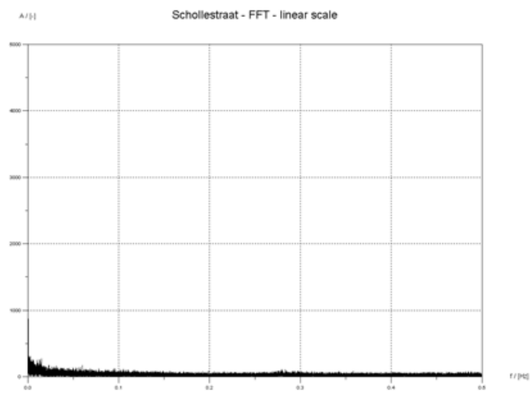
Picture 22: FFT 2 “Luchtbal”



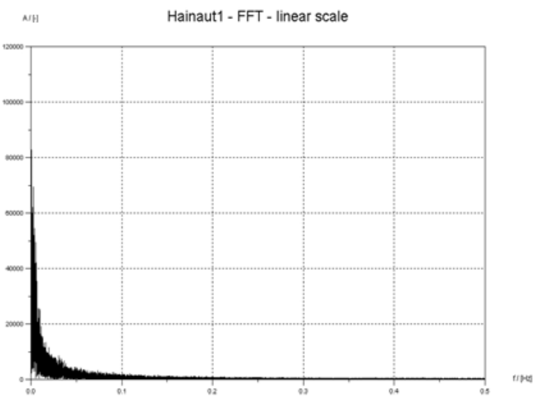
Picture 23: FFT 3 “Rijkswacht”



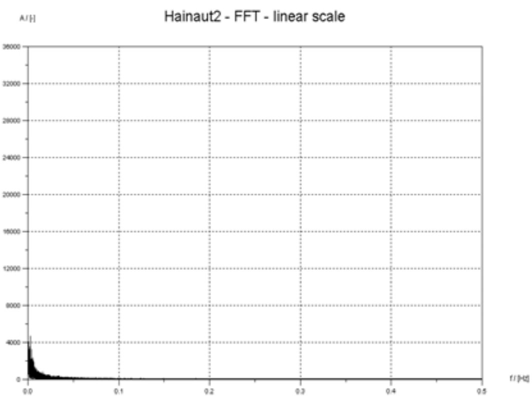
Picture 24: FFT 4 “Schollestraat”



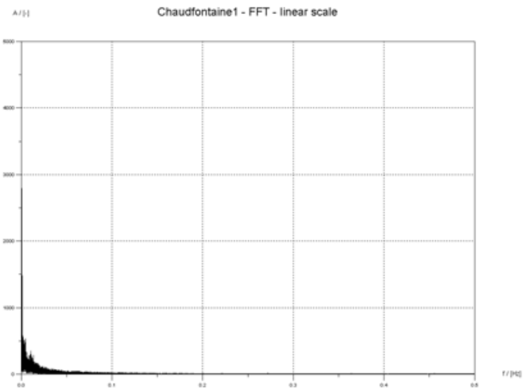
Picture 25: FFT 5 “Hainaut 1”



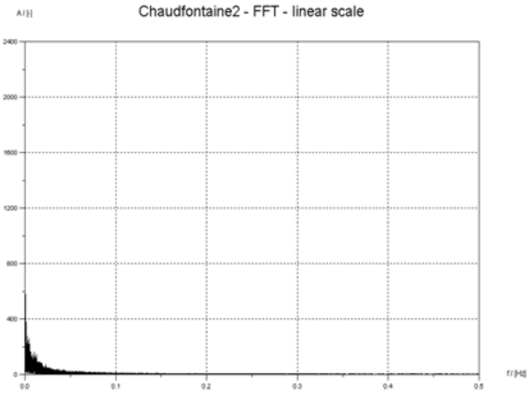
Picture 26: FFT 6 “Hainaut 2”



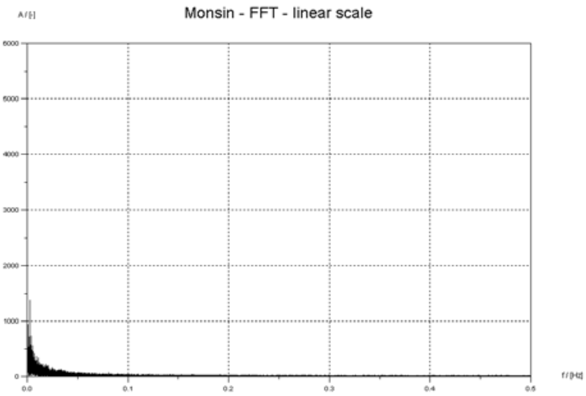
Picture 27: FFT 7 “Chaudfontaine 1”



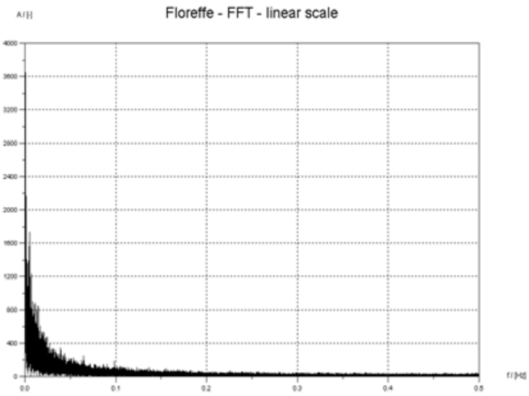
Picture 28: FFT 8 “Chaudfontaine 2”



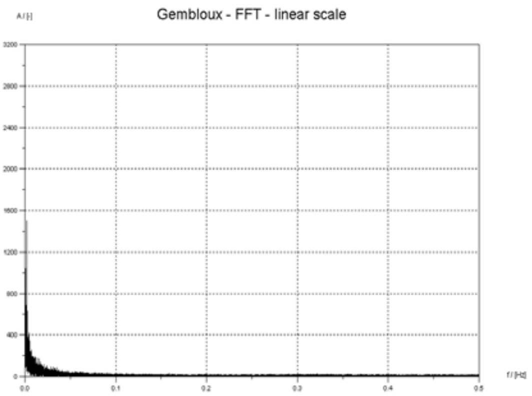
Picture 29: FFT 9 “Monsin”



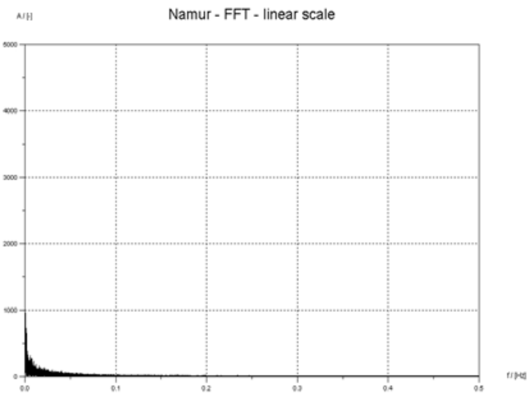
Picture 30: FFT 10 “Floreffe”



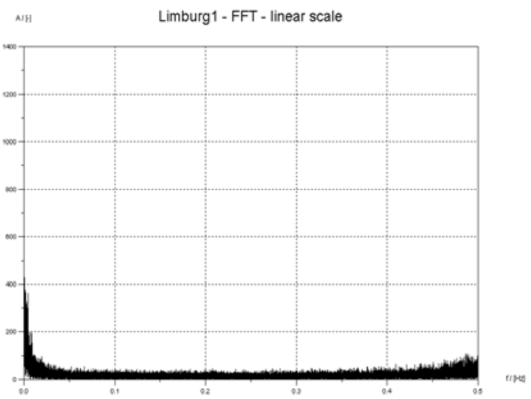
Picture 31: FFT 11 “Gembloux”



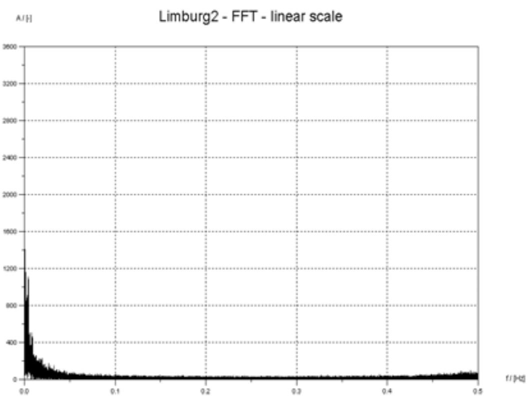
Picture 22: FFT 12 “Namur”



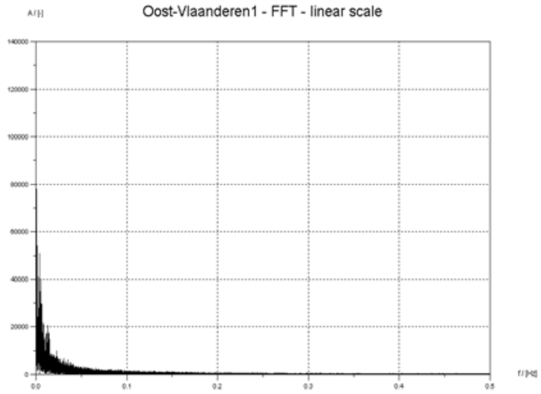
Picture 33: FFT 13 “Limburg 1”



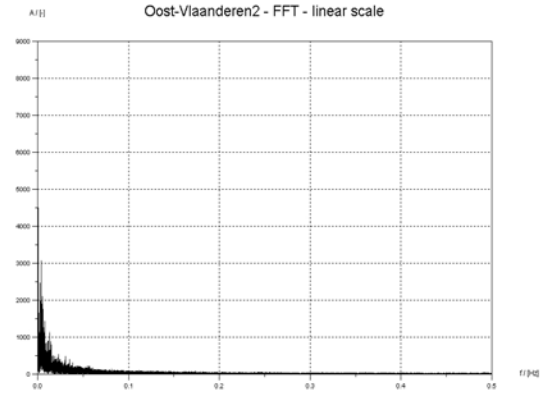
Picture 24: FFT 14 “Limburg 2”



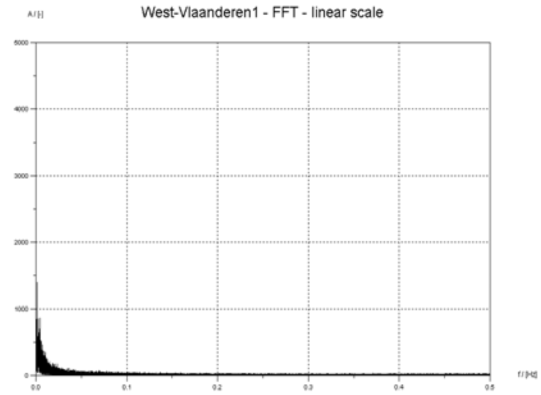
Picture 35: FFT 15 “Oost-Vlaanderen 1”



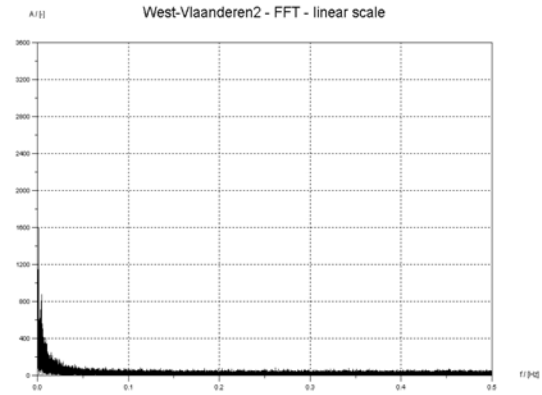
Picture 26: FFT 16 “Oost-Vlaanderen 2”



Picture 37: FFT 17 “West-Vlaanderen 1”



Picture 38: FFT 18 “West-Vlaanderen 2”



Picture 39: RTU with rechargeable battery pack