AC INTERFERENCE ON PIPELINES IN SOUTHERN SWEDEN

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ABSTRACT

AC interference on a section of pipeline in southern Sweden was measured in February 2011 and October 2012. The measurements were made with fast sample dataloggers with GPS timing that allowed the waveform and time of the pipe-to-soil potential variations to be captured. These show that the AC interference were out of phase at opposite ends of the pipeline section. The recorded waveforms were not simple sinusoids but had considerable distortion. Spectral analysis showed, as well as the AC fundamental (50 Hz), there were significant components at the 3rd (150 Hz) and 7th (350 Hz) harmonics, as well as the 4th (200 Hz) and 8th (400 Hz) harmonics. Odd harmonics frequently occur on a power system. However, even harmonics do not usually occur but are produced by the AC/DC converter on a nearby DC cable. AC ground beds are used to reduce 50 Hz and will normally also reduce higher frequencies.

Introduction

In southern Sweden a branchline built in 1985 to transport natural gas is connected to the mainline in the vicinity of Oxie and supplies measuring and reduction stations: Svedala, Östra Grevie and Trelleborg. When a DC power cable was built in 1991 this created changes in pipe-to-soil potential that interfered with the cathodic protection of the pipeline. To reduce this interference insulating joints were installed to break the pipeline into shorter sections. The measurements reported here were made on the southern-most section from Trelleborg to north of Svedala. In the vicinity of this pipeline section there are high voltage AC transmission lines, a DC overhead line and an underground DC cable, all of which are potential sources of interference on the pipeline. This paper presents a series of recordings of pipeline potential variations made to investigate the interference contributions from these sources.

Pipeline and Surroundings

The pipeline is constructed for 80 bar and has 323.9 mm diameter and 7.5 mm wall thickness from the insulating joints to Östra Grevie and from Östra Grevie to Trelleborg the pipeline has 219.1 mm diameter and 5.1 mm wall thickness with polyethylene (PE) coating. The pipeline is 19.2 km long and runs approximately north-south as shown in Figure 1. Cathodic protection is provided by rectifier with horizontal magnetite anodes. AC earthing connections are installed at 4 sites, each site consisting of capacitors connected to 4 zinc rods.

There are both AC and DC power lines close to the pipeline. The AC lines include a 130 kV 3-phase power line parallel to part of the pipeline. There is also a 400kV AC power line that crosses the northern part of the pipeline section. The DC line is the overland part of the Baltic Cable that runs from Sweden to Germany [1]. The Baltic Cable provides monopolar DC power transmission, meaning that the electric current passes through the cable from Sweden to Germany and the return current flows through the Earth. The earth return current flows to an electrode in the sea off the south coast of Sweden and from there flows along an underground DC cable back to the converter station.

Measurements

Two sets of pipeline potential recordings were made: the first in February 2011 and the second in October 2012. The recordings were made with two different dataloggers connected between the pipeline test post and a CuCuSO4 electrode used as a ground connection. The first datalogger was a SmartloggerII that was configured to make 5-second recordings at a sampling rate of 2000 samples/sec. The second datalogger was a digital audio recorder set with a sampling rate of 8000 samples/sec that recorded continuously for hours. Both recorders had sampling rates fast enough to capture the shape of the AC waveform. During both recording intervals the AC earthing connections (capacitors connected to zinc rods) were disconnected from the pipeline.

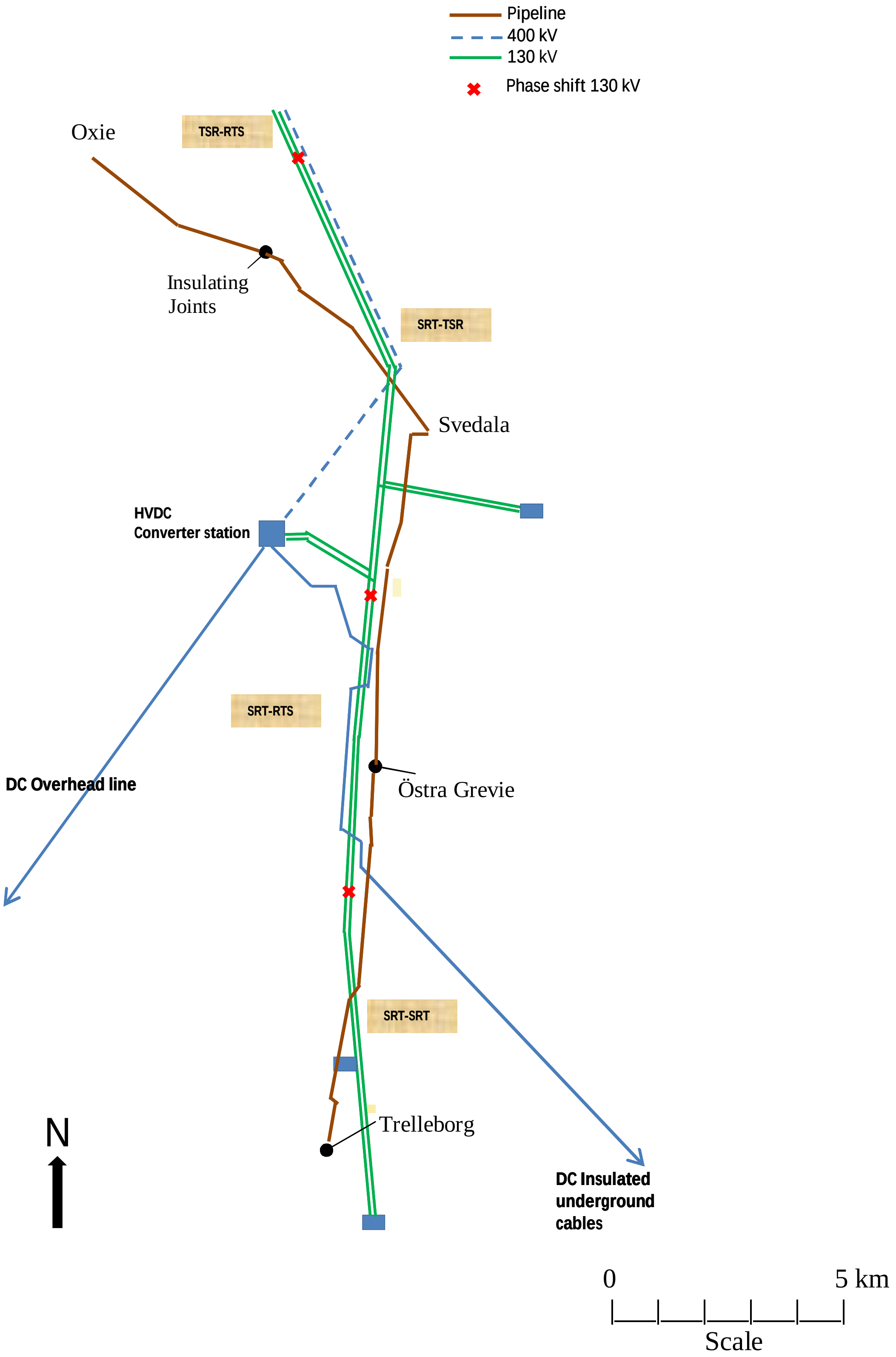

Figure 1. Map of pipeline and AC and DC lines in southern Sweden.

February 2011 Recordings

During the first period of recordings in February 2011, two GPS-timed dataloggers were used. One datalogger made recordings at one location chosen as a 'reference' site and the other 'portable' datalogger was used to make recordings at other sites. Recordings were made simultaneously on the portable and reference dataloggers and the accuracy of the GPS timing enabled the recordings to be used to determine the phase relation between the AC waveforms at the two sites. By comparing the phase relation from all the portable recordings to the simultaneous reference recordings enabled the relation between the AC waveforms at all recording sites along the pipeline to be determined (Figure 2).

The recordings shown in Figure 2 are ordered from north (top) to south (bottom). These show that the AC waveforms on the pipeline have changes in phase from north to south. Thus the voltage fluctuations are out of phase at opposite ends of the pipeline.

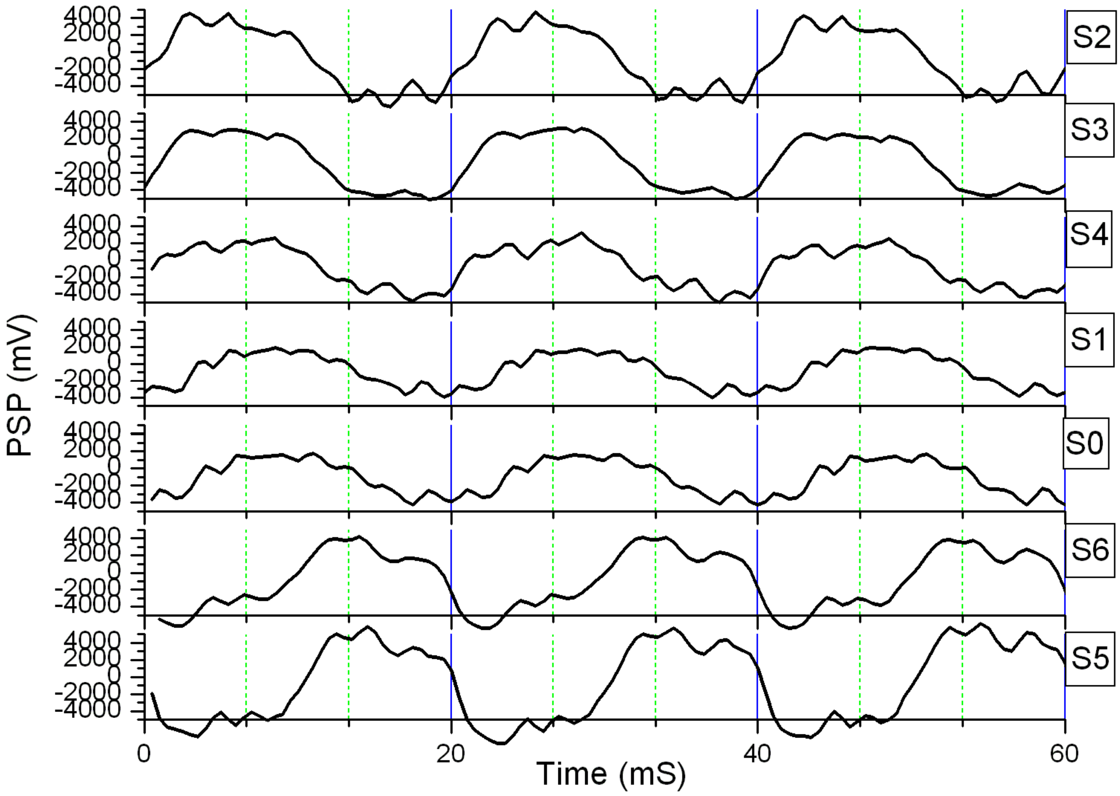

Figure 2. Recordings of AC waveforms.

Spectral analysis was performed by taking a Fast Fourier Transform of each 5-second recording. A Hamming window was used to reduce end effects in the data. This analysis gives the amplitude of the spectral components up to a frequency of 1000 Hz. In practice the components above 500 Hz were small so only the spectral components from 0 Hz to 500 Hz are considered.

An example of the recordings, from the reference site, S0, together with a spectral analysis of the recording are shown in Figure 3. As well as the expected 50Hz signal there are signals at 16.7Hz and 33.3Hz and at harmonics of 50Hz, particularly the 3rd harmonic (150 Hz) and the 8th harmonic (400 Hz). The other sites had slightly different sizes of the spectral components but all featured the 3rd and 8th harmonics. Odd harmonics are often found on AC power systems, however even harmonics are not usually produced. Therefore the signals at 400Hz seen at most sites are unusual.

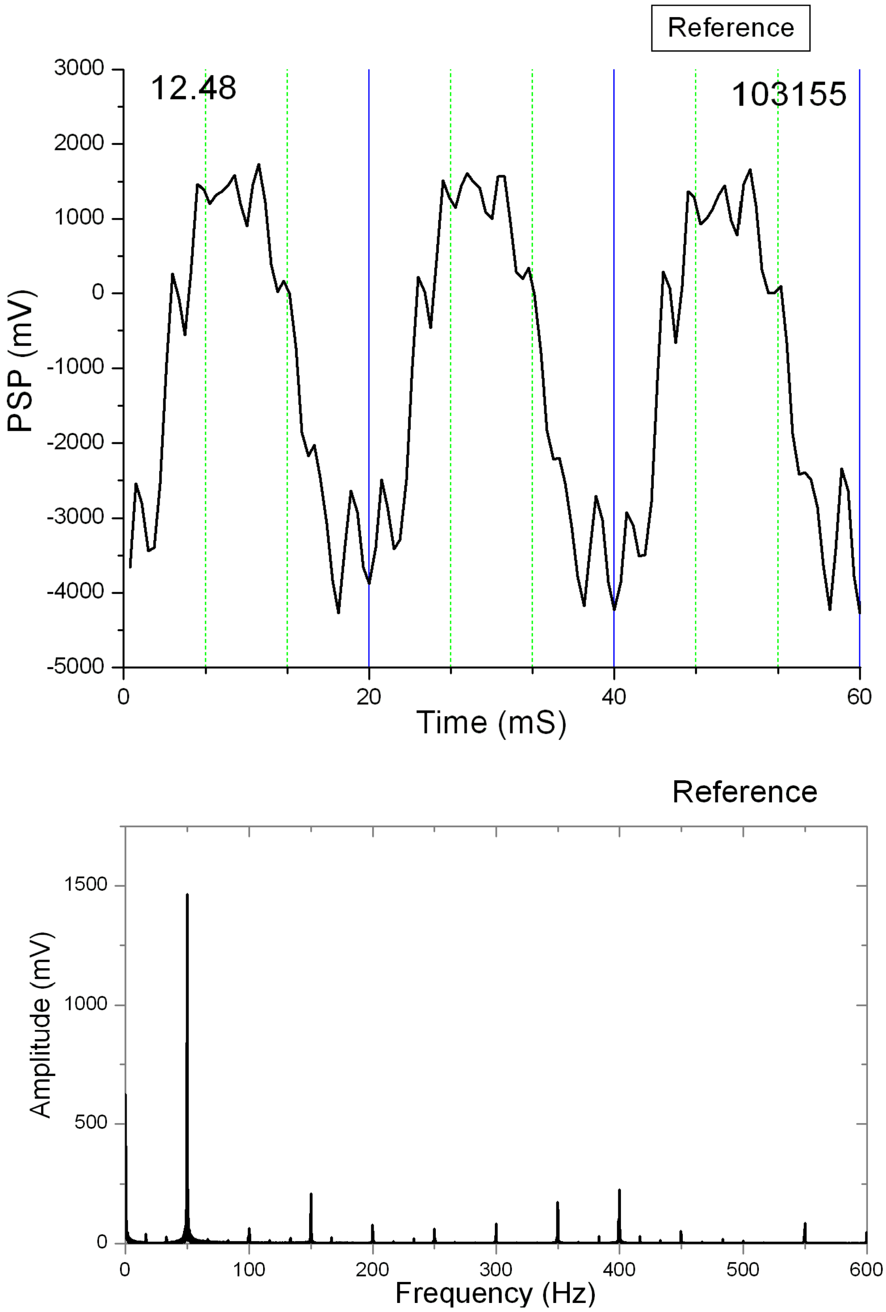

Figure 3 a) Recording at the reference site,
b) Spectral analysis of the waveform.

October 2012 Recordings

To investigate the source of the even harmonics a second set of recordings was made in October 2012. These recordings were made at two times: (i) when the power transfer on the DC cable was on, and (ii) when the power transfer on the DC cable was switched off. Figure 4 shows an example of the recordings made when the DC cable power was on.

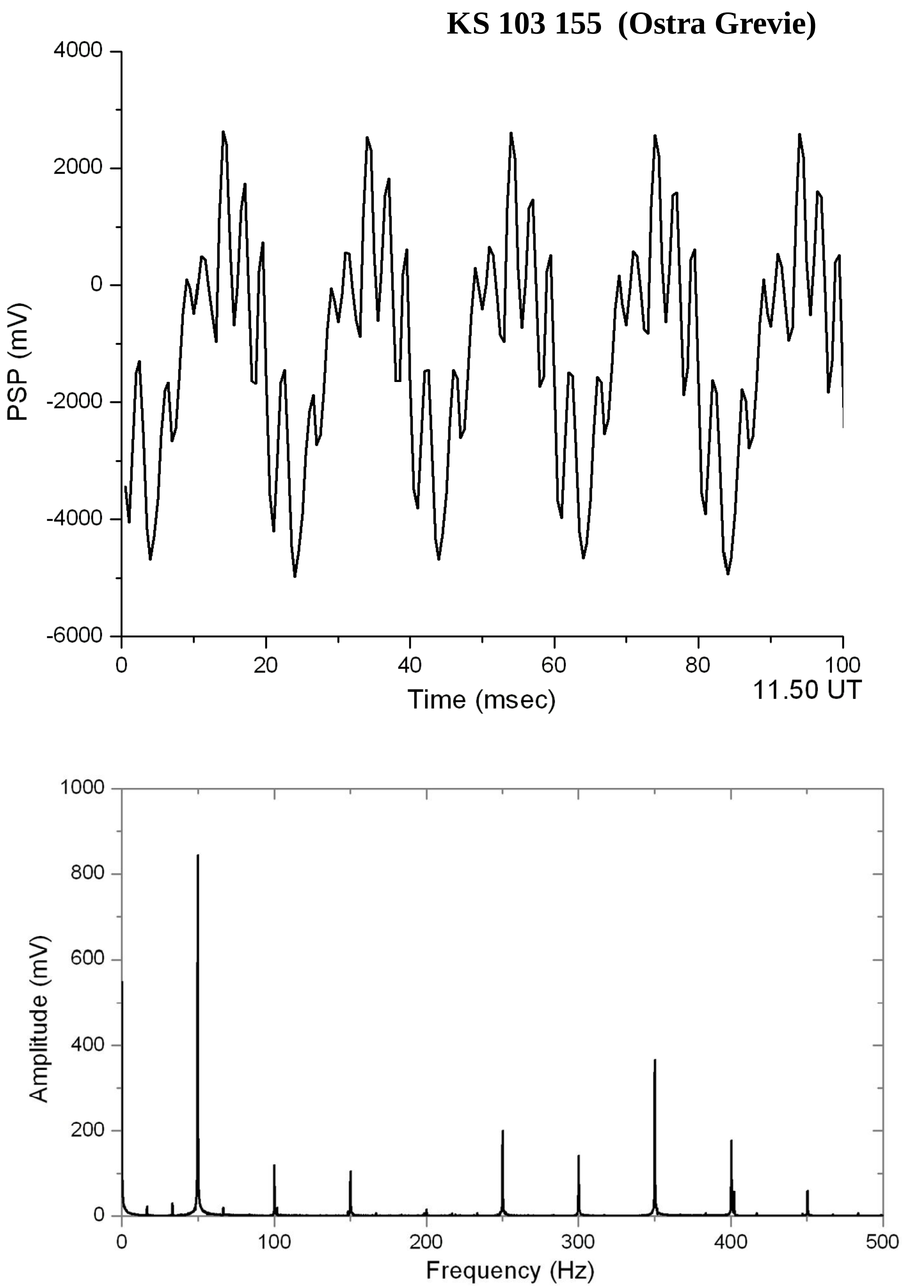

Fig 4. Recordings made with DC cable power transfer on.
a) waveform, b) spectrum

This shows the distorted waveform seen in the 2011 recordings (Figure 3) and a similar harmonic content. Recordings made when power transfer on the DC cable was switched off show a much less distorted waveform and a similarly reduced harmonic content (Figure 5). A significant feature of Figure 5b is that the even harmonics appear to have been completely removed. Replotting Figure 5b with a logarithmic amplitude scale shows that there are still some even harmonics present but that they are now an order of magnitude less than the odd harmonics.

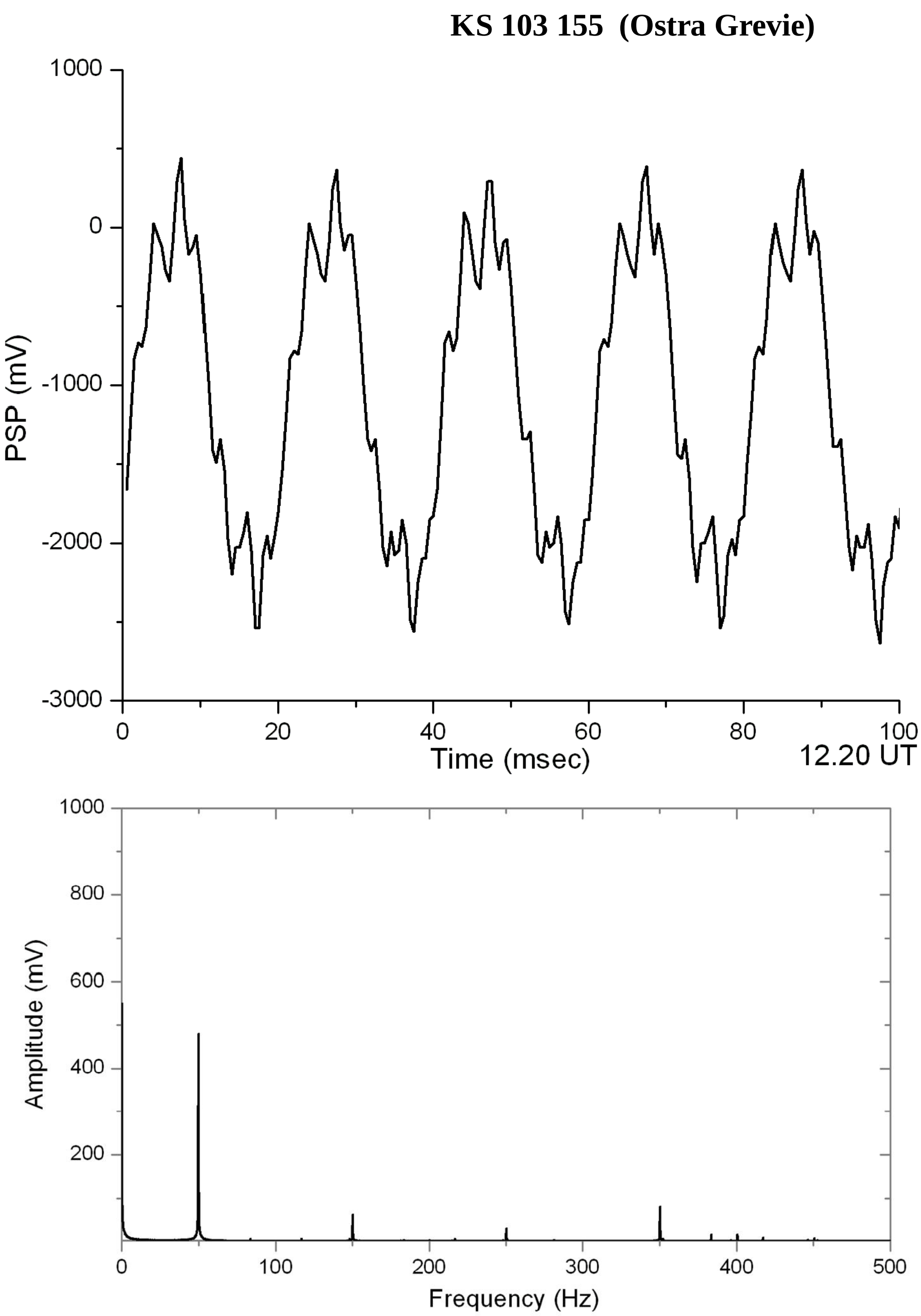

Fig 5. Recordings made with DC cable power transfer off.
a) waveform, b) spectrum

Recordings were also made with the digital audio recorder and used to calculate the root-mean-square (rms) values every second for the PSP. These rms values show a drop between 12.00 UT and 12.06 UT (Figure 6) that coincides with the reduction in power transfer on the DC cable.

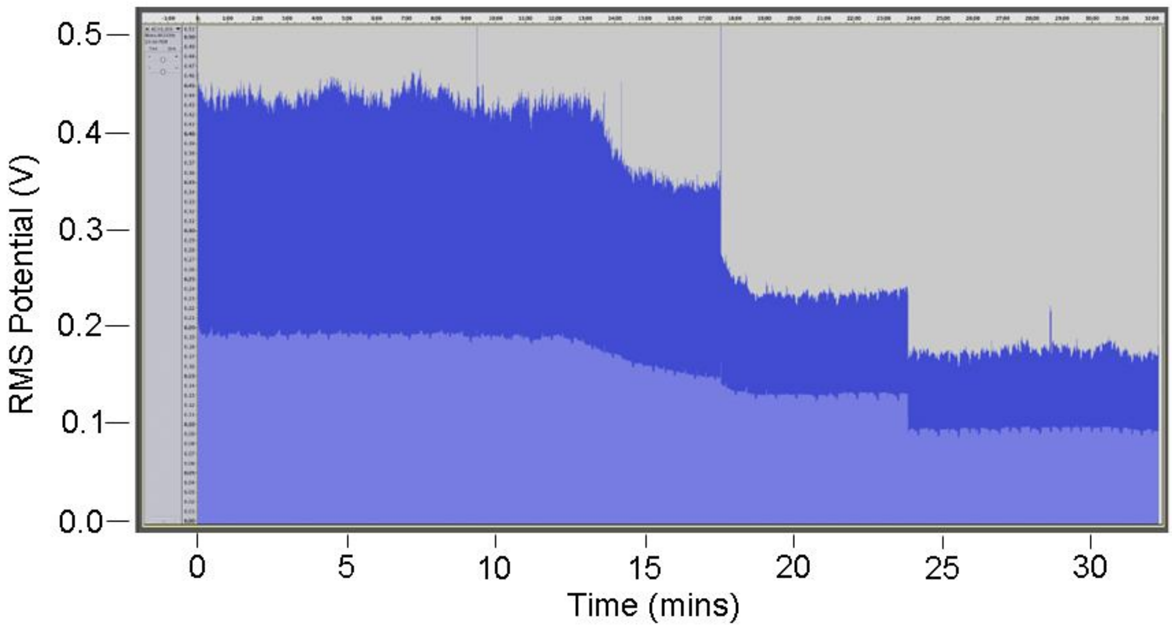

Figure 6. Pipe to soil potential (PSP) variation change in amplitude during the switch off of the DC cable.

Discussion

AC induction in pipelines has been recognised for a long time as a concern for maintaining pipeline integrity, eg [2]. Considerable work has gone into modelling the electromagnetic induction produced by AC power lines when pipelines and AC power lines share a common right-of-way [3 - 5]. These studies have all focussed on induction at the fundamental frequency of the AC, which is 50 Hz in Sweden. However recent measurements have shown that higher harmonics can also be induced in pipelines [6].

The measurements reported in this paper show that HVDC system can also give rise to harmonics on neighbouring pipelines. These harmonics arise from the AC/DC converters. Filters are installed on the AC and DC sides of the converter to reduce these harmonic currents so that they do not cause unacceptable interference on neighbouring phone lines. Improvements in technology have led to a change from passive filters to active filters [7]. The Baltic Cable uses an active DC filter that reduces the harmonics in the frequency range 500 - 3000 Hz [8]. However this still leaves some harmonics at the lower frequencies.

AC induction in pipelines depends not only on the amplitude of the AC currents but also their phase relationship. The fundamental frequency currents in 3-phase transmission lines are 120° out of phase and, in normal operation, will sum to zero. Similarly the magnetic and electric fields produced at an adjacent pipeline will be 120° out of phase. If the three phase conductors of the transmission line were equi-distant from the pipeline then these fields would also sum to zero at the pipeline. However, in practice the phase conductors are often approximately one above the other. Their different distances from the pipeline means that the contributions from the three phases do not exactly sum to zero. The fields are reduced compared to those produced by in-phase currents by a "geometric factor" dependent on the distances to the phase conductors. For the power line / pipeline situation in [6] the geometric factor had a value of 600 and similar values can be expected in other cases.

AC induction at harmonic frequencies depends on the phase sequence at each harmonic. The 2nd, 4th, 5th, 7th, 8th harmonics have a phase relation described as 'positive sequence' or 'negative sequence' where the currents are 120° out of phase. Triplen harmonics (3rd, 6th, 9th, etc) are zero sequence, meaning that the currents in the three phases are in phase. The significance of this is that the triplen harmonics induce electric fields in the pipelines that are all in phase, whereas the other harmonics experience the same "geometric factor" reduction as the AC fundamental frequency. Thus the harmonic currents which are all in phase produce larger electric fields in the pipeline compared to the other harmonics.

For the DC line, there is a single conductor for the submarine cable. At the Swedish end, in the vicinity of the pipeline, there is an overhead line as shown in Figure 7. This shows that the DC current is carried on two conductors, but these conductors are electrically connected so the harmonics on each conductor will be in phase. This means there is no tendency for cancelling of fields as there is with the fundamental and non-triplen harmonics on 3-phase AC lines. Thus calculation of induction from the DC line harmonics does not include the "geometric factor" reduction used for AC fundamental frequency and non-triplen harmonics.

Figure 7. HVDC overhead lines in Sweden as part of the Baltic Cable.

This study has shown that a HVDC system connected to AC lines are a source of induction of AC harmonics on pipelines. There are established procedures for analysing AC induction in pipelines, although these have been focussed on the fundamental AC frequency. The expanding use of DC power transfer means that similar procedures may also be necessary for analysing AC induction from DC lines. In both cases it is necessary to extend the analysis to include the AC harmonics and to take account of the harmonic phase relationships as well as the harmonic amplitude. This would provide indication of the potential fluctuations that can be expected on pipelines adjacent to AC and DC power lines.

On the pipeline in Sweden the addition of AC zinc electrodes reduces the pipeline potentials down to safe levels. These electrodes, which were disconnected for the duration of the recordings described above, were installed to reduce the levels of the 50 Hz AC induction, but are effective at the harmonic frequencies as well.

Conclusions

AC harmonics have been observed on a pipeline in southern Sweden adjacent to AC and DC power lines. Recordings during a shutdown of power transfer on the HVDC system show that this is a significant source of the harmonics.

The recordings at multiple sites show that the AC voltage variations are out of phase at opposite ends of the pipeline.

Odd harmonics occur on AC power lines, but both even and odd harmonics occur on the DC line. These harmonics result from the operation of the HVDC converter. Filters are installed on both the AC and DC side of the converter station to reduce harmonic levels at frequencies that may interfere with telephone circuits. However, the filters do not reduce the amplitude of lower frequency (< 500 hz) harmonics on the DC line.

Induction due to harmonics on AC lines is significantly affected by the phase relationship of the harmonics on the three phase conductors. The triplen harmonics are in phase so their fields sum together at the pipeline, whereas the fields from non-triplen harmonics tend to cancel.

Induction due to harmonics on the conductors of the overhead part of the DC line are in phase so that the fields they produce at the pipeline will sum together.

The connection of AC earthing capacitors to the pipeline to reduce the AC voltages at the fundamental frequency (50 Hz) also has the effect of reducing the voltages at the harmonic frequencies.

Acknowledgements

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