Gathering data from the waves

Elizabeth Nicholson, Cathodic Technology Ltd, Canada, explores the use of waveforms as diagnostic tools for close interval cathodic protection surveys.

Waveforms, or scopes, have been around in the world of close interval potential surveys (CIS/CIPS) for decades, but are often underutilised. A lack of knowledge about their usefulness is the main cause. The name associated with the data comes from the equipment used to obtain it. The reading is taken with an oscilloscope-like device (hence 'scope read'), which displays and records the waveform of a set period. Many modern CIS instruments have this ability built in, making it easy to view and record a waveform during a survey.

A standard waveform will take over 1000 data points every second for a set duration. This allows a graph to be created showing both the AC and DC being read by the instrument at that point. Electronics professionals use this frequently to diagnose both electronic component and signal issues. Cathodic protection (CP) surveyors can use waveforms to:

- Confirm that reading delays are set correctly.
- Confirm current interrupter synchronisation.
- Observe rectifier function and efficiency.

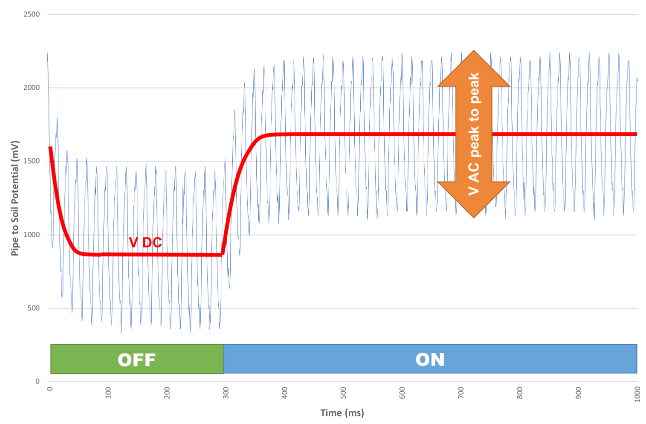

Figure 1. Typical waveform with OFF/ON and AC.

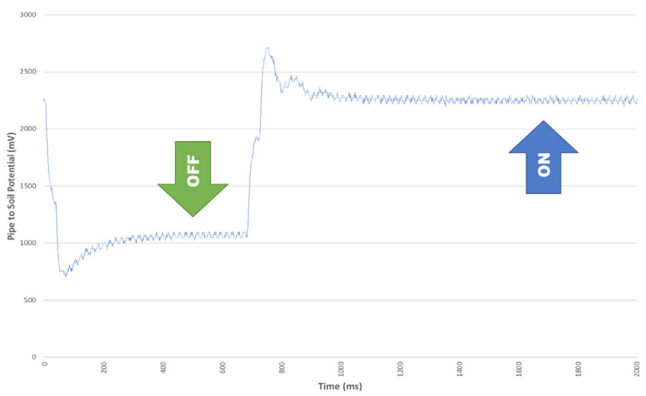

Figure 2. Induction spike.

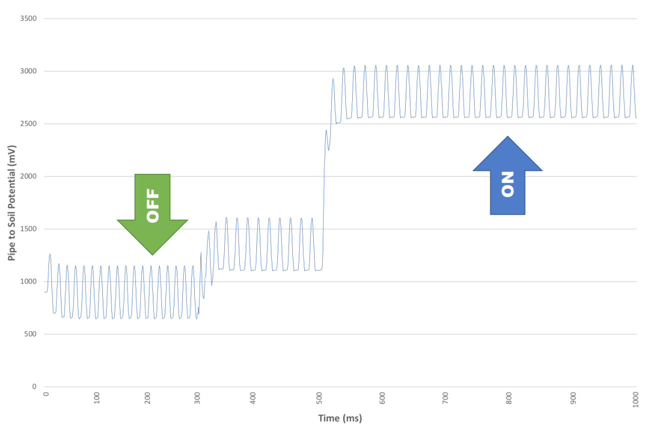

Figure 3. Unsynchronised interrupter cycles.

- Examine the magnitude of AC at a specific location.
- Confirm that all influencing rectifiers are interrupted through frequency analysis.

Typical waveform

Figure 1 shows a standard waveform from a CIS survey, a series of sine waves. This waveform records 2000 readings/sec. for the duration of the one second survey cycle. The OFF and ON portions of the cycle are easily visible, as is a small amount of background AC on the structure. There is a curved shape to the start of both the ON and OFF, shown by the red line. This is caused by capacitance of the pipeline coating in the soil, which occurs on most lines. The AC wave is shifted away from zero by the DC voltage of the pipe. AC rejection on survey instruments is a hardware and software calculation to eliminate any AC from the DC reading, with the output being a pure DC measurement – the pipe-to-soil potential.

Figure 2 shows an induction spike. Instead of the curve at the start of the OFF and ON, as seen in Figure 1, there is a spike instead. Attempting to record minimum/maximum with a digital voltmeter (DVM) would capture the spikes, and not the true OFF and ON readings required for CIS.

Measurement delay

The capacitance of the coating and inductance of the pipe are the primary reasons for measurement delays in CIS. If the equipment takes a reading at the same time as the current interrupter switches, the reading can be distorted. Waiting a short time and then taking the reading during the stable section of the cycle ensures the most accurate reading. This setting can be found on many instruments, and is known as 'delay time' or 'measurement delay'. It can be pre-programmed by the manufacturer or set by the user. Adjusting the cycle timings and delay times is the best way to compensate for the induction and capacitance. Being able to set and adjust these delays is one factor that sets true CIS instruments apart from standard DVMs. In the case of Figure 1, measurement delays of 200 msec. for the OFF and 500 msec. or more for the ON are recommended. For Figure 2, delaying the measurement to 500 msec. OFF and 1700 msec. ON will avoid any induction or capacitance distortions.

When all current interrupters (CI) are synchronised, a clear ON and OFF will be visible on the waveform. Any waveform with extra steps in it indicates synchronisation issues. With the current use of GPS, synchronisation problems are reduced, but can still occur, especially if one current interrupter has a different program. Figure 3 shows the effect of two interrupters that are synchronised but set to different OFF times. One is set to 300 msec. OFF, the other to 500 msec. OFF. A distinctive step pattern is visible in the waveform. Ideally, the surveyor should change the interruption cycle. If this is not possible, careful planning of the delay time will still allow the surveyor to obtain accurate readings. In this case, obtaining the OFF at 200 msec. and the ON at 800 msec. should yield accurate CIS results.

Auto-potential rectifiers

Another unique waveform is found when interrupting auto-potential rectifiers. Figure 4 shows a normal OFF cycle, with

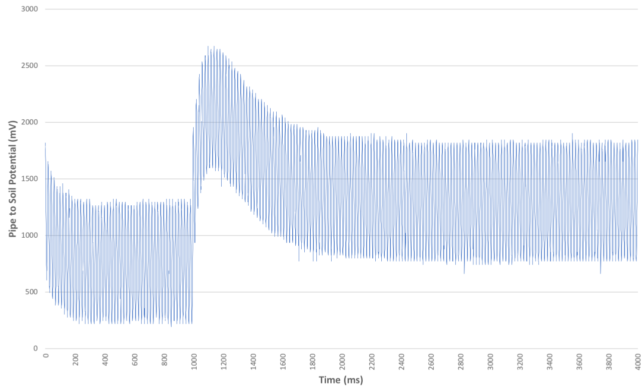

Figure 4. Auto-potential interruption.

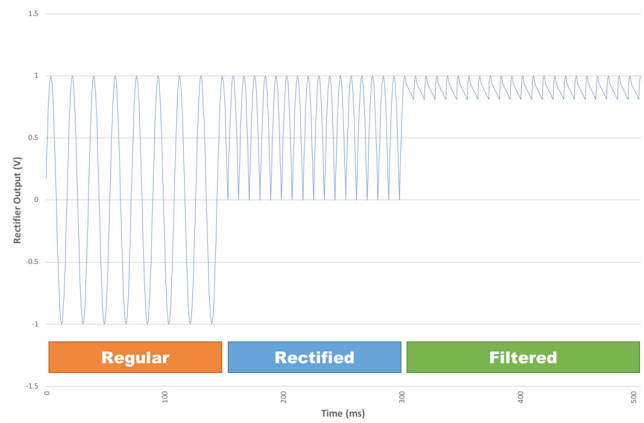

Figure 5. AC wave, rectified and then filtered.

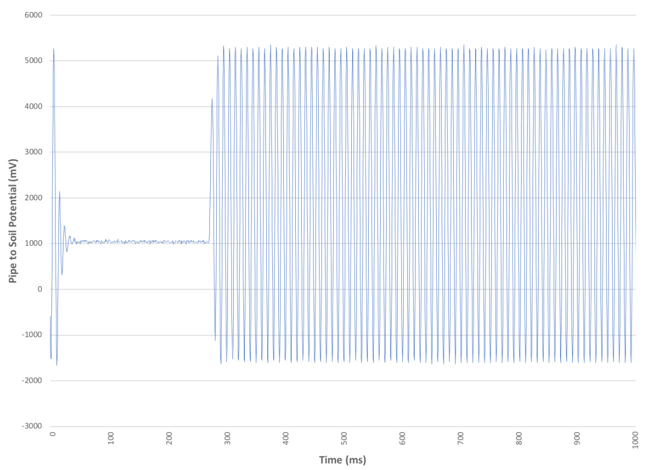

Figure 6. Unfiltered rectifier.

the pipe-to-soil potential decreasing. During the OFF, the rectifier has registered the decrease in potential as well. The rectifier will increase the voltage to the maximum output to attempt to immediately restore the pipe-to-soil potential. As soon as the CP current flow is restored, the rectifier spikes with the maximum voltage, then decreases back to normal operation. This is the cause of the large spike at the beginning of the ON in Figure 4. Auto-potential rectifiers are beneficial for maintaining consistent CP in dynamic stray current conditions, but are very difficult to survey with. Ideally, all have an interruption feature built in that will prevent such spiking. However, most surveyors are forced to use longer cycle times to allow the spiking to dissipate prior to obtaining their reading.

Rectifier function

Most CP rectifiers operate by rectifying AC, as shown in Figure 5. The incoming AC is rectified, allowing the current to flow in one direction only. This has a side effect of doubling the number of waves (frequency) seen in a waveform reading. The output is then filtered to reduce the fluctuation in the DC output and stabilise the pipe potential.

Rectifier filtration

Waveforms are extremely useful in the field to confirm proper interruption and rectifier function. The waveform in Figure 6 shows an interrupted rectifier that has very poor or non-existent filtration on the output, hence the significant wave after 250 msec. This shows good interruption during the OFF phase of the cycle; the CIS should record valid OFF data. Improved rectifier filtration will improve the efficiency of the rectifier and ensure consistent DC flow for the CP.

AC analysis

In electrical parlance, the distance between the peaks is referred to as the peak-to-peak AC voltage (Figure 1). However, most AC magnitude is recorded in root mean squared (RMS) voltage to denote the effective power of the AC wave. To convert from one to the other is a simple mathematical formula:

$$RMS = \frac{Peak - to - peak}{2.8}$$

Or, rearranged:

$$Peak - to - Peak = 2\,x\,\sqrt{2}\,x\,RMS$$

Standard North American voltage of 120 V AC RMS would have a peak-to-peak of 336 V AC. European voltage of 230 V AC RMS would have a peak-to-peak of 650 V AC. Fortunately for operator safety, such high levels are rarely seen on pipelines. Induced local AC below 10 V peak-to-peak is much more common, and does not generally present any safety hazard for touch or step potentials. The voltage in Figure 1 is 1 V peak-to-peak or 0.36 V AC RMS. More information about AC safety and mitigation on pipelines is provided in NACE standard SP0177.

A waveform taken at a test point near AC power lines will give a good indication of the induced AC on the pipe in that area. However, a waveform taken further away may be distorted by induced AC voltage on the trailing wire. Best survey practice is to take and save a waveform when the trailing wire is short, such as immediately after connecting to the test point.

Pipe locator influence

Waveforms can also be used to detect other influences in the area, such as pipe locators. Figure 7 shows a lot of electrical activity superimposed on the expected CP and induced AC

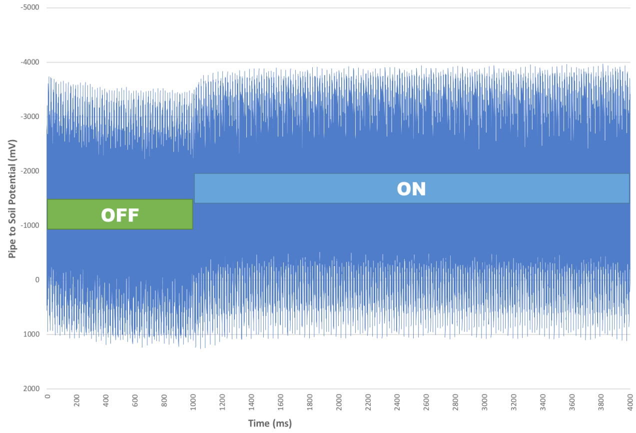

Figure 7. Pipe locator interference.

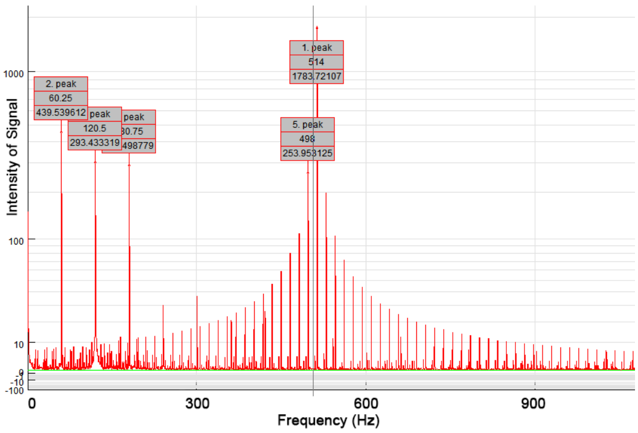

Figure 8. Fast fournier transform (FFT) analysis.

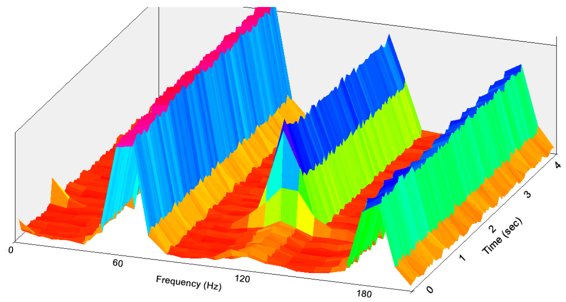

Figure 9. Frequency vs time.

voltages. This makes it difficult to visualise the OFF and ON portions of the cycle, although it can be faintly seen.

Frequency analysis

It can be useful to compute the frequencies in a waveform to either troubleshoot unexpected results or confirm rectifier and CI function. Fast fournier transform (FFT) is an algorithm that allows the user to input a data set and calculate the frequencies found in it. Some CIS instruments can perform FFT analysis in the field. For those that cannot, the file can be saved and analysed back in the office by a signal analysis program.

Further analysis of the Figure 7 waveform by FFT is shown in Figure 8, where the largest influence is at 514 Hz. In the field, a pipe locator was set up at the same test post, operating at approximately 512 Hz during the CIS. Most of this extra activity was from the pipe locator. Harmonics (echoes) of the pipe locator are also seen decreasing on both sides every 16 Hz from the 514 Hz.

Common frequencies observed in North America are 60 Hz, 120 Hz and 180 Hz (Figure 8). In Europe and Asia, the corresponding frequencies are 50 Hz, 100 Hz and 150 Hz. These correspond with local one phase (60/50 Hz) and three phase (180/150 Hz) AC. Decreasing harmonics of the mains 60 Hz can also be seen at 240 Hz, 300 Hz, etc. The interesting frequency is the 120 Hz, which represents the rectified AC from the CP rectifier. Looking for 120 Hz in North America or 100 Hz in Europe during the OFF will indicate if there are rectifiers influencing the survey area. Figure 6 shows significant 120 Hz AC during the rectifier ON and minimal ripple during the OFF phase. Figure 7 is more difficult to visualise from the waveform, however plotting frequency, time, and magnitude on a 3D plot can yield clear results (Figure 9).

There is both 60 Hz and 180 Hz voltage present throughout the interruption cycle in Figure 9. However, the 120 Hz is not present in the first quarter of the cycle and returns in the rest of the cycle. This matches the interruption cycle that was programmed at the rectifier, 1 sec. OFF followed by 3 sec. ON. Therefore, all rectifiers influencing this area are properly interrupted. The presence of voltage at 120 Hz during the OFF phase would indicate that at least one rectifier is not interrupted; it should be found and interrupted prior to continuing the survey to ensure accurate results. If all rectifiers are interrupted and there is still 120 Hz during the OFF, then there may be a foreign CP system influencing the pipeline.

Conclusion

When surveying, the best practice is to observe and save the waveform:

- At the start of every survey day.
- When hooking onto a new test point.
- When near overhead AC lines.
- When the CIS data is unusual.

During a CIS it is important to take, view and save waveforms to ensure accurate data is being gathered. The waveform can be used in the field to confirm synchronised rectifier interruption and proper delay times. Later, it can be used to troubleshoot questionable data and provide proof to the pipeline operator of correct survey procedure. Additional information about stray currents, pipe locators, rectifier filtration and other details can also be seen. Waveforms are often misunderstood and forgotten, resulting in a loss of critical survey data. Increased awareness and education about waveforms will help the surveyor to quickly diagnose any issues and ultimately obtain the most accurate data from the field.