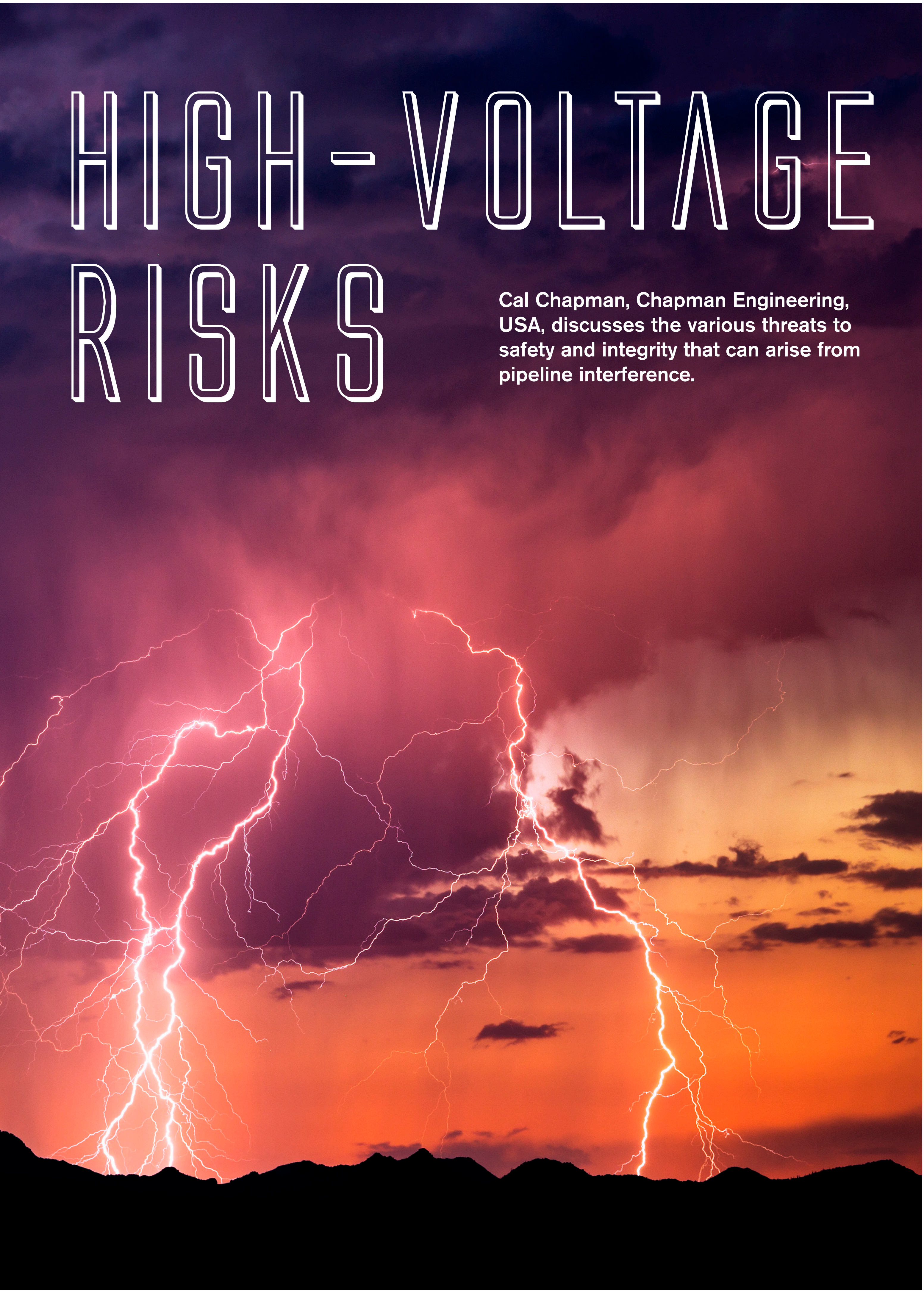
Underground steel pipelines are the transportation mode of choice for many crude oil, natural gas, and other petroleum products, as well as for water, wastewater, and other liquid or gaseous products. Steel pipelines have electrical properties, since the welded steel line pipe becomes a long, electrically active 'wire'. Some specific types of electrical behaviour relate to electrochemical pickup or loss of cathodic protection (CP) currents, and conduction of those direct currents (DC) through the pipeline metal. Others arise from high-voltage power lines, other electrical circuits in the area, and natural phenomena such as lightning and what are called telluric currents, or 'earth currents'.

Electrical and electromagnetic interferences often occur between two or more steel pipelines, when they cross one another and even when they run relatively close together. The two most common types of interference, both arising from the application of CP for control of external corrosion, are called 'anodic interference' and 'cathodic interference'.

Some experts in this field will call the interactions an 'influence' if no damage is being caused, and 'interference' when there is damage actually occurring to one or more of the pipelines involved. However, with changing environmental conditions, time passing, and even more pipelines or other below-grade structures

HIGH-VOLTAGE RISKS

Cal Chapman, Chapman Engineering, USA, discusses the various threats to safety and integrity that can arise from pipeline interference.



may readily change to interference, and even back to influence again.

Two major gas transmission pipelines lie close to one another in Grant County, Kansas (US), as shown in mapping from the US National Pipeline Mapping System (NPMS) online database (Figure 1). Each pipeline is more than 30 years old, with coatings that are aged and relatively ineffective. This means that each pipeline requires large CP systems designed and installed at fairly regular intervals along the right-of-way (ROW).

Anodic interference

Anodic interference is that caused by a positive voltage field formed around an impressed-current CP system anode bed, affecting a foreign body of metal (usually pipeline) passing through the voltage field. The foreign metal structure is electrochemically shifted to become more positive, causing aggressive corrosion to any of the 'foreign' metal exposed to soil and moisture contact.

In Figure 2, each pipeline is seen to have a 20-anode 'conventional' anode bed installed (the two beds shown inside yellowed ellipse outlines), with each anode bed showing circular 'dead grass' patterns over anode locations. For the CP system at the upper left, protecting the more northerly pipeline, it was recently using approximately 80V DC to deliver 85A DC of

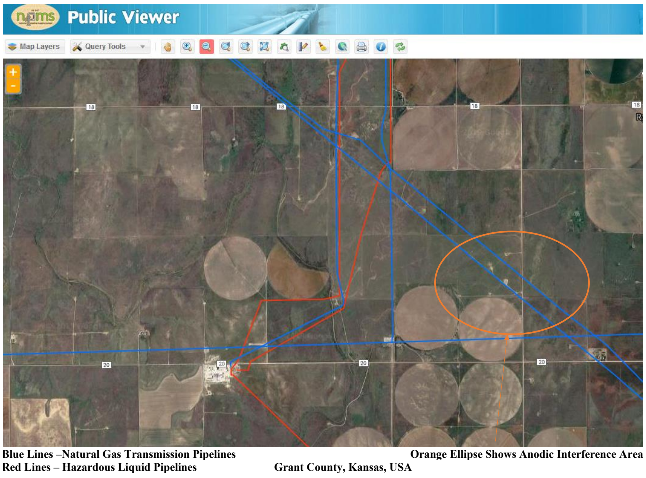


Figure 1. US National Pipeline Mapping System map of two pipelines in Kansas, US.

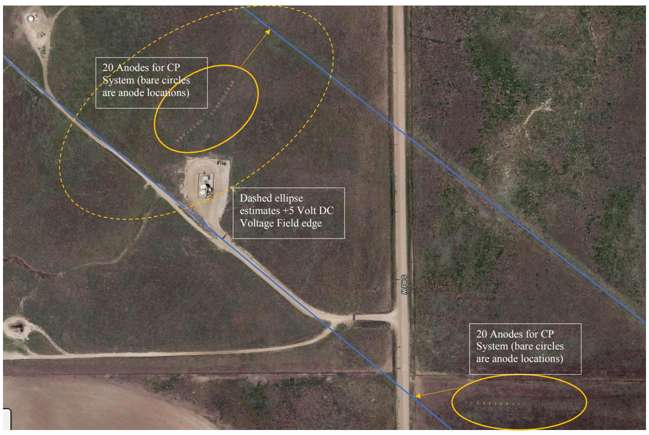


Figure 2. Two pipelines, each with a CP system causing influences.

protective current. This 80V maximum field strength is so potent, and the electrochemical reactions at each anode so aggressive, that the soil dead grass spots appear. These anodes, likely around 5 ft in original length and 2 - 3 in. in diameter, were installed in vertical borings. While the burial depth should have been 15 ft or 20 ft for the bottom of each anode, the dead circles suggest that anodes were buried to shallower depths.

As each anode has positive DC driven from it, with that current then flowing through soils to deliver protective current to exposed pipeline metal, the anode surface and soils beside it are chemically acidified. As a result of these chemical reactions taking place, water as soil moisture is consumed, and the local soils immediately around each anode dry out severely. The actual temperature of soil beside and above each anode may increase. All of these factors contribute to plants dying above and around each anode.

Risks

This localised effect, though, is not the significant danger. The strong electric voltage field, which is present due to the CP system rectifier applying power to anodes through the system wiring, is a danger to someone walking across the area. For each step taken, if a DC voltage across the person's feet is greater than approximately 15V, the human body (or a four-legged animal) may receive an electric shock. Called a 'step potential' threshold, this needs to be assessed by the pipeline operator. If the risk is too great (and it could be worse during or after a rainfall), then this area should be blockaded and signage added to warn of the danger. Think of workers who might be checking the well pad just to the south. What if a cow had walked into that voltage field and collapsed due to electric shock? What if a worker, or rancher, then walks out to check on the cow? Might the person collapse there, as well?

There is a third and substantial threat present. The pipeline located to the south is not electrically connected with the northern pipeline, and does not get protection from this CP system just north of the well pad. However, this CP system, applying an 80V electric field, is producing an electrochemical voltage shift on the well pad metal, and on the southern pipeline. Whenever a buried piece of metal suffers a shift in local voltage in the positive direction, it becomes much more susceptible to external corrosion. This is specifically called anodic interference. Cathodic interference occurs when CP current collects on an unintended, foreign pipeline, then jumps from that line to the to-be-protected pipeline. Any time DC leaves a body of metal, it aggressively corrodes that metal surface from which it 'jumps'.

Problems arise when many pipelines and CP systems are constructed in fairly tight geographic areas. One company's CP causes adverse consequences to other companies' pipelines, and vice versa. This happens due to the protective DC taking different pathways than just the pipe for which protection is intended. Nature sometimes offers a lower electrical resistance for part of the overall electric CP circuit by using another pipe. Where current transfers from the intended pipeline to the unintended one, the first party's pipe can corrode rapidly. Then, when the 'borrowed' protective current leaves the second party's pipe to go back to the first pipe and to the original CP system (which it always must do), corrosion occurs rapidly at that second party jump-off point, too. When this corrosion attack is concentrated in a small enough area, a pipe fails, and a leak can occur.

The 30 in. diameter red pipeline (Figures 3 and 4) was crossed 42 times in 2.5 miles by other steel pipelines. The pipeline operator had dug up three sections of this pipeline along approximately 2 miles of length. By detailed inspection of the pipe external surface, and condition of the red coating, three different patterns of damage showed interaction of foreign CP current with this pipeline.

First, on some portions of the pipeline, small water-filled bubbles had been formed under what looked to be intact coating. Figure 3 shows water bubbles under coating, and the water's pH of 12 - 12.5, strongly alkaline, and demonstrating a large CP voltage shift in place on pipeline metal. The amount of CP being applied in this area was creating the water bubbles, due to cathodic over-protection. Because the company's only CP system on this line, within 60 miles, was less than a mile away and not sending much current, foreign CP currents were the suspects in this case of over-protection.

At another pipeline dig more than a mile west, similar water-filled bubbles and pH measurements were found. However, at a dig location not more than 0.25 miles from the first dig described, the following conditions were found.

The litmus paper in Figure 4 shows a pH in the range of 8 - 8.5. Because the pH scale is logarithmic, a change from 8 to 9 represents an increase in alkalinity by a factor of 10. Comparing this pH with the earlier one, a change in pH from 8.5 to 12.5 represents a factor of 10 000 difference in alkalinity or acidity. CP was being applied at each position on this pipeline, since the pipeline was made of continuous carbon steel. However, the amount of effective CP applied at the defect was approximately 0.01% of that applied at two pipe locations, to the west and east of this defect. This is caused only by foreign CP currents being present, and counteracting the operator's CP current at this defect, while they add to the CP effect at the other two reference locations.

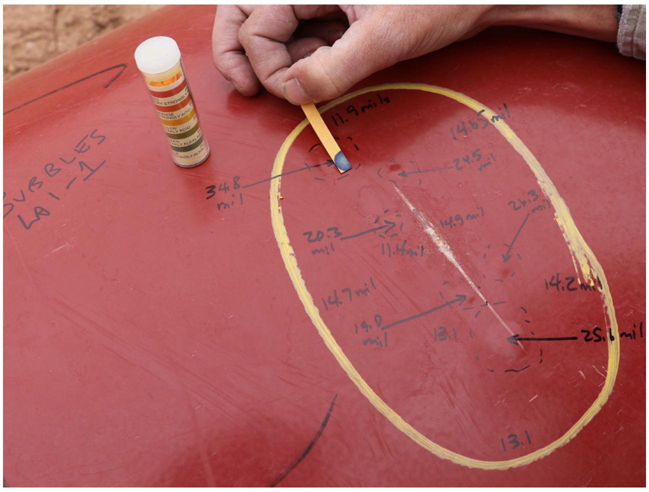


Figure 3. **Water bubbles built under coating by cathodic over-protection and electro-osmotic reactions.**

Figure 4. **In-between dig and exposed pipeline metal with acidic conditions.**

With so many pipelines laid in this area, each with separate CP system networks in use, the cathodic interference patterns, risks, and damages occurring are complex and very hard to separate. On the red pipeline – which was in the ground for less than three years when these digs were opened – the worst corrosion pit found had already penetrated one-third of the wall thickness.

Other types of electrical interference can arise from:

- High-voltage power lines running close to pipelines. This happens due to Faraday's law of induction; a wire cutting a changing electromagnetic field induces alternating current (AC) power onto that wire. This happens when a steel pipeline, with good-quality coating (electrical insulation preventing contact with the soil/water electrolyte), is passing through the electromagnetic field of a high-voltage power line run.
- A separate electric current put on the pipeline, perhaps by lightning strike, or by a large electric arc welding machine, or possibly by an AC power system's fault current (think of an electrical tower and high-voltage lines collapsing in a storm onto an above-ground pipeline valve set). When this happens, the conductively coupled current, whether AC or DC, travels at nearly the speed of light to go to ground. If a human is part of that grounding at the wrong instant, death or severe injury occurs.
- The accidental electrical joining of a regional power grid's AC neutral wire system to metal with CP systems. This can result in most CP current being applied to buried copper wiring and other structures, rather than the intended pipeline(s).

Conclusion

The more crowded a particular geography becomes, the more likely these electrical interference patterns will cause irreversible damage to pipelines and other metal structures being used, unless good survey and other predictive steps are taken. There may be threats to personnel, and if on an open pipeline ROW with exposed metal appurtenances, threat to the general public. This comes from voltages becoming too high, and the hazard of shock. Either touching an energised pipeline, or even stepping into an elevated voltage field, can cause injury or death to people and animals.

References

1. 'Corrosion control's lines of defence', *World Pipelines*, May 2019.

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Company Profile

Chapman Engineering, Inc., a Texas USA corporation founded in 1989, offers corrosion control and engineering, environmental engineering, subsurface environmental assessment and corrective action, ground-water availability studies, and specialty construction and survey related to corrosion control. Starting in underground fuel storage tank (UST) release detection and cathodic protection of steel USTs, Chapman Engineering has worked in the corrosion protection marketplace since the mid-1990s. It designs, constructs and manages cathodic protection systems for water, sewer and
electrical utilities and infrastructure, oil and gas production and transportation systems, and refining/petrochemical complexes.
The firm's multifaceted engineering team has over three decades of experience in corrosion control design, installation of cathodic protection (CP), coating quality and AC power interaction evaluations with pipelines, and review of existing asset integrity, as well as CP system commissioning,
testing and optimizing across the industries. Our team has a proven track record of effectively mitigating the corrosion risk for steel, ductile iron, concrete pressure pipe, storage tanks, and other metal assets across North America.