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CORROSION CONTROL

The Effect of Overhead AC Power Lines Paralleling Ductile Iron Pipelines

by Richard W. Bonds, P.E.

Last Revised:
March 2017

Sharing of rights-of-way by AC power lines and buried pipelines has become quite common. This trend is mainly due to the numerous restraints imposed by private and governmental agencies concerning the routing and the environmental impact that construction of such facilities have on a given area. These restrictions become even more severe as new construction approaches high density urban areas. This sharing of rights-of-way raises the question as to the effect overhead AC power lines have on buried pipelines.

Voltage on Pipelines

Voltage can be induced on a pipeline from overhead power lines in close proximity by (1) capacitance, (2) conductance, and (3) induction. The electrical influence exerted by a power line on a pipeline varies with the electrical characteristics and geometry of the individual system. AC voltage induced on a pipeline poses a shock hazard rather than a corrosion concern. Studies conducted by Galimberti¹ and Williams² concluded that AC current may cause corrosion at a rate that is only about 1 percent that of a similar electric quantity of direct current. Similarly, Pookote and Chin's³ investigation concluded that AC corrosion rate was less than 1 percent of the equivalent DC corrosion rate at the same current density.

A literature search regarding the effect of overhead power lines on pipelines sharing the same rights-of-way reveals that the vast majority, if not all, of the documents pertain to electrically continuous steel pipelines with a dielectric bonded coating. This is no surprise because the severity of the effect of an overhead power line on a pipeline is directly related to the pipeline's electrically continuous length that parallels the power lines and how well the pipeline is insulated from ground (the adjacent earth).

According to Lathrop, "Bare gas pipes would be expected to be relatively free of neutral currents because they are grounded their entire length. If AC entered the pipe, it would be free to exit a short

distance away. The pipe will be at ground potential, the same as the neutral wire grounds. Therefore, current flow between the electrical and gas system should be limited. Coated metallic gas pipes, on the other hand, are insulated from ground except at holidays or points of damage in the coating."⁴

Blasingame states, "Probably the single most important factor which is causing the most problems is the dramatic improvements in the quality of pipeline coatings in the last quarter of a century. Earlier pipelines had so many holidays they were effectively grounded and high voltages could not build up."⁵

Ductile Iron Pipelines

Ductile Iron Pipe is manufactured in nominal 18- and 20-foot lengths and employs a rubber-gasketed jointing system. These rubber-gasketed joints offer electrical resistance that may vary from a fraction of an ohm to several ohms, but, nevertheless, is of sufficient magnitude that Ductile Iron Pipelines are considered to be electrically discontinuous. The rubber-gasketed joints segment the pipeline and prevent magnetic induction from being a problem. Additionally, in most cases, Ductile Iron Pipelines are installed bare and are therefore essentially grounded for their entire length, which further prevents magnetic induction on the pipeline. For these reasons, even parallel overhead transmission lines normally do not create a concern for Ductile Iron Pipelines.

In corrosive environments, the Ductile Iron Pipe Research Association and the manufacturers of Ductile Iron Pipe recommend encasing the Ductile Iron Pipeline with loose polyethylene encasement rather than a tight, bonded coating. Polyethylene encasement is not designed to be a watertight system. The film is overlapped at pipe joints and not sealed; therefore, typically some ground water will seep beneath the wrap. Due to this normal presence of moisture between the film and pipe, and electrically conductive moisture paths to the adjacent soil at pipe joints where the film is overlapped, the coating resistance of loose polyethylene encasement will typically be less than that of a tight, bonded coating. This condition will allow induced AC current to return to ground.

Capacitance

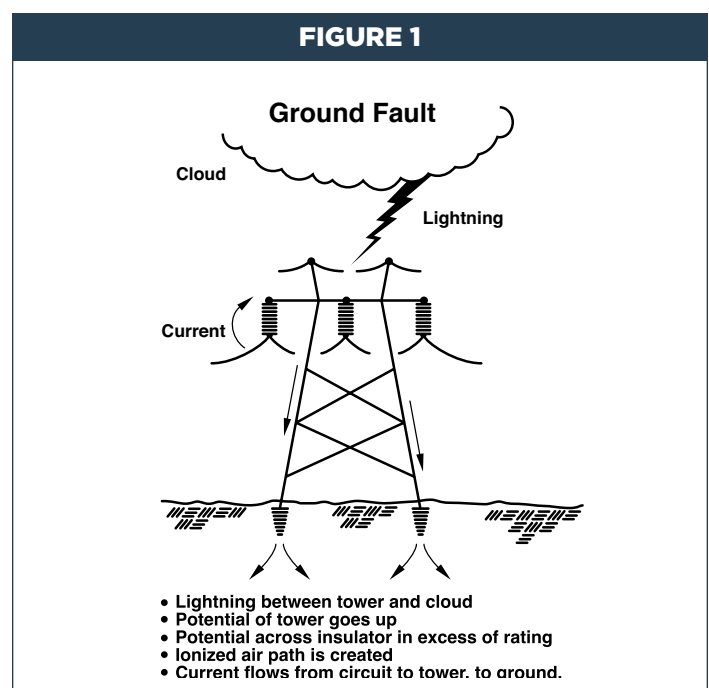
As noted earlier, voltage from overhead power lines can be induced by a capacitance effect (electrostatic voltage). This is a form of capacitive coupling operating across the capacitance between the AC transmission lines and the pipeline, in series with the capacitance between the pipeline and adjacent earth. Such a potential is not normally induced on a buried pipeline since the capacitance between the pipeline and earth is negligible, even when dielectric bonded coatings are used. However, during installation, a voltage can be produced by the influence of a strong electrical field on an insulated pipe when located above and insulated from the ground. The electric field tends to move electrons from the earth to the pipe and also from the pipe to the overhead power line. In some cases, the voltage can be above maximum safe voltage limitations for a pipe; however, in normal situations, contacting the pipe will only result in a slight electrical shock and the pipe voltage is immediately reduced to zero. During construction, safety precautions can be established during pipe installation to protect construction personnel from the hazard of electric shock. These include “limit of approach,” regulations governing construction equipment, grounding straps, chains attached to vehicles with rubber tires to provide a ground, etc.

Conductance

Problems involving conductance can occur during construction and also after installation. Electrical conductance can be caused by direct contact or ground fault conditions.

If accidental contact were made between an energized AC conductor and a metallic pipe, the pipe would rise to the potential of the conductor until the AC line is de-energized. Fortunately, this type of direct contact is very rare.

Electrical conductance can also be caused by a ground fault. In an electrical transmission system, the full potential of the circuit exists across the insulators separating the energized conductors and the tower. If lightning strikes between the tower structure and an overhead cloud, the potential of the tower could be raised to an extremely high voltage, which might result in the potential across an insulator to be in excess of its rating. When this occurs, an ionized air path will be created between the circuit conductor and the tower structure, which permits current to flow from the electric circuit to the tower structure, from the tower structure to earth and, via an earth path, back to the point of generation (Figure 1). Because the impedance in the ground fault circuit can be significantly lower than the normal circuit impedance, the magnitude of the fault current can be much greater than the normal balanced phase current.



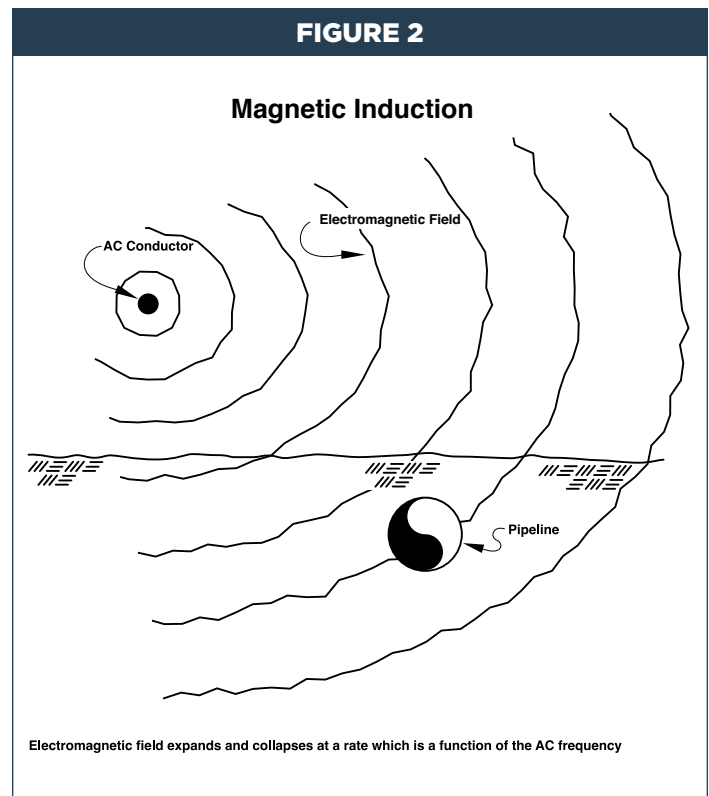
The ground fault current flows to earth through a grounding system installed at the base of the tower and then spreads uniformly through the earth (assuming a homogenous soil resistivity) in all radial directions. This current will result in a potential rise of the soil traversed by the ground fault current. However, an electrically continuous pipeline nearby with a dielectric bonded coating will remain at a relatively low potential (that of remote earth) due to the resistance of the coating. Therefore, the ground around the pipeline will be at a relatively high potential with respect to the pipeline potential. This could result in the coating and/or metallic pipe being damaged. If the fault current potential gradient is of sufficient magnitude, it could puncture a hole in the bonded coating. Furthermore, if the potential gradient occurs at the location of an existing coating holiday, a heating effect can flash the soil moisture and moisture in the holiday to steam and enlarge the holiday by stripping back previously adherent coating surrounding it.⁶

There are also possible hazards to personnel in the vicinity of ground fault currents. Should a person be touching an above ground pipeline appurtenance,— i.e., a main line valve, hydrant, etc.,— a large potential difference could exist between his hands (which are at a potential of remote earth due to the bonded coated, electrically continuous pipeline) and his feet (which are resting on earth undergoing the influence of the fault current). The person's hands would be at a potential representative of remote earth while his feet might be in an earth gradient of many thousands of volts.⁷ On the other hand, if the pipe coating has a low resistance, the pipeline collects a significant amount of current from the surrounding soil and rises in potential. At the same time, ground surface potentials in the vicinity of the pipeline decrease because of the influence of the pipeline. As a result, the potential difference between the pipeline and the surface ground can be reduced significantly.⁸ This would be reduced even further if the pipeline was bare. Additionally, if the pipeline is electrically discontinuous, its potential would be that of adjacent earth rather than remote earth. For these reasons, ground fault conditions pose far less of a concern for electrically discontinuous Ductile Iron Pipe.

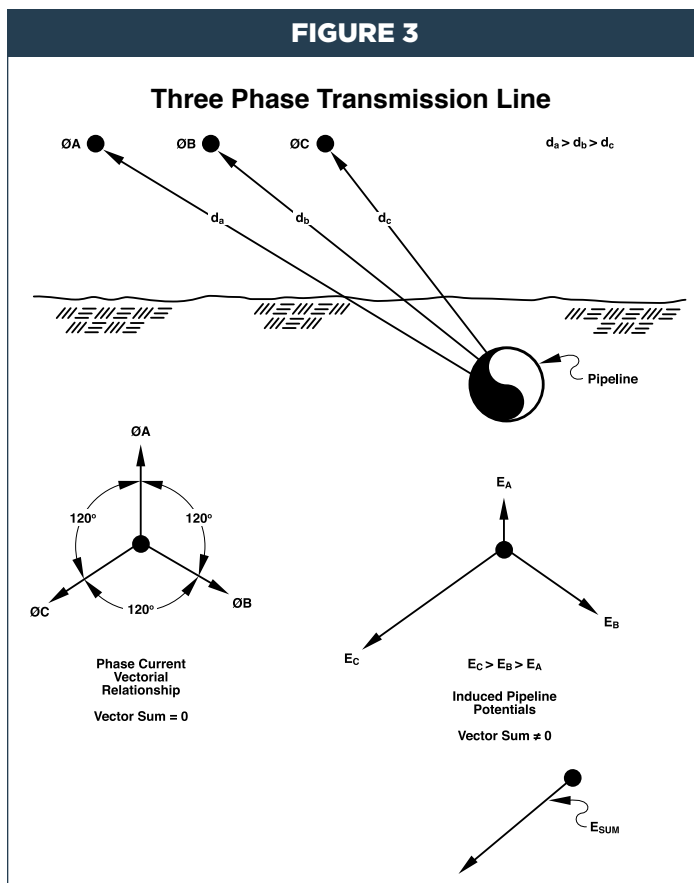
Hazards also exist at the tower structure. If a person is touching the tower structure while his feet are in contact with the earth's surface, the ground fault current would flow in a parallel circuit consisting of the person's body and the tower with the current divided as a function of the inverse of the branch resistances.

Induction

One of the greatest causes of voltage induction on pipelines is line current flow. Current flow in an AC conductor creates an electromagnetic field of force which always lies at right angles to the current that produces it. With alternating current, the field expands away from the conductor and then collapses towards the conductor at a rate which is a function of the system frequency. In the U.S.A., 60-cycle electric transmission lines are used to transport electric power. A cycle consists of one complete set of positive and negative; therefore, a buildup and collapse occurs 120 times a second. If a pipeline is close enough and parallel to the electrical transmission line, the electromagnetic field will “cut” through the pipeline at right angles (Figure 2). Where an electrically continuous coated pipeline parallels an AC transmission system for long spans — usually measured in miles — a voltage could be induced on the pipeline.



In the case of a three-phase AC transmission system where the current magnitudes in the three phases are equal and, where the three overhead phase conductors are equally distant from the axis of the pipeline, no induced potential would be present on the pipeline. However, the much more frequently encountered configuration in which there is no symmetry between the three phase conductors and the pipeline will result in a measurable induced AC potential as shown in Figure 3.⁷



The magnitude of the induced voltage and current on the pipeline is a function of the following:

1. Physical geometry of separation between conductors, and conductors and pipeline.
2. The resistance of the pipeline coating.
3. The longitudinal resistance of the pipeline.
4. The length of electrically continuous pipeline which parallels the electrical transmission system.
5. Magnitude of electric system current flow.
6. Frequency of the electric system.
7. Nature of the electric system, i.e., single or three phase.
8. Resistivity of the soil.
9. Discontinuities (where the pipeline diverts from the power line, where the pipeline changes distance with respect to the power line, etc.)

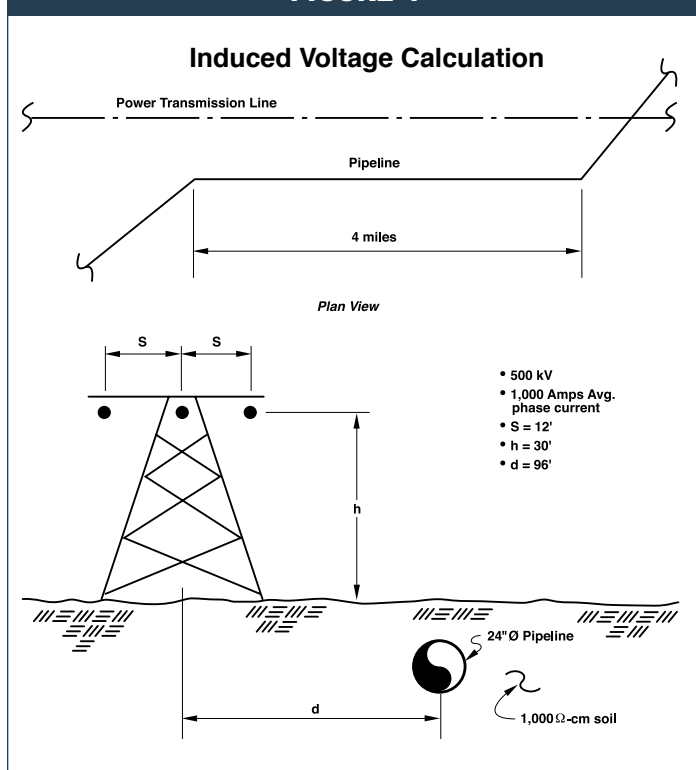
The items related to the pipeline that greatly affect the magnitude of induced voltage are the length of electrically continuous pipeline parallel to the electrical transmission system, the resistance of the pipeline coating, and the longitudinal resistance of the pipeline.

As late as the mid-1970s, analytical techniques for calculating induction levels were not accurate. When equations using Carson's series, developed to predict the coupling between AC power lines and adjacent aboveground communications circuits, were applied to underground pipelines, errors by an order of magnitude (10 times) or more would result. Using this method for buried pipelines failed because buried pipelines exhibit a continuously distributed resistance to earth. Hence, for the pipeline, the induced voltage is continuously drained to earth, thus limiting its peak value.⁹

In 1976, the American Gas Association and the Electric Power Research Institute co-founded a research program to investigate the induced voltage prediction and mitigation problem. The program was successful in the investigation of new mitigation techniques and in obtaining predictive techniques with accuracies on the order of 10 percent.¹⁰

Dabkowski¹¹, utilizing this work, reported a considerably simplified approach for a simple right-of-way, i.e., the single AC power transmission tower and the single pipeline, "worst case" voltage calculations, and mitigative designs with only a moderate loss of accuracy.

Assuming three coating conditions (bare, polyethylene encasement, and a well-applied dielectric bonded coating), the effect of pipe coating resistance can be realized when applying the hypothetical case shown in Figure 4 on the next page, to the procedures outlined in Reference 11. If non-electrically continuous joints are assumed in conjunction with any of these coatings, the induced voltage on the pipeline is virtually non-existent due to the 18- to 20-foot lengths of pipe acting electrically independent of one another; therefore, for this illustration it is assumed that the pipeline is electrically continuous.

FIGURE 4

For the configuration shown in Figure 4, the worst case voltage level occurs at the two discontinuities (where the pipeline diverts from the power line). This worst case voltage level is half the calculated open circuit induced voltage and is opposite in polarity at the two discontinuities. This is shown graphically for a perfectly coated pipeline in Figure 5. For the example, the worst case voltage level is 1.5, 9.5, and 42 volts for the bare, polyethylene encased, and dielectric bonded coated pipelines respectively. NACE RP-0177 "Mitigation of Alternating Current and Lighting Effects on Metallic Structures and Corrosion Control Systems" considers 15 volts AC open circuit to constitute an anticipated shock hazard.

If the pipeline is electrically discontinuous, as is a Ductile Iron Piping system, induced voltage is virtually non-existent. The effect of non-electrically continuous Ductile Iron Pipe with a perfect coating is shown in Figure 6, and comparison of it versus an electrically continuous pipeline with the same coating is shown in Figure 7. For a bare pipeline, the induced voltage is essentially zero along the length of pipe with possibly a slight rise at its ends. This is shown for an electrically discontinuous bare Ductile Iron Pipeline in Figure 8, next page.

Whether bare or coated, for all practical purposes, the induced voltage on electrically discontinuous Ductile Iron Pipe is essentially not measurable.

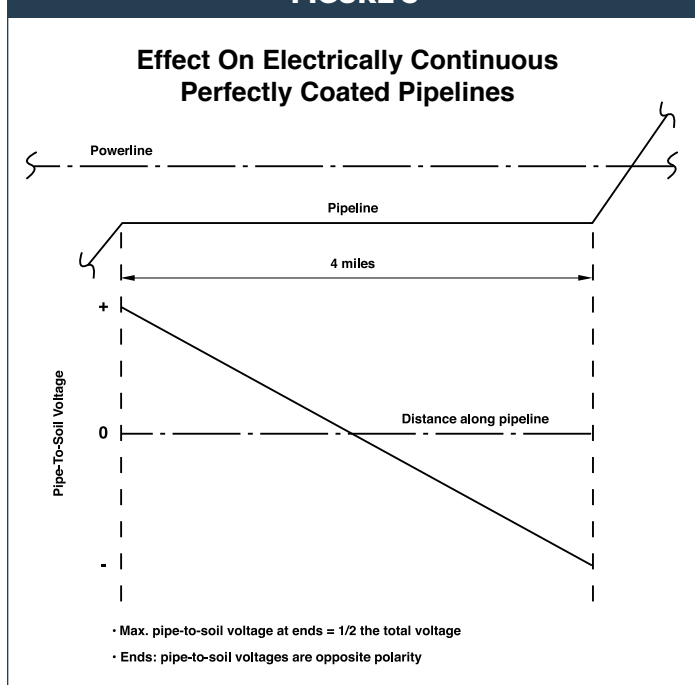
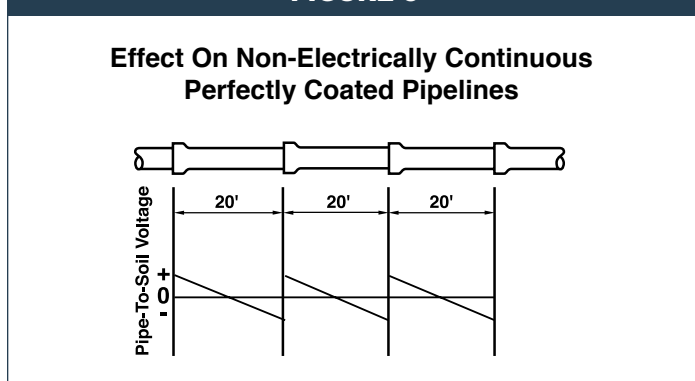
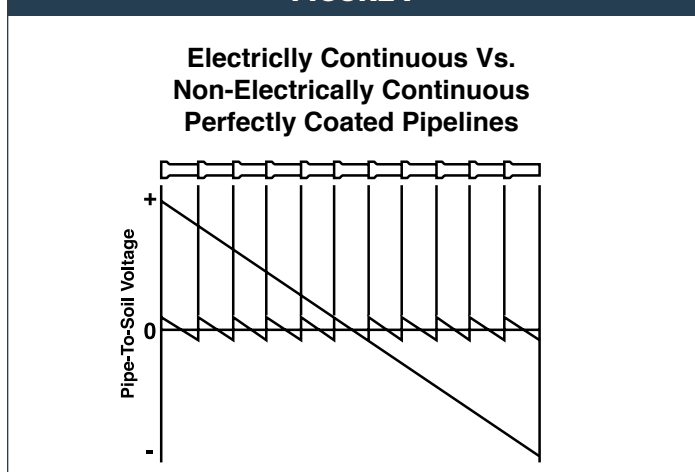
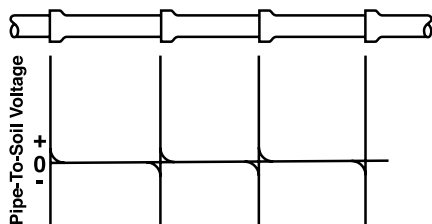
FIGURE 5**FIGURE 6****FIGURE 7**

FIGURE 8**Effect On Non-Electrically Continuous Bare Pipelines****Conclusion**

A consequence of AC power lines and buried pipelines sharing rights-of-way is that AC voltages and currents can be induced on the pipelines by conduction during ground fault conditions and by induction from the expansion and contraction of magnetic fields. The magnitude of the induced voltage and current on the pipeline is a function of a number of variables, including the length of pipeline paralleling the AC power line, the longitudinal resistance of the pipeline, and the resistance of the pipeline coating.

Ductile Iron Pipe is manufactured in nominal 18- and 20-foot lengths and employs a rubber-gasketed jointing system. These rubber-gasketed joints offer electrical resistance that is sufficient for Ductile Iron Pipelines to be considered electrically discontinuous. In effect, the rubber-gasketed joints segment the pipe and prevent magnetic induction from being a problem. Also, in most cases, Ductile Iron Pipelines are installed bare and are therefore essentially grounded for their entire length, which further prevents magnetic induction on the pipelines. The fact that Ductile Iron Pipelines are electrically discontinuous and normally installed bare significantly reduces the potential difference between the pipeline and the surface ground during a ground fault condition. Additional safety precautions for ground fault conditions could include the installation of potential gradient control mats at exposed valves, hydrants, etc.

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Ductile Iron Pipe Research Association

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P.O. Box 190306
Birmingham, AL 35219
205.402.8700 Tel
www.dipra.org

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