

Basic Concepts of Induced AC Voltages on Pipelines

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The phenomena of induced AC on pipelines sharing common rights-of-way with overhead high-voltage electrical transmission power lines is discussed. Basic concepts and techniques for personnel safety and some pipeline protective measures are reviewed.

The potential for induced AC voltages on pipelines has always been with us. Early pipeline construction included bare steel or cast iron pipe, which essentially was grounded. Bell and spigot, mechanical, or dresser-style joint couplings often were used, creating electrically discontinuous pipelines. Although induced AC affected any pipeline parallel to a high-voltage alternating current (HVAC) power line, the effects were not noticeable. With the advent of welded steel pipelines, modern cathodic protection (CP) methods and materials, and the vastly improved quality of protective coatings, induced AC effects on pipelines have become a significant consideration on many pipeline rights-of-way.

In the last two to three decades, the incidence of joint occupancy of the same right-of-way by one or more pipelines and power lines has increased. As the cost of right-of-way

and the difficulty in acquisition, particularly in urban areas, have risen, the concept of joint occupancy rights-of-way has become more attractive to many utility companies. Federal and state regulations usually insist on joint-use right-of-way when a utility proposes crossing regulated or publicly owned lands, if there is an existing easement. Such joint use allows the induced AC phenomena and may create electrical hazards and interferences to pipeline facilities. Underground pipelines are especially susceptible if they are well coated and electrically isolated for CP.¹

Induced AC Mechanisms

There are three coupling modes of primary concern by which voltages are induced in pipelines.

Electrostatic coupling, commonly known as "capacitive" coupling, is caused by the electrostatic field surrounding the energized conductor. This electrostatic field is proportionally produced by the voltage in the overhead conductor. The closer the pipeline is to the energized overhead conductor, the stronger the electro-

static voltage induced in the pipeline.

Electrostatic coupling is of primary concern when a pipeline is under construction near an overhead HVAC system. The length of the exposed conductor is also a factor in the electrostatic charge induced in the structure. A relatively short conductor isolated from ground, such as a single joint of line pipe supported by a nonmetallic sling or on a rubber-tired vehicle on the right-of-way, will become charged like a capacitor. (A rubber-tired vehicle on the right-of-way should have drag chains to ground the vehicle.)

As the length of the pipeline aboveground increases, the electrical charge in the line increases. If the aboveground section is long enough, hazardous or even lethal currents can discharge.

Once the pipeline is backfilled, electrostatic coupling is no longer of any real concern because the pipeline coating will allow sufficient leakage to earth through pinholes or holidays, effectively grounding the electrostatic effects.

Electromagnetic Coupling

Electromagnetic coupling is also known as "transformer action." When current flows in an energized conductor, it produces an electromag-

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netic field at right angles to the conductor. In AC power systems, electric current flowing in the conductor changes direction 120 times per second for 60-Hz and 100 times per second for 50-Hz systems. Thus, the electromagnetic field surrounding the energized conductor is constantly expanding and contracting.

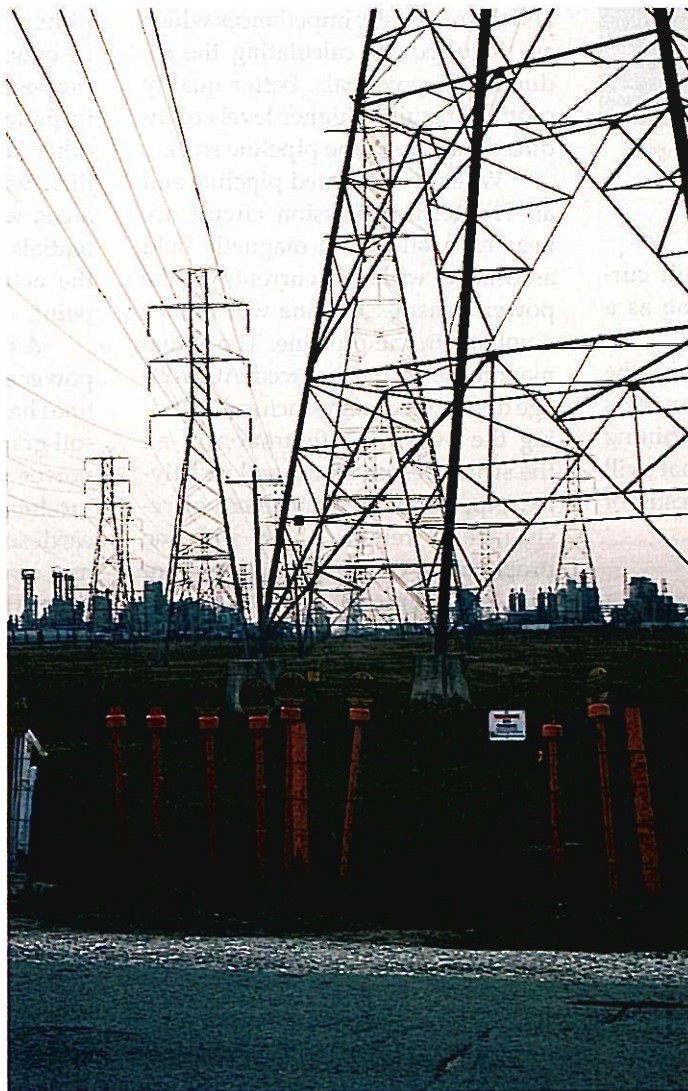
Whenever electromagnetic lines of force cut through another conductor, a voltage is induced in that conductor. This is the principle upon which power transformers, alternators, and generators function. A well-insulated pipeline parallel to an overhead HVAC line then becomes the secondary of an air core transformer. With sufficient parallel length, rather significant voltages can be induced into the pipeline. These voltages can be hazardous to anyone who comes in contact with the exposed pipeline or appurtenances, and potentially may damage the pipeline or related facilities.

Pipeline Hazards

A products pipeline failed because of lightning and fault current actually penetrating the pipeline wall, a clear case of arc burn penetration of the pipe wall.² There are other case histories where actual pipe wall penetration has occurred with or without an actual line failure. People have been killed contacting an energized pipeline under construction. We must be aware of these electromagnetic and electrostatic effects on influenced pipelines and know how to avoid injury and damage.

An excellent source of information on this subject is NACE Stan-

dard RP0177-83. Section 4 of the standard discusses biomedical effects of AC on humans and discusses safe work practices during construction, normal operations, and maintenance of pipeline facilities. The entire document is directed to personnel safety and mitigation of induced AC effects on pipelines and other continuous un-



Multiple pipelines and steel tower pipelines near a major electric generating station, a likely site for induced AC phenomena.

derground structures.³ Additional information is in IEEE Standard 80.^{4,5}

Resistive Coupling

Resistive coupling is another mode of electrical coupling between a pipeline and a parallel overhead power system. This is a concern during "fault conditions" on the power system. If lightning strikes one of the

energized conductors on the overhead power line, the resulting voltage rise on the wire will exceed the breakdown insulation level (BIL) of the insulator at the nearest tower. When the BIL is exceeded, a flashover will occur from the energized conductor to the tower and then to the tower ground. Current will flow from the energized conductor to the tower structure via the ionized gases (plasma) generated by the lightning. Fault current will flow for a fraction of a second, until the circuit protection device has a chance to operate. Many of these are set for automatic re-closure. In this mode, the circuit will remain de-energized for one or more seconds and then automatically re-close. If the fault has been the result of a lightning flashover, the circuit normally will remain energized. However, if the fault is the result of a failed insulator, a downed conductor on the ground, or other mechanical problem, automatic re-closure will usually occur twice, resulting in three successive faults to ground. Any one of these faults can have many times the energy found in a lightning strike.

As a result of these fault currents, current will radiate from the tower foundation and grounds in all directions from the faulted tower. A very severe potential gradient will occur across the earth, radial to the faulted tower. If there is a nearby pipeline in the earth, the gradient field will be distorted and accentuated. This effect is greatest with bare pipelines and pipelines that are near the tower foundation. Consequently, a



Lightning induced fault current damage to a rectifier door.

significant portion of the fault current may flow in the pipeline as a result of resistive coupling.

Physical separation between the pipeline and the power line tower is an important factor in determining the extent of the damage that will occur on the pipeline as the result of a fault.

Predicting AC Voltages on a Pipeline

Induced AC voltages on a pipeline can be measured by methods similar to those used to conduct a DC pipe-to-soil survey. A multimeter is placed on the appropriate AC voltage range and a steel pin is used in place of the copper/copper-sulfate reference electrode. A detailed AC pipe-to-soil potential survey should be conducted over any area where induced AC voltages are suspected. It is important to note the time of each reading because many power companies maintain a record of currents in the circuit. The voltage induced in the pipeline is directly proportional to the line currents in the overhead conductors, and this can provide valuable information on the peak voltages that can be anticipated at each location under maximum line loading conditions. The voltage profiles can be recalculated for various proposed grounding schemes so that the most cost-effective method can be used. The initial induced AC survey is necessary to ensure that valid

data is computed for the pipeline section under investigation.³ Soil resistivity and a number of other field measurements are necessary to properly evaluate an induced AC right-of-way.

Soil resistivity data and pipeline coating resistance (measured in ohms/ft²) are essential values for computing propagation constants and characteristic impedances which are required for calculating the induced AC potentials. Better quality coatings result in higher levels of induced voltage in the pipeline steel.

Whenever a coated pipeline and an HVAC transmission circuit are near each other, the magnetic field associated with the currents in the power transmission line will induce a voltage in the pipeline. The actual magnitude of the induced AC voltage depends on many factors, including the overall configuration of all the structures involved, soil resistivity, pipe coating effectiveness or resistance to remote earth, pipeline propagation constant, magnitude of the line currents in the power circuit(s), and any current imbalance between the phases.

If the line currents in a three-phase power system were perfectly balanced and the pipeline was equidistant from each of the phase conductors and each of the grounded shield wires, the total voltage induced in the pipeline would be zero. This ideal situation is seldom seen in practice. Therefore, one may generally anticipate the measurement of an actual AC voltage induced on the adjacent, parallel pipeline. Much greater potentials can be encountered on the pipeline during single phase-to-ground or phase-to-phase fault currents in three-phase power systems because of the magnitude of the fault currents and the less than ideal circuit geometry. Voltage induced in the pipeline under fault conditions can be two or more orders of magnitude greater than the induced voltage in the pipeline under steady-state conditions. Protecting pipelines from the dangers of induced AC voltages and currents can be considered similar to

providing lightning shield wires on a power line.

The magnitude of steady-state AC potentials induced on an underground pipeline by parallel high-voltage transmission lines can be estimated accurately using the appropriate mathematical formulas.⁶ The formulas characterize the circuit in terms of "steady-state" line currents, phase relationships, pipeline-to-conductor distances, pipeline propagation constants, characteristic impedances, soil resistivity, and other factors. The technique can predict, with reasonable accuracy, the areas where the maximum AC potentials will occur and approximate the actual induced voltage at that point.

A major safety consideration for power system effects on nearby pipelines has to do with fault-induced AC soil gradients. A fault current from a power line structure into the earth produces a potential gradient in the earth surrounding the faulted power line structure. This can create hazardous voltages between the pipeline steel and the surrounding soil. These voltages can appear at aboveground appurtenances such as valves, CP test leads, and metering facilities. Gradient control mats and/or bonding can reduce the gradients to less than the tolerable step-and-touch potential levels in the immediate vicinity. CP engineers and field technicians should have adequate safety training for working in these areas.

Because of the conductivity of the pipeline steel, ground fault-induced gradient voltages can be seen on the pipeline at a considerable distance from the site of the fault. If the surrounding soil mass is at normal remote earth voltage but the pipeline steel is influenced by the gradient voltage or transient voltage from a remote fault, a serious voltage difference will exist across the coating between the pipeline steel and the earth. This is known as "transfer voltage." Grounding techniques must be used to mitigate transfer voltage if calculations predict voltages above safe step-and-touch levels. If grounding alone

is not sufficient to reduce step-and-touch voltage to safe levels, it must be supplemented with gradient control mats. Without effective mitigation, these voltages could be lethal. Currents at the fault site or at current discharge sites remote from the pipeline can damage the pipeline coating, or, if high enough, they can burn a hole through the steel wall of the pipeline. These discharges can limit the magnitude of the transfer voltage.

Mitigation Techniques

Mitigation techniques that can control induced voltages on an influenced pipeline include the following.

- Supplemental grounding of the pipeline with sacrificial anodes or other grounding.
- Bonding the pipeline to individual power line pole grounds or towers through the use of polarization cells.
- Installation of parallel mitigation wires bonded to the pipeline at regular intervals.
- Changing phase relationships between multiple power line circuit conductors.
- Use of Faraday cages with sacrificial anodes.
- Relocation of the pipeline or power line to provide greater separation from the influencing power system.
- Installation of a nonmetallic pipeline such as high-density polyethylene pipe, if designed pressures permit.
- Installation of gradient control electrodes or mats at all aboveground appurtenances.
- Security fencing around aboveground appurtenances.

Supplemental grounding of a pipeline with sacrificial anodes can serve the dual function of grounding a pipeline while supplying the necessary CP current. Individual anodes are limited to the amount of steady-state and fault currents they can safely dissipate. These anodes also function as grounding electrodes, so their permanency must be ensured.

Bonding to individual structure foundations at every structure where parallelism exists brings the pipeline and power system grounding into one

commonly bonded network. Each bond must contain a cathodic decoupling device such as a polarization cell.⁷ A commonly bonded system provides the most uniform step, touch, and mesh potentials of any of the mitigation systems. A disadvantage of this method is that the percentage of fault current injected into the pipeline at the faulted structure will actually be increased where such a bond exists. Also, the system is expensive.

Carefully designed parallel mitigation wires can be an effective grounding technique in many situations. Galvanic anode ribbon or galvanized steel wire and groundrods can be directly connected to the pipeline. Corrosion-resistant grounding materials, such as copper conductors and ground rods, can be connected to the pipeline via polarization cells. This technique is most useful in low-to medium-resistivity soils for well-coated pipelines that are separated from the power system by at least a moderate distance. In higher-resistivity soils, the mitigation wires may not provide sufficient grounding.

Where multiple power line circuits are influencing a common pipeline, the phase relationships between the various power system conductors should be investigated. In some instances, it is possible to reduce the

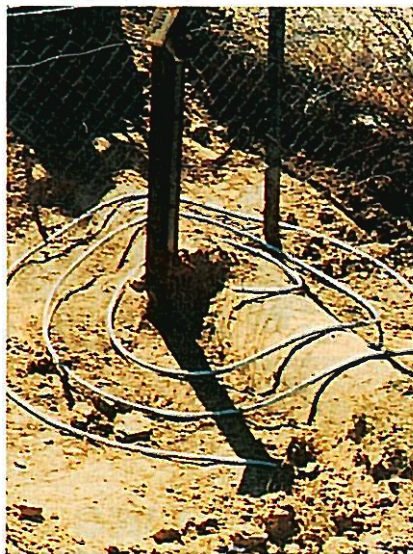
levels of voltage and current induced into a nearby pipeline by rearranging phases, which could cancel a large portion of the net electromagnetic field generated by the power system conductors. This technique is most useful for dual power circuits with vertically arrayed conductors. Therefore, the mitigation engineer should be involved in circuit design before actual construction begins.

Faraday cages can be effective in special cases where a pipeline and power line are near each other. They are used most commonly in the situation of a pipeline and power line crossing each other or for closely parallel pipe and power lines. Usually, sacrificial anode materials are used to construct the Faraday cage. Another form of Faraday cage or shield involves the use of a bare split pipeline casing grounding the pipeline in the area of maximum exposure. The bare casing is coupled to the pipeline through a polarization cell.

Whenever there is a pipeline closely parallel to a power line for any significant distance (for example, closer than 500 ft or more than 2,000 ft), further investigation is warranted. If 5 V AC or more is measured at any point on the parallel section, this voltage should be related to line loading to estimate the pipeline-induced AC voltage at peak line-loading conditions. The induced voltage should be mitigated if the calculated values approach or exceed 15 V AC. Fault conditions and step-and-touch voltages also must be considered.

Personnel Safety

On any construction or maintenance project, safety is an attitude. This attitude is developed by proper training. A valuable source for such information is Section 4 of NACE Standard RP0177.³ NACE also offers an audio-visual presentation that deals with the effects of electric shock in such situations.⁸ RP0177 should be included in the construction specifications whenever a pipeline is built or exposed for maintenance on an energized HVAC right-of-way. One of the inspectors should be designated



Zinc ribbon ground mat to protect personnel from step-and-touch potentials at a test station.

in charge of electrical safety. This individual must be familiar with and properly equipped to test for safe levels of induced voltage in the pipeline. A safety meeting should be held prior to construction with employees to discuss electrical safety requirements.

The right-of-way must be vacated if thunderstorms come within 10 miles of the pipeline right-of-way or the power line(s) that is influencing the pipeline.

Never work on an influenced pipeline during a thunderstorm because of the potential for a direct lightning strike; power system fault currents will flow in the earth if lightning causes flashover of a power line insulator. A person on the right-of-way is in danger, even if they are not touching the pipeline.

Corrosion and maintenance personnel should be very cautious about stringing test lead wire on the right-of-way where the lead wire parallels the influencing HVAC line. Extremely

hazardous voltages can be induced on a significant length of test lead wire laid on top of the ground.

The practice of using insulating rubber gloves should also be discouraged, unless the work is being performed by a trained power company employee. Rubber goods must be specially cared for to ensure their reliability.

The only safe alternative in the pipeline environment is to test the level of induced AC on the pipeline before contacting anything that may be a conductor. If voltages are safe, normal measurement or repair and maintenance techniques may be employed. If unacceptably high voltages are encountered, one must work on a ground mat. A ground mat can be as simple as a piece of 6 ft² road mesh laid on top of the ground and bonded to the pipeline or appurtenance with an automotive jumper cable. Since the individual, the ground mat, and the pipeline appurtenance are all at equal potential, it matters little as to how

high the actual measured voltage is on the pipeline.

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