Contents

Overview of a Typical Interference Study

A pipeline, railway or telecommunication cable (referred to herein as victim line) sharing a common corridor with ac power transmission or distribution lines captures a portion of the electromagnetic field energy surrounding the power lines in the air and soil. This captured energy, often designated as ac interference can result in an electrical shock hazard for people touching the victim lines or metallic structures connected to them or simply standing near them. Furthermore, excessive stress voltages across rails, telephone pairs or pipe walls and coating surfaces can result in degradation or damage to equipment and puncture of pipe coating, leading to accelerated corrosion and can damage insulating flanges and rectifiers. In the case of extreme soil potential rise, the pipeline wall itself can be damaged or punctured. Excessive rail-to-rail voltages (difference of potentials between rails) can compromise the normal operation of the signal and protection systems of the railways. Excessive induced power frequency noise in the telecommunication cables can degrade the signal quality of the cables.

Electromagnetic interference caused by electric transmission and distribution lines on neighboring metallic utilities such as oil, gas and water pipelines, railways and telecommunication cables has increased significantly in recent years. This is due to the tremendous increase in the load and short-circuit current levels that are the result of the growing energy demand. Another reason for increased interference levels originates from the more recent environmental concerns which impose on various utilities the obligation to share common corridors in an effort to minimize the impact on wildlife and other related threats to nature.

The cause and effect of ac interference from electrical power lines to adjacent utilities are well understood and the relative codes and standards are well documented. Several methods and software tools to analyze and compute the ac interference levels have been developed. Various mitigation techniques to reduce ac interference levels to the safe limits have been introduced and implemented widely. This document describes the essential methods and steps to carry out an ac interference study.

What follows is an outline of the objectives and tasks associated with a typical study of the electrical interference occurring in one or more victim lines due to their proximity to transmission lines which exist in the same corridor.

Objectives

The primary objectives of an interference study are as follows:

- Determine what mitigation is required to reduce victim lines potentials to less than a given maximum level throughout the right-of-way during worst case steady state conditions. This level is typically 15 volts, but can be as high as 50 volts in some areas or as low as 10 volts in others.

- Develop gradient control grid designs to protect exposed appurtenances, such as pipeline valve sites, during fault conditions, according to IEC Standard 479 or ANSI/IEEE Standard 80 safety criteria. Verify also that touch voltages at these installations are less than 15 volts during worst case steady state conditions. This requirement is set forth in NACE standard RP0177and CSA Standard C22.3 No. 6 - M1991. Cigré WG 36.02 Technical Brochure No.95, 1995 provides

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similar guidelines. For railways, AREMA standards or equivalent should be used. Similar standards apply for other types of victim lines.

- Determine the maximum stress voltages occurring during fault conditions along the victim lines. These stress voltages should not exceed prescribed limits. If necessary, design mitigation to reduce these stress voltages.

Project Tasks

The tasks involved in an interference mitigation design study are as follows:

Project Set-Up.

Data Collection and Review: Provide a detailed description of the data required for the study as soon as you are ready to perform the work.

Site Selection for Soil Resistivity Measurements.

On-Site Training of Group Making Soil Resistivity Measurements and Associated Preparation (if necessary): It is important that the measurement team fully understand the procedures that must be followed in order to obtain correct readings and troubleshoot any problems that might arise. They must use special equipment to filter out 50/60 Hz noise flowing in the earth or induced in equipment leads by the magnetic field surrounding the AC power line. They must also minimize inter-lead coupling and coupling between different pieces of equipment. Furthermore, they must avoid the influence of bare buried conductors. This requires suitable test equipment, correct measurement techniques, and constant monitoring of the readings for anomalies, so that rapid remedial action can be taken.

Soil Resistivity Measurements (by the trained group or qualified team).

Telephone/Fax Support of Team Making Soil Resistivity Measurements: This will be especially important during the initial days following the training, during which the team is likely to have questions. During this period also, the readings should be closely monitored for signs of trouble.

Interpretation of Soil Resistivity Measurements.

It is important that the soil resistivity measurements be resolved into multilayered soil structures so that conductive interference from faulted transmission line structures is properly computed in order that the necessary grounding and gradient control mitigation systems are designed in a safe and cost-effective manner.

Right-of-Way Model.

A detailed model including electric power lines, pipelines, railways, telecommunication lines and any associated facilities (e.g., power plants, substations) and grounding (e.g., sacrificial anodes, tower/pole grounding) should be created, in order to account for the interactions of all of these entities in the determination of inductive and conductive interference levels in the victim lines. It is important to include overhead ground wires, neutral conductors, other nearby metallic lines or conductors not explicitly under study as well as guy wire anchors connected to overhead ground wires.

Load Simulations.

During power line load conditions, magnetic field inductive interference constitutes essentially all of the interference present, once the victim line is constructed: the key concern here is victim line potentials (that lead to touch and step voltages and other possible equipment stress voltages). In the study of load conditions, it is important to consider possible phase unbalance. The influence of significant harmonic currents during steady-state conditions should be examined, if applicable.

Fault Simulations.

During fault conditions, conductive (through-earth) and inductive interference levels must be combined in order to compute victim line potentials, stress voltages and touch & step voltages. Faults should be simulated at representative intervals throughout the joint-use corridor (preferably at every transmission line structure, if possible) and currents injected into the earth by transmission line structures properly considered. Stress voltages and touch voltages at representative locations throughout the corridor length should be computed.

Power Plant and Substation Models.

The modeling of the skeletons of the grounding systems of any power plants or substations close to the victim lines under study may be necessary, for the estimation of through-earth transferred voltages during fault conditions. Power plants directly connected to the victim lines under study must also be modeled.

Mitigation Design: Gradient Control Wires.

This step determines the required extent of the gradient control wires in terms of zones along the exposed length. The particular characteristics of the mitigation wire elements in each zone should be determined as a function of the local multilayered soil model and interference levels: e.g., the number of wires required and whether any existing counterpoise conductors associated with transmission line structure grounding must be relocated or removed.

Gradient Control Grids for Exposed Appurtenances.

If required, grounding system designs should be elaborated for victim line appurtenances at which touch or step voltages remain excessive with gradient control wires added.

Final Report.

A letter report or a detailed, bound final report should be presented upon completion of the study. The key elements to be included are as follows:

- Tabulated multilayer soil structures from multilayer soil resistivity analysis.
- Graphs comparing measured apparent soil resistivity values with those generated by equivalent multilayer soils obtained from interpretation of the measurements.
- Plots of victim line potentials as a function of position along the corridor, for worst case load conditions, with and without the proposed mitigation.
- Plots of victim line potentials and stress voltages resulting from magnetic induction, as a function of position along the corridor, for all faults modeled, with and without mitigation.

- Plots of victim line touch and stress voltages resulting from the combined effects of conductive interference from nearby faulted transmission line structures and inductive interference, for representative sites, with and without mitigation.
- Perspective and plan-view plots of touch voltages associated with any gradient control grid design required for exposed victim line appurtenances.

Summary of Data Needed for AC Interference Study

See below as well as Appendixes E, F, G and H for detailed information on the data required in order to complete a typical interference analysis. Appendix I provides additional information on this subject as well. The following gives a brief summary of the required analysis tasks.

AC Interference for Pipelines

Data you will need: Refer to Appendix E & F

Load Conditions

- Inductive Interference
- Capacitive Interference

Fault Conditions

- Inductive Interference
- Conductive Interference
- Capacitive Interference

Results Needed to Be Explored:

- Transferred Potentials
- Coating Stress Voltages
- Safety for Exposed Appurtenances: Touch And Step Voltages
- Rating of Cables and DC Decouplers
- Leakage Current Density

Mitigation Criteria:

- Load Conditions:
    - Touch Voltages at Exposed Pipeline Appurtenances: < 15 V
    - Touch Voltages on Non-Exposed Pipeline Appurtenances : < 50V
    - Transferred Potentials Outside Joint-Use Corridor
    - Leakage Current Density (ac induced corrosion)
- Fault Conditions:
    - Touch and Step Voltages at Exposed Pipeline Appurtenances: IEEE safety criteria
    - Coating Stress Voltage: 2 kV ~ 5 kV

AC Interference for Railways

Data you will need: Refer to Appendix E & G

Load Conditions

- Inductive Interference
- Capacitive Interference

Fault Conditions

- Inductive Interference
- Conductive Interference
- Capacitive Interference

Results Needed to Be Explored:

- Transferred Potentials: Rail Ground Potential Rises, Touch And Step Voltages (For Personnel Safety, Arrestor Rating Under Fault Conditions,)
- Rail-To-Rail Voltages (For Equipment Susceptibility)
- Voltages Across Insulated Joints (For Personnel Safety)
- Longitudinal Current Flows In The Rails

Mitigation Criteria:

- Load Conditions:
  - Rail Ground Potential Rise Along The Rail Tracks: < 25 V
  - Touch Voltages On Rail Tracks:
  - Rail-To-Rail Voltage On Equipment: < Equipment Susceptibility
  - Voltage Across The Insulting Joint: < 50 V
- Fault Conditions:
  - Touch And Step Voltages On The Rail Tracks: IEEE Safety Criteria
  - Longitudinal Current In The Rails: DCD & Arrestor Rating

AC Interference for Telecommunication Cables

Data You Will Need: Refer To Appendix E & H

Load Conditions

- Inductive Interference
- Capacitive Interference

Fault Conditions

- Inductive Interference
- Conductive Interference
- Capacitive Interference

Results Needed To Be Explored:

- Transferred Potentials: Sheath Ground Potential Rises (Common Mode Voltages), Touch And Step Voltages (For Personnel Safety, Arrestor Rating Under Fault Conditions,)
- Cross-Talk Or Transverse Voltages (For Equipment Susceptibility)
- Voltages Across Wires And Sheaths (For Personnel Safety)
- Longitudinal Current Flows In The Sheaths

Mitigation Criteria:

- Load Conditions:
    - Sheath Ground Potential Rise
    - Touch Voltages:
    - Transverse Voltage On Equipment: < Equipment Susceptibility

- Fault Conditions:
    - Sheath Ground Potential Rise
    - Voltage Across Wire Pairs And Across Sheath And Wires
    - Touch Voltages On The Sheaths: IEEE Safety Criteria
    - Longitudinal Current In The Sheaths

Soil Resistivity Measurements and Interpretation

Soil resistivity measurements and interpretation are one of the key tasks in any serious accurate ac interference study. Please refer to Appendix I or measurement and interpretation techniques recommended by SES.

The time required to measure the required soil resistivity data over the entire X km of victim line will depend on several factors, including the number of daylight hours during the measurement process, ease of site access, the weather, and the terrain. We have seen a team of two men completing two measurement sites per day, where each measurement site requires on the order of 15 measurements, at Wenner pin spacings varying between 0.5 m and 100 m (between adjacent pins). Sites are selected where particularly high levels of interference are expected, where exposed appurtenances are located and at intervals of 2 km or less within and near the interference zones, where the actual spacing required depends on the degree of uniformity of the soil structure along the length of the pipeline route.

Note that care should be taken in selecting the soil resistivity measurement equipment, in choosing the exact measurement traverse locations, and in taking the measurements, to insure satisfactory results. SES can provide support in this regard. No other field data is required provided that the drawings and data supplied by the gas and electric companies are complete and accurate. Collecting the data, however, should not be underestimated as a task, since data is frequently incomplete or unclear and requires further questioning or even field checks. Soil resistivity measurements are made over a considerable range of depths, as voltages transferred to the pipeline location by faulted transmission line towers or poles can be greatly influenced by deeper soil resistivities, as can the performance of long gradient control mitigation wires: as described in the paper transmitted to you previously, the soil layering can result in order-of-magnitude differences in conductive interference levels and mitigation performance. Having this data permits accurate modeling and, ultimately, cost-effective mitigation designs.

See Appendix I for further details.

Appendix E

Data Request for AC Interference Study: Power Company

Right-of-Way Data: Conductor Positions & Phasing

1. **Strip Maps.** Please provide strip maps indicating, throughout the common right-of-way, transmission line routing, conductor heights above ground, and structure positions, for all circuits which run parallel to the victim line (including victim line feeds or taps) for even a short distance. Please note that at locations where the power line and victim line veer apart, it is important to know the relative positions of the power line and victim line up to a point where they are about 2 km apart.

2. **Phase Transpositions**. Specify the locations of all phase transpositions as well as the configuration of all conductors whose positions change due to the transpositions: please provide enough information to allow three-dimensional modeling of all conductors throughout each transposition.

3. **Power Line Cross Sections.** Please provide typical cross sections of the power line right-of-way with:
   a) Phases and circuits labeled;
   b) Conductor spacings and heights above ground (at structure and midspan) clearly indicated. Include overhead ground wires.

4. **Remote Substation Locations.** For all circuits which are present within the common right-of-way, even for a short parallel distance, please specify the distance between the point where they leave the common right-of-way and the substation beyond the common right-of-way to which they are connected. Please also indicate how many structures are present within this distance.

5. **Structure Grounding.** For all circuits, indicate the footing type of the supporting structures: please provide a detailed description which includes the dimensions of the footing and of any associated grounding conductors, including rebars in concrete foundations. Please also indicate the distance between the structure footings if more than one are associated with a given structure (e.g., for lattice towers).

6. **Guy Wire Anchors.** Please indicate at what locations there are guy wire anchors that are electrically continuous with static wires or neutral conductors: i.e., guy wires do not have insulating breakers in them and are bonded to static wires or neutral conductors at pole top.

7. **Counterpoises.** Please indicate positioning, length and conductor diameter of all existing buried counterpoises or other conductor networks which are within or close to the common right-of-way.

8. **Nearby Substation and Power Plant Grounding Systems.** Please provide drawings of the grounding systems of any substations within 5 grounding system dimensions of the victim line (i.e., for a 30 m x 25 m substation, please provide a sketch if the substation is within 5 x 30 m = 150 m of the victim line) or of power plants (including substations) which are fed by the victim line.

9. **Single Line Diagrams.** Please provide single line diagrams showing networks associated with all circuits present in the common right-of-way.

Conductor Characteristics

Specify precisely the conductor type of all phase wires and static wires of all circuits in the common right-of-way. For long counterpoises, please also indicate the conductor type.

Ground Resistances

1. **Structure Ground Resistances.** Please provide, if available, a listing of the ground resistances of all power line structures in the common right-of-way and of all structures within a distance of 2 km beyond the point where each circuit leaves the common right-of-way. If a listing of measured ground resistance values is unavailable, please provide typical value(s).
2. **Substation Ground Resistances.** Please provide a listing of measured ground resistance values of all substations to which the circuits existing within the common corridor are connected.
3. **Static Wire Connections.** For all circuits, indicate whether the static or neutral wires are electrically continuous with the structures which support them and with the substations at which they terminate. Provide the BIL rating for static wire insulators (if any). Indicate which structures are bonded to the static wires and the locations of static wire discontinuities.

Fault Current Data

1. **Fault Current Contributions.** Please provide the single-phase-to-ground fault current contributions (magnitude and angle) from both sides of the faulted circuit <u>and in all other transmission lines or circuits in the common right-of-way, even those whose parallel exposure to the victim line is short or is far from the fault location, and in all circuits connected to substations/plants fed by the victim line</u>, for the following fault locations:

    > At roughly 10% intervals of the common right-of-way length on **each** of the circuits present in the common right-of-way. For circuits with only a short parallel exposure to the victim line, a minimum of one fault is required. Please be sure to include data for a fault occurring at any substations which exist within the common right-of-way.

    Note that a printout from a typical short circuit computer software package would be satisfactory and very helpful <u>if a sufficient number of nodes</u> have been defined to include <u>all circuits</u> of interest <u>for every fault location</u>. If possible, please provide currents in all phases (including non-faulted phases), in amps.
2. **Soil Resistivity.** Please indicate what soil resistivity was assumed for the computation of the line parameters used to calculate fault current values.
3. **Future Expansion.** Please indicate for what period of time the fault current values are valid and what percentage increases can be expected in the future.
4. **Fault Duration:** primary and secondary fault clearing times for all circuits for which fault current data has been provided. Please also provide details on automatic reclosure, if any.
5. **X/R Ratio.** Please provide subtransient X/R ratio for each fault.
6. **Fault Type.** Were fault current contributions determined assuming a bolted fault? If not, please explain.

Load Current Data

For all circuits within the common right-of-way, even those with only a short parallel exposure to the victim line, please indicate the following:

1. Phase-to-phase energization voltage,
2. Magnitude and angle of present and well-defined future peak load and emergency load flow. Indicate if maximum load currents in one circuit necessarily coincide with small (or large) load currents occurring in another circuit or circuits: i.e., is there any correlation between the magnitudes and angles of the load currents in different circuits?
3. What percentage increase can be expected to occur in the future for the values provided in item 2?
4. Maximum load unbalance for each circuit.
5. Maximum load harmonic currents for each circuit, if applicable.

System Frequency

Please specify the operating frequency of the power system (i.e., 50 Hz or 60 Hz or other).

Power Plants Fed by Victim Line

For each power plant fed by each victim line under study, please provide the following information, similar to that requested in the previous sections for the power lines paralleling the victim line:

1. Geographical map, to scale, showing all circuits connected to plant and the substations to which they are connected at the far end.
2. Cross sections of all power line circuits connected to these plants/substations.
3. Single line diagrams for all circuits associated with the power plants/substations.
4. Conductor and overhead ground wire characteristics for all circuits.
5. Structure ground resistances and span lengths along all circuits.
6. Substation and plant ground impedances (at both ends of each transmission line circuit).
7. Grounding details of plant and substation (plan and specifications) to which the victim line is connected.
8. Plan drawing of plant, showing and labelling all power line circuits entering the plant.
9. Current flows in all circuits connected to the plant/substation and in all circuits running parallel to the victim line, during single-phase-to-ground faults occurring at the plant/substation and at 10% intervals along each circuit connected to the plant/substation.

Resource Person

Please provide the name, telephone number, FAX number, and e-mail address of a resource person who can respond to inquiries related to the data requested above.

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Appendix F

Data Request for AC Interference Study: Pipeline Company

Physical Data of Overall System

1. **Overview of System.** Please provide a map on which are indicated the following:

    a) The pipelines under study,

    b) All parallel or roughly parallel high voltage circuits which come within 1 km of the pipelines,

    c) All other pipelines feeding or being fed by the pipeline under study,

    d) All exposed structures, such as valve sites, pig launchers & receivers, M&R stations compressor stations, and other such facilities on the pipelines listed above,

    e) All insulating flanges on the pipelines listed above,

    f) All anode beds on the pipelines listed above,

    g) Other pipelines which are parallel to the pipelines under study for significant distances (i.e., on the order of ½ km or more), or which cross them, or which come within 10 m of them,

    h) All electric substations and generating plants within 300 m of the pipelines under study or fed by the pipelines under study.

    i) Electric substations of both ends of each high voltage circuit shown on the map.

    Note that it is important to study the pipeline of interest as part of a system and not in isolation: AC interference does not recognize changes in pipeline ownership nor is it necessarily blocked by an insulating flange. Please include in the drawing therefore, all parts of the pipeline network which is under the influence of high voltage power line circuits and show all circuits which are in proximity with the pipeline network.

2. **Details of System Layout.** Please provide plan view drawings of the system described in Item 1 above, allowing lengths and separation distances of all power lines and pipelines to be easily determined. In particular, please provide, for each power line structure (i.e., tower or pole), the following:

    a) Separation distance of the pipeline under study from the center of the structure,

    b) Separation distance of the pipeline under study from the edge of the structure (e.g., from the outside of the nearest tower leg).

    Also, for all substations within 300 m of pipeline or generating plants fed by the pipeline, indicate the location of the pipeline on a layout drawing of the entire facility.

3. **Pipeline Dimensions.** Please indicate the burial depth, the diameter and the wall thickness of the pipelines described in Section 1. Please also indicate the width of the bottom of the pipeline trench, for new construction.

Soil Resistivity Data

Soil Resistivity Measurements: should be made using frequency-selective equipment and the Wenner method at spacings spanning the range of 0.1 to a minimum of 100 m (preferably, 200 m) at:

1. All exposed structures (since gradient control grids may be necessary): e.g., at all valve sites, pig launchers, pig receivers, metering and regulating stations, compressor stations, etc.;
2. Locations where one or more power lines deviate away significantly from the pipeline or vice-versa, at phase transposition locations, at power line crossings, and at intervals along the parallelism (so that the performance of mitigating wires can be assessed);
3. Locations where the pipeline is particularly close to power line structures or grounds, including substation and power plant locations (for conductive coupling calculations).

SES can provide specifications and training to ensure that these measurements are made properly. Note that since the safety of the mitigation designs and their cost are highly dependent on the soil data, it is essential that these measurements be made by well trained personnel. Recommended Wenner spacings in meters are: 0.1, 0.2, 0.3 0.5, 0.1, 1, 2, 3, 5, 7, 10, 20, 30, 50, 70, 100, 200, and so on.

Frost Depth. If the soil freezes to 12” or more in winter, provide the maximum depth of the frost line.

Exposed Structures

Please provide drawings of valve sites, pig launchers & receivers, metering and regulating stations and other exposed locations located along the pipeline under study or at its extremities. These drawings should clearly indicate the fence line, the locations and dimensions of gates, the property boundaries (i.e., the maximum extent of any gradient control grid which may be required), the locations and diameters of structures protruding out of the ground.

Note that for sites requiring protection, safety considerations often require that gradient control conductors extend at least 1 m beyond the fence line: it is therefore best that the fence line be at least 1 m within the property line so that gradient control grid conductors do not encroach on adjacent property. Furthermore, a layer of crushed rock may be required to extend outside the grid.

Electrical Data

1. **Coating Resistance.** Provide an estimate or a measured value for the coating resistance of the pipeline, as installed. Note that a factory value is of no value here because damage to the coating during handling and installation reduces the coating resistance by several orders of magnitude from the factory value. Typical values lie in the range of 6,000 ohm-m² - 140,000 ohm-m² or less, with the lower values being highly dependent on the local soil resistivity.

   Please also provide this data, if possible, for all other pipelines identified in Item 1.1.
2. **Anode Beds.** For each anode bed identified in Item 1.1, indicate its physical dimensions, configuration of anodes (diameter, length, spacing, horizontal/vertical orientation) and how the anodes are interconnected (with bare or insulated leads). If the ground resistances of the beds are known, please provide them.

Resource Person

Please provide the name, telephone number, FAX number, and e-mail address of a resource person who can respond to inquiries related to the data requested above.

Appendix G

Data Request for AC Interference Study: Railway Company

1. Provide scaled maps of the track system that parallel the path of the new 345 kV line. Maps should indicate railroad mileposts, road crossings, catenary structures, and signal locations, including road crossing names.
2. Identify main and side track circuits along the path of the 345 kV transmission line, including start and ending locations.
3. Identify any rail yard that exists along the path of the new 345 kV transmission line.
4. If electrified railroad, provide scaled maps of the power distribution system, including locations and one-line diagrams of electrical substations.
5. If electrified railroad, provide the following information: distribution (electrified supply) cable/conductor size and composition; electrical insulator continuous voltage rating and BIL (basic Insulation Level) rating; location and applicable ratings of surge/lightning arresters (same as item 8); list and ratings of substation equipment, including grounding details; electrical one-line diagram of the electrified railroad car's power and traction system, including ratings of electrical equipment.
6. If electrified railroad, provide typical grounding details of catenary structures, including typical a.c. (alternating current) footing resistance.
7. Typical range of ballast electrical resistivity for the track system; typical thickness or range of thickness, of the ballast.
8. Unit length of the rails.
9. Unit weight of the rail.
10. Size of rails.
11. Size and composition of ties.
12. Provide the following for each manufacturer: Insulating Joints; electrode or other type of signal; electric lock; batteries; relays; tuned joint couplers; narrow band shunts; wide band shunts.
13. Specify the range of impedances: inductance for electric locks, electrode or other type of signal circuits; capacitance for narrow and wide band shunts and tuned joint couplers.
14. Provide location of track surge arresters, manufacturers, rated capacities, and destruction rating currents.
15. Provide location and grounding details of track equipment housings.
16. Briefly describe the approaches for each crossing.
17. Provide physical layout of all communication systems along the path of the new 345 kV transmission line.
18. For communication cable system, provide the following: type of cable, size of cable, high voltage rating of cable insulation and manufacturer of cable system.

RESOURCE PERSON

Please provide the name, telephone number, FAX number, and e-mail address of a resource person who can respond to inquiries related to the data requested above.

Appendix H

Data Request for AC Interference Study: Telephone or Telecommunication Cable Company

1. Provide scaled maps of communications or media cables (including fiber optic) that parallel the path new 345 kV transmission line. Information concerning underground duct bank configuration (if any) is also required.
2. Location of switching, control and amplification equipment and enclosures, including details of electrical grounding.
3. Location and manufacturer of electrical surge protection devices, whether independent or integral to other communications or media equipment. Provide information regarding the maximum continuous operating voltage (MCOV) and maximum current or energy rating.
4. Provide information pertaining to the manufacturer specifications of any overhead or underground communications and media cable(s) that parallel the path of the new 345 kV line. The specifications should include both electrical and mechanical construction specifications. These specifications, for example, may include cable diameter; sheath material, diameter and thickness; dielectric material and thickness; etc.
5. Provide information pertaining to the installation of any communications or media cable, such as locations of and methods used for electrical grounding; typical height above ground; typical depth below ground; etc.

RESOURCE PERSON

Please provide the name, telephone number, FAX number, and e-mail address of a resource person who can respond to inquiries related to the data requested above.

Appendix I

Soil Resistivity Measurements

Introduction

Soil resistivity measurements constitute the basis of any grounding study and are therefore of capital importance.

Soil resistivity measurements are made by injecting current into the earth between two outer electrodes and measuring the resulting voltage between two potential probes placed along a straight line between the current-injection electrodes. When the adjacent current and potential electrodes are close together, the measured soil resistivity is indicative of local surface soil characteristics. When the electrodes are far apart, the measured soil resistivity is indicative of average deep soil characteristics throughout a much larger area.

In principle, soil resistivity measurements should be made to spacings (between adjacent current and potential electrodes) which are at least on the same order as the maximum extent of the grounding system (or systems) under study, although it is preferable to extend the measurement traverses to several times the maximum grounding system dimension, where possible. Often, it will be found that the maximum electrode spacing is governed by other considerations, such as the maximum extent of the available land which is clear of interfering bare buried conductors.

The attached data sheets provide electrode spacings that can be used, starting at short electrode spacings, for information about the surface soil layers, and ending at the largest electrode spacings. As can be seen, the electrode spacings increase exponentially in order to cover the entire range of required measurement depths as efficiently as possible.

Special Precautions

Background Noise. Due to nearby sources of 50 or 60 Hz current and its harmonics, electrical noise at these frequencies are expected in the measurements, particularly for the larger electrode spacings. Conventional measurement methods can confound this noise with the measurement signal, resulting in apparent soil resistivity readings that can be an order of magnitude or more in excess of the true values. This suggests the need for equipment that uses a signal frequency other than 50 or 60 Hz and its harmonics and can efficiently discriminate between the signal filter and the noise. A soil resistivity tester such as the SYSCAL Junior or R1 Plus (the latter is strongly recommended when very large pin spacings or high resistivity surface material are expected), manufactured by Iris Instruments (Orleans, France), or the SuperSting R1 IP single channel memory earth resistivity and IP meter manufactured by Advanced Geosciences, Inc. of Austin, Texas, USA, achieves this function: both equipment are able to accurately measure its low frequency signal, even when the background 50 or 60 Hz noise is several thousand times larger in magnitude. In the following, we refer to the SYSCAl resistivity meter. However, the SuperSting meter has equivalent capabilities as well. Some high end resistivity meters manufactured by other organizations may have similar capabilities or better. Please compare products before selecting the equipment that best fits your needs and budget.

Interlead Coupling. Another problem that can be encountered at large electrode spacings, particularly when apparent resistivities are low to moderate, is magnetic field coupling between the current injection leads and the voltage measurement leads. This coupling induces noise at the same frequency as the signal into the measured voltage and amplifies the measured resistivity. While some equipment can detect the resulting phase shift in the measured voltage and make a partial correction, other equipment cannot. The SYSCAL soil resistivity tester circumvents this problem through use of a very low frequency signal (from 500 millisecond to 2000 millisecond square wave pulses, with 2000 milliseconds being the preferred setting), which generates negligible magnetic field coupling.

Influence of Bare Buried Metallic Structures. Bare metallic structures (including concrete-encased metal) of significant length buried in the vicinity of the measurement traverse can distort measured earth resistivities. When a measurement traverse runs parallel to a long structure of this type, significant error begins when the clearance between the traverse and the structure is on the same order as the electrode spacing. The error increases as the electrode spacing increases compared with the clearance. A similar effect is observed when the electrodes are placed near relatively small grounding systems which are interconnected by means of overhead wires. As a rule of thumb, to avoid significant error, there should be no bare metallic structures of significant size buried within a radius **r** of any of the measurement electrodes, where **r** is the spacing between adjacent current and potential electrodes. When the measurement traverse runs perpendicular to a buried metallic structure without crossing it, the clearance requirement need not be as severe. Computer modelling of the buried structure and measurement electrodes can provide an estimate of the measurement error to be expected for different soil structure types.

Weak Signal. A weak measurement signal can result from a low-power source, a low-voltage source, or a high contact resistance of one or both of the current injection electrodes. The problem is most often experienced when driving electrodes in high resistivity surface soils or when the electrode spacing becomes large (the signal strength is inversely proportional to the electrode spacing, for the Wenner[1] 4-pin method, and inversely proportional to the square of the electrode spacing, for the Schlumberger 4-pin method, all other things being equal). Use of a powerful, high-voltage source is an obvious first step to eliminating this problem. Even with a good source, however, contact resistance can easily become a problem in high resistivity soils at the larger electrode spacings. The solution in this case is to drive the current-injection electrodes as deep as possible and wet the soil around these electrodes with saltwater[2]: this should be done only for the larger electrode spacings. If need be, multiple rods can be driven into the ground and connected together to constitute a larger, lower impedance electrode. On solid rock or in rock with a shallow soil layer over it, the electrodes can be laid horizontally on the rock and covered with conductive material, such as saltwater-moistened earth. If the rock is highly localized, then the electrode position can be altered (and noted) to avoid the rock; interpretation software such as the RESAP module of the CDEGS software package will account for this.

[1] The Wenner and Schlumberger 4-pin methods differ only in the spacing of the two inner potential electrodes. Details on the recommended method will follow.

[2] Note that only the area in the vicinity of the current injection electrodes should be wetted in this way. This will not influence the measurements significantly, provided that the wetted area is small compared to the inter-electrode spacing.

The SYSCAL soil resistivity tester constitutes a high-voltage, high-power source, compared to many other available models: its output voltage varies from 50 V to 400 V or higher and its output power can reach 50 –250 W (depending on the model).

A weak signal can be detected by examining the magnitudes of the measured signal voltage and injection current; also by verifying the consistency of the readings. The SYSCAL can provide reasonably accurate readings for injection currents as low as 1 mA (a minimum of 5 mA is preferable) and signal voltages as low as 1 mV, in the presence of 50 or 60 Hz noise which is 4389 times larger in magnitude. On the other hand, very low frequency background noise may require a stronger signal for good accuracy. Such a need can be detected by the standard deviation value, **q**, reported by the instrument as it takes a series of readings with a square wave of alternating polarity: when **q** is 0 at the end of the series of readings, the measurement is reliable; otherwise, a stronger signal should be sought. A series of 10 cycles or so should be selected for each measurement. Also, **q** should be watched as the measurements are made: if the string "***" appears during the readings, the measurement should be rejected. This is usually an indication that one of the current injection leads has become disconnected. A further precaution is to read the resistivity at two different injection currents, if possible: if consistent, then the reading is good. The attached data table reminds the instrument operator to record these important values.

Erratic Readings. Erratic readings can occur due to poor connections or high contact resistance, background noise at a frequency similar to that used by the measurement equipment, nearby buried metallic structures, equipment failure, operator error, and other factors. Measured resistivities should be plotted on log-log graph paper in the field to permit detection of irregular measurements, so that corrective action can be taken immediately. Resistivity should be plotted versus electrode spacing: a smooth curve is expected. Sharp changes suggest a need for checking the equipment set-up, repeating measurements, and taking additional measurements at shorter and larger electrode spacings close to the problematic one.

Excessive Voltage Magnitude. Certain versions of the SYSCAL require an input voltage (including both signal and noise) of less than 5 V to provide a reading. A voltage exceeding 5 V can occur when background noise is excessive: in this case the input voltage must be reduced with a voltage divider circuit (e.g., the voltage from the two inner potential electrodes is applied to a 100 kΩ resistor in series with a 1 MΩ resistor and the voltage across the 100 kΩ resistor is measured by the M-N terminals of the SYSCAL, resulting in a 90.9% voltage reduction). An excessive voltage can also occur at short electrode spacings due to excessive signal strength. In this case, the voltage can be reduced by reducing the source voltage setting or by decreasing the current electrode depth. The attached data sheet provides typical electrode depths.

Note that the depth of the current injection pins should never exceed 33% of the spacing between adjacent current and potential electrodes; the inner potential measurement pins should be driven to even shallower depths, as shown in the attached data sheet. This improves measurement accuracy at short electrode spacings.

Measurement Details

The current injection leads are connected to the instrument terminals labelled "A" and "B", the potential leads are connected to the terminals labelled "M" and "N". The electrode spacing is keyed in and the measurement process is launched. The instrument records and averages as many readings as the user sets the instrument to take (e.g., 6 or so).

Measurements are to be made along the traverses determined in conjunction with SES (provided in a separate document). It is important that the maximum spacing between the two current injection pins along the longest traverse be at least equal to three times the maximum extent of the grounding system being designed, as a bare minimum, if this can be achieved without interference from nearby buried metallic structures.

Schlumberger Method

The measurements are to be made based on the Schlumberger 4-pin method, taking the precautions described in this document. The P1 and P2 potential pins should be installed at the center of the traverse, initially 1.0 m apart. The C1 and C2 current pins are to be driven into the ground at progressively increasing distances from their respective potential pins, starting 0.10 m from the nearest potential pin and increasing up to the maximum pin spacing specified by SES for each measurement traverse. The "maximum pin spacing" indicated for any given traverse is the maximum distance between each potential pin and its adjacent current pin. The separation distance between the inner potential pins remains at 1.0 m for the first few measurements, then increases as necessary to obtain a sufficiently strong measurement signal (i.e., at least 1-10 mV, if possible, and a **q** value of 0). Note that before increasing the spacing between the potential pins, all practical attempts should be made to improve the contact resistance of the outer current injection pins: drive them deeper, use clusters of rods at the larger spacings, wet the ground close to the pins with saltwater (without wetting the ground close to the potential probes!). Ensure that the injection current is 5 mA or more and the measured signal voltage 1 mV or more, if at all possible. Each time the potential pin spacing is increased, repeat the preceding measurement: i.e., place the current pins to the distance separating them from the potential pins during the preceding measurement, for validation.

Wenner Method (Fixed C1 & C2 Pin): One-Sided

The measurements are to be made based on a modified Wenner 4-pin method, taking the precautions described earlier in this document. The test method chosen here gives greater weight to transferred potentials from the C1 electrode to locations tested in the future mine area and also obviates the need to move the C2 test electrode.

The C1 electrode should be installed at the center of the future 260 kV substation site under test (there are two such substation sites). The C2 electrode should be installed 4 km away (the locations are specified below). The C1 and C2 electrodes must be installed such as to have low ground resistance: we wish to obtain approximately 500 mA or more of current flow from the soil resistivity meter when it is connected in series with the two electrodes. Start by driving 3 ground rods 0.7 – 1.0 m into the ground, in a triangular formation, spaced about 1.7 m apart, with the 3 ground rods interconnected. Drive the rods deeper and add rods if need be; also pour salt water around each ground rod, if need be, to achieve a sufficiently low ground resistance. Connect a lead from the "A" terminal of the SYSCAL test meter to the C1 electrode array and another lead from the "B" terminal of the meter to the C2 electrode array. Use the Rtest function to verify that the total resistance of the C1-C2 circuit is on the order of 800 ohms or less.

This electrode set-up should be used for all readings in which the P1 electrode is 30 m or more from the center of the C1 electrode array. When the P1 electrode is less than 30 m from the C1 electrode, the latter should be reduced to a single ground rod driven 0.7 m or so into the ground. For even shorter spacings, the depth to which the C1 electrode is driven should never exceed 30% or so of the distance between C1 and P1. There is no need to modify your C2 electrode set-up: it can remain the same for all electrode spacings.

The P1 and P2 electrodes are installed between the C1 and C2 electrodes, such that all electrodes are in a straight line. Connect the P1 electrode to the "M" terminal of the SYSCAL and the P2 electrode to the "N" terminal. For the first measurement of each traverse, place P1 and P2 such that the distances between adjacent electrodes (i.e., C1-P1, P1-P2, P2-C2) are all equal. This is the standard Wenner arrangement. After this first test, however, only the two potential electrodes are to be moved and always towards the C1 electrode. The C1-P1 and P1-P2 spacings are always equal: indeed, if it were not for the C2 electrode that remains immobile, the test would be a true Wenner test. From each pin spacing to the next, the C1-P1 and P1-P2 spacings are reduced by 1/3: in other words, multiply each pin spacing by 2/3 to obtain the next smaller pin spacing. The minimum required pin spacing is 0.3 m.

The P1 and P2 rods (just one rod or spike each) should be driven only a few inches into the ground, such as to achieve reasonable contact resistance: if the electrode presents resistance when pulled out of the earth, then it is certainly deep enough. For small electrode spacings, the depth to which the P1 and P2 electrodes are driven should not exceed 10% of the electrode spacing.

To estimate apparent resistivity, use **double** the spacing between C1 and P1, instead of simply the spacing between C1 and P1 as you would for the regular Wenner method: i.e., apparent resistivity is approximately equal to $4 \pi a R$, where a is the C1-P1 spacing and R is the apparent resistance. If you are using the SYSCAL to compute apparent resistivities for you, always enter double the spacing that you are testing. This will be valid for most pin spacings and is certainly satisfactory for the purpose of checking the data for erratic behaviour.

All the data indicated on the data sheets are to be recorded for each traverse, from the minimum pin spacing indicated on the form, up to the maximum pin spacing associated with the traverse (as indicated on the list of measurement traverses required for this project).

At each pin spacing, measurements are to be made at two significantly different injection current levels, if possible, which can be achieved by varying the applied source voltage: a factor of two difference (on that order) between the two injection currents is to be obtained. The measured resistivity should be the same for both current levels: if not, start troubleshooting!

On the attached form:

- "Source Voltage" is the voltage applied to the current injection pins (12 V, 50 V, 100 V, 200 V, 400 V or 600 V) and is set by a knob on some instruments; on others, this is automatically set by the instrument.
- "Q:***?" indicates whether 3 asterisks appeared as a value for Q, ***while the meter is injecting current*** into the C1 and C2 pins. Either "yes" or "no" should be entered in this column.
- "Q%" is the standard deviation value, Q, reported by the meter.
- "Vsignal" is the voltage measured by the soil resistivity meter between the potential pins (P1 and P2).
- "Iinject" is the current injected by the soil resistivity meter into the current pins (C1 and C2).
- "Apparent Resistivity" is the apparent resistivity of the soil, as computed by the meter or by hand.

The measured apparent resistivities are to be plotted versus pin spacing on log-log graph paper, as the measurements are taken. A fairly smooth curve should result. Wire connections and rod-to-soil contact should be verified if abrupt changes are observed; the presence of long buried metallic structures can also be responsible for such variations. As indicated above, if the low current test values do not match the high current test values, then a problem exists and the source of the problem should be investigated. Similarly, if Q% is greater than 0, connection and rod-to-soil contact should be checked.

In addition, for each measurement traverse:

1. **Attach a sketch showing the traverse location & starting point in relation to existing nearby structures, including approximate distances from them; also show traverse on site plan.**
2. **Please report any signs of pipes, pipelines, conduits, long sections of reinforced concrete, fences, or any other long, metal-bearing structures anywhere near the traverse.**

If an instrument is used which does not filter out voltages induced in the potential measurement leads by the current injection leads (this should be assumed if there is no indication to the contrary), then the following precautions should be taken:

1. Separate the current injection test leads from the potential measurement leads by a fixed distance (e.g., 10 feet).
2. For every pin spacing, take the measurements using another set potential leads that are significantly further away from the current leads and separated from them by a fixed distance (e.g., 100 ft).
3. SES can compare these two sets of data to estimate induced voltages and correct the data for induced voltages.

Interpretation

The apparent soil resistivities measured at each site can be plotted along with the curve corresponding to the equivalent soil computed by the RESAP module of the CDEGS software package. Each graph also shows the equivalent soil structure corresponding to this data and indicates the location on the pipeline to which it corresponds. Good agreement between the two orthogonal traverses and the computed curve fits usually can be achieved, so that a multi-layer soil model is obtained and used for the ac interference analysis.