

IEEE Recommended Practice for the Implementation of Inductive Coordination Mitigation Techniques and Application

IEEE Power and Energy Society

Sponsored by the
Power Systems Communications and Cybersecurity Committee

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IEEE Recommended Practice for the Implementation of Inductive Coordination Mitigation Techniques and Application

Sponsor

**Power Systems Communications and Cybersecurity Committee
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IEEE Power and Energy Society**

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IEEE-SA Standards Board

Abstract: Guidance for controlling or modifying the inductive environment and the susceptibility of affected wire line telecommunications facilities in order to operate within the acceptable levels of steady-state or surge induced voltages of the environmental interface (probe wire) defined by IEEE Std 776™ is provided in this Recommended Practice. Procedures for determining the source of the problem are given. Mitigation theory and philosophy are discussed, and mitigation devices are described. The application of typical mitigation apparatus are addressed. Advice for determining the best engineering solution is offered, and general safety considerations are discussed.

Keywords: coordination, coupling, harmonic, ICEP, IEEE 1137™, impedance, inductive, influence, mitigation, mutual, noise, power, susceptibility

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Introduction

This introduction is not part of IEEE Std 1137™-2018, IEEE Recommended Practice for the Implementation of Inductive Coordination Mitigation Techniques and Application.

This document was suggested during the preparation of IEEE Std 776™-1987 as a companion in the area of implementing mitigating techniques. The following individuals made a significant contribution to the effort.

David Boneau	Harold Held	Dick Nelson
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The Wire-Line Subcommittee issued, in 2009, a Corrigendum to correct errors in [Table 3](#) and to correct typos in 8.5 of the printed 1991 edition. In 2017 the Wire-Line Subcommittee decided to revise this Guide and upgrade it to a Recommended Practice to include the changes made by the Corrigendum, and to bring the document in line with the latest IEEE-SA Style Manual and to further make minor editorial revisions to clarify the content.

Since many noise specialists and subject matter experts have either retired or left the telecommunications industry in the recent past, the revision to this Recommended Practice also includes [Annex C](#) with information on activities to be conducted on noise reduction investigations prior to implementing the procedures outlined in IEEE Std 776. The information contained in [Annex C](#) should be considered a handy reference for those persons that have replaced the specialists that have left or are new to the field of inductive coordination or noise investigations.

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IEEE Recommended Practice for the Implementation of Inductive Coordination Mitigation Techniques and Application

1. Overview

1.1 Scope

This Recommended Practice offers users assistance in controlling or modifying the inductive environment and the susceptibility of affected wire-line telecommunications facilities in order to operate within the acceptable levels of steady-state or surge-induced voltages of the environmental interface (probe wire) defined by IEEE Std 776™.¹ The methodology, application, and evaluation of results for mitigative techniques or devices in general are addressed for all Specific Type A and Specific Type B coordination methods also defined by IEEE Std 776.

1.2 General

In IEEE Std 776, the recommended procedures for determining the source and type of inductive interference are explained. Detailed methods are provided to determine the cause and effect relationship by calculation or direct measurement on the probe wire interface. Tables are given to set the environmental thresholds for the initiation of inductive coordination.

This recommended practice examines the implementation of general and specific mitigation techniques. Note that long accepted practice suggests that both power and communications companies design, construct, operate, and maintain their respective systems utilizing general coordination methods, as defined in IEEE Std 776. Some of the mitigation devices and procedures that are defined as specific mitigation measures have been used by companies as economic tradeoffs against more expensive general coordination methods. This recommended practice neither recommends nor condemns this practice. IEEE Std 776 suggests that specific mitigation methods should not be employed as the best engineering solution until each company is employing general coordination methods. However, users of this recommended practice should note that implementation of any method or device should include the consideration of timeliness and economics irrespective of the system to which it is to be applied in order to meet each utility company's obligations to their mutual customers and regulatory bodies, as applicable.

¹Information on references can be found in Clause 2.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 367™, IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault.^{2,3}

IEEE Std 487™, IEEE Standard for the Electrical Protection of Communications Facilities Serving Electric Supply Locations – General Considerations.

IEEE Std 776™, IEEE Recommended Practice for Inductive Coordination of Electric Supply and Communication Lines.

IEEE Std 820™, IEEE Standard Telephone Loop Performance Characteristics.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁴

coupling: The means by which electric power may be transferred from one conductor to another.

drainage reactor: A center-tapped inductor with a high mutual impedance between the windings.

harmonic suppression reactor (HSR): A mitigation device that is connected between the wye point of a capacitor bank and the grounded neutral conductor to limit the harmonic current flow through the capacitor bank by changing the impedance of the neutral to ground path and, thereby, the resonant frequency of the network with respect to ground.

influence: The capability of a power circuit to couple voltage and/or current into nearby communication circuits.

longitudinal balance: The ratio of the disturbing longitudinal rms voltage (V_s) to ground and the resulting metallic rms voltage (V_m) of the network under test, expressed in decibels as follows: longitudinal balance = $20 \log_{10} V_s/V_m$ (in dB), where V_s and V_m are at the same frequency. Also known as balance.

longitudinal choke: A two-winding transformer designed to have each winding connected in series with one of the wires of the pair that typically make up a common circuit.

loop current: The dc current flowing in the communications metallic circuit at the customer interface during the talk and signaling states.

mitigation: The engineering approach of reducing, suppressing, controlling, and/or eliminating inductive interference through long-term cost effective solutions.

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⁴IEEE Standards Dictionary Online is available at: <http://dictionary.ieee.org>

negative impedance converter: An active (i.e., powered) device for introducing negative impedance into a communications cable shield or other bunched conductor ground return circuit; its effect is to improve the cable shield factor by reduction of impedance in the shielding circuit.

power influence (PI): The power of a longitudinal signal induced in a communication circuit by an electromagnetic field emanating from a conductor or conductors of a power system. The unit of measurement is dBrnC.

susceptiveness: The characteristics of a communications circuit including its connected apparatus that determine the extent to which it is adversely affected by inductive fields.

voltage-to-ground: The unweighted longitudinal voltage induced in a communication circuit by an electromagnetic field emanating from a conductor or conductors of a power system. The unit of measurement is volts rms or dBrnC.

3.2 Acronyms and abbreviations

AML	actual measured loss
ARS	active reduction system
CO	central office
CT	current transformer
HSR	harmonic suppression reactor
ICT	induction control transformer
ICEP	inductive coordination and electrical protection
INT	induction neutralizing transformer
MDF	main distributing frame
MGN	multigrounded neutral
NI	network interface
NID	network interface device
NMS	noise measuring set
OSP	outside plant
PI	power influence
PT	potential transformer
RT	remote terminal
SA	spectrum analyzer
TEN	transformer exciting network
VF	voice frequency
VOM	volt-ohm-meter

4. Determining the source of the problem

4.1 General introduction

Power interference in a communication system results from a threefold interaction between the power and communication circuits, as depicted in Figure 1.

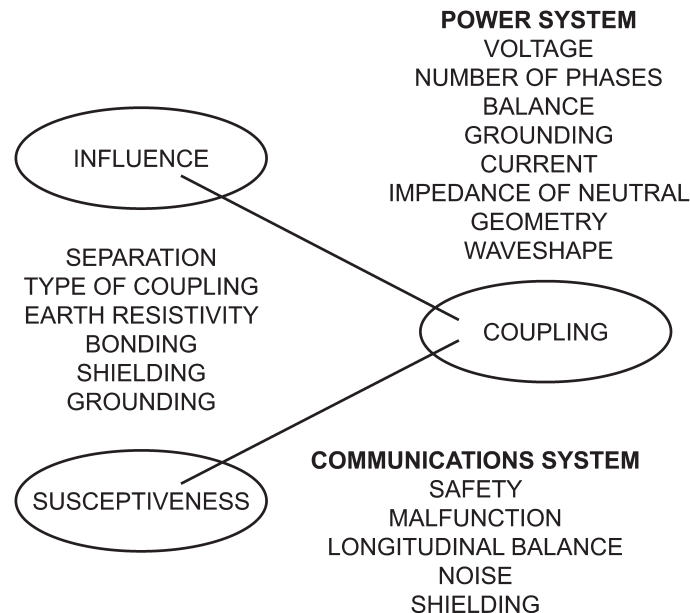


Figure 1—Interaction: Influence-coupling-susceptiveness

4.1.1 Influence

Influence refers to the capability of a power circuit to cause interference in a nearby communication circuit. Unbalanced phase currents, excessive earth return currents, and distorted voltage or current wave shapes contribute to high influence. The power utility and its users jointly control or affect influence. A measure of the influence of a power line is obtained by either utility, through measurements on a probe wire interface placed near and parallel to the power line. Refer to IEEE Std 776.

NOTE—The term power influence (PI) introduced in 4.2.1 has a completely different meaning from this traditional concept of the influence of a power system.⁵

4.1.2 Coupling

Coupling refers to the mutual impedance between the power and communication lines (see Sunde [B5] and Carson [B2]).⁶ Magnetic (inductive) coupling and electric (capacitive) coupling depend upon length of exposure, earth resistivity, frequency, separation, and shielding. Mutual impedance is computed by using equations as found in IEEE Std 367TM.

Conductive (resistive) coupling depends upon the size and proximity of ground electrodes of the two systems, as well as on earth resistivity, frequency, and upon the presence or absence of metallic connections between grounded parts of the two systems (and upon the resistance or impedance of such bonds, if present).

⁵Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

⁶The numbers in brackets correspond to those of the bibliography in Annex A.

Coupling may be affected by either utility, through route planning and facility design/construction.

4.1.3 Susceptiveness

Susceptiveness (or susceptibility) refers to those characteristics that determine the extent to which the service rendered by a communications circuit can be adversely affected by a given longitudinal voltage or current. Susceptiveness can be expressed in terms of relationships between the longitudinal voltage or current and the resulting metallic voltage or current (balance). Alternatively, susceptiveness can be expressed as the limiting voltage or current that a device or system can withstand without malfunction or damage. The communication utility and its users jointly control the susceptiveness of the communication circuit: Refer to IEEE Std 776. It should be noted that susceptiveness is frequency dependent.

4.2 Communication noise investigation

4.2.1 Preliminary measurements

Communication lines are, in general, reasonably quiet and free from audible interference. Noise investigations usually only take place upon receipt of a customer complaint. A technician would be dispatched to investigate the complaint. Standard equipment is commercially available for the technician to make the following tests from the network interface (NI):

- Loop current. The tester should measure and record the milliamperes of direct current flowing through the loop and a 430 Ω resistor with the customer equipment in the on-hook condition. This measured current should be 20 mA or more. Refer to IEEE Std 820™.
- Circuit loss. The tester should use a test handset to dial up the office milliwatt. This results in a transmission of a 1004 Hz tone from a 0 dBm supply (1 mW) from the central office (CO). The measuring set in the “circuit loss” setting measures the received level as a negative dBm value. This value should be recorded by the tester. The reading should not be less (more negative) than –10 dBm. This would represent a circuit loss of 10 dB, which should not be exceeded for good communication transmission. Refer to IEEE Std 820.
- Circuit noise. Many test milliwatts automatically switch to a quiet line termination after a short period of time. If this does not happen, the tester should dial a separate Quiet Line number to obtain a grounded balanced termination at the CO. The test set, with the circuit noise setting, would read C Message Weighted Metallic Noise in dBmC. The tester should record this reading.
- Power influence (PI), also called C message weighted longitudinal noise or C message weighted noise-to-ground. See Equation (1). (Note that some noise measuring sets (NMS) need a 40 dB correction to be added to the reading to obtain PI. But the test sets generally available to the technician usually measure PI directly in dBmC.) This reading should be recorded.
- The tester should calculate and record the longitudinal balance from the measured PI and Circuit noise by taking the difference (in dB) between the PI reading and the circuit noise reading.
- For the purpose of comparing unweighted to weighted values, measure the rms ac voltage across a 100 000 Ω resistor from the circuit to ground. Convert the voltage reading to an unweighted dBmC reading and compare to the C message noise-to-ground reading in dBmC. Refer to IEEE Std 776.

$$PI_{dBmC} = 20 \log \left[\frac{V_1}{V_2} \right] \quad (1)$$

where

V_1 is measured rms voltage

V_2 is $[\text{Resistance} \times \text{pico watt } (10^{-12})]^{1/2}$

Resistance is usually 600 Ω or 900 Ω (test set input resistance)

4.2.2 Noise performance thresholds

Information on noise performance thresholds for C message weighted metallic noise, C message weighted longitudinal noise, and balance, is given in Table 1, Table 2, and Table 3, respectively (see also IEEE Std 820). With respect to the performance categories, the Recommended levels should be considered as the basic design levels, as well as the objective maintenance levels. The Acceptable category should be considered as a temporary situation only, with full expectation that the performance will be improved to Recommended in a short period of time, or, when required, for general or specific coordination.

Table 1—C-Message weighted metallic noise performance thresholds

Noise level (dBrnC)	Performance category
≤ 20	Recommended
> 20 and ≤ 30	Acceptable
> 30	Not recommended

NOTE—Table 1 is taken from IEEE Std 820.

Table 2—C-Message weighted longitudinal noise performance thresholds

Noise level (dBrnC)	Performance category
≤ 80	Recommended
> 80 and ≤ 90	Acceptable
> 90	Not recommended

NOTE—Table 2 is taken from IEEE Std 820.

Table 3—Longitudinal balance performance thresholds

Longitudinal balance (dB) (C-Message)	Performance category
> 60	Recommended
50–60	Acceptable
< 50	Not recommended

NOTE—Table 3 is taken from IEEE Std 820.

For example, traditional wisdom indicates that Noise metallic C message weighted less than 20 dBrnC will not result in a customer complaint for a noisy line but Noise metallic C message weighted greater than 30 dBrnC will, with some possibility of a complaint between these two levels. Based on this possibility, some jurisdictions impose an upper limit of 5% of their lines greater than 20 dBrnC with an immediate action limit at 30 dBrnC, recognizing, of course, that the root of the noise problem could be influence, coupling, or susceptibility.

Similarly, Acceptable, or even Not recommended, longitudinal noise or balance performance categories could be tolerated if there was no impact on the metallic noise performance of a pair or route.

4.2.3 Analysis of measurement results

The circuit noise/power influence/balance relationship has the following implications:

- A high PI reading indicates one or more of the following: high influence of a nearby power line, insufficient separation between the power line and the communication cable, or poor shielding of the communication cable. Poor shielding is usually due to defective bonding and/or grounding of the communication cable.

- b) A low longitudinal balance usually indicates cable trouble (i.e., defective splices or wet cable), left-in service wire, grounded ringers, or operated protectors. Note that the balance may be degraded by either a series unbalance, where the impedance of the two communication conductors is not equal, or by a shunt unbalance, where the impedance to ground of both communication conductors is not the same.

4.2.4 Communication technician's follow-up

Communication utilities have standard practices regarding repair and maintenance of their network facilities. The follow-up for any case of trouble usually includes the following:

- a) Checking and replacing (if necessary) the NI or communication protector.
- b) In the case of low balance, progressively sectionalizing the circuit into smaller and smaller sections, testing in each direction from the point of sectionalization, to seek and correct the source of unbalance.
- c) If PI is still excessive, the trouble is referred to an expert in noise mitigation measurements and techniques, or to a specialist versed in inductive coordination and electrical protection (ICEP). To simplify further discussion, such specialist will hereinafter be referred to as the "ICEP engineer."

4.3 Coordination between power and communication utilities

4.3.1 ICEP engineer's follow-up

Having received a complaint of high PI in a particular communication cable, the ICEP engineer could employ any of a number of trouble-shooting techniques to determine the worst exposure and to analyze the nature of the interference.

Many power utilities have inductive coordination engineers, protection engineers, or communications engineers who are experts in, not only their own system operation, but noise measurement and mitigation as well. For future discussion, such a person will be referred to as the power engineer. The ICEP engineer should be acquainted with the power engineer. Ideally, both of them would have a day-to-day working arrangement for the investigation and mitigation of power interference.

A common denominator in the search for the interference is the use of some type of spectrum analyzer (SA), as a substitute for, or in addition to, the simpler test set used by the technician. SAs range from a hand-tuned analog variety with a "nixie tube," or a light-emitting diode's (LED's) digital display to the Fast Fourier Transform (FFT) device with a visual display of the whole spectrum.

Some communication utilities also utilize personal computers to control, via an appropriate interface, the measurements by the SA. A few utilities have specially designed and equipped mobile laboratories housed in vans to identify and initiate the best engineering solution in a timely manner. Following are some measurement techniques:

- a) Exploring coil. The ICEP engineer should use a hand-held or vehicle-mounted exploring coil to follow the suspect power line, while observing the reading of an NMS or SA connected to the exploring coil. The exploring coil consists of a number of turns of insulated fine-gauge wire formed into a circular or rectangular air core coil. For safety reasons, two persons would customarily participate in any vehicular reconnaissance.
- b) Probe wire. As described in IEEE Std 776, a 30.48 m (100 ft) long insulated wire should be placed on the ground parallel to the power line and terminated on a ground rod or probe at each end. The measuring set input circuit is connected in series with the probe wire and ground electrodes. The standard radial separation of the probe wire from the power line is 15.24 m (50 ft) for a distribution line and 22.86 m (75 ft) for a transmission line. See IEEE Std 776.

- c) Power station current transformers (CTs) and potential transformers (PTs). Most electric substations contain control circuitry that depends upon measurements of phase current and voltage-to-ground for relaying, telemetering, or supervisory control.

With the concurrence of the power engineer, and with the assistance of the power utility relay technician(s), access may be gained to the secondaries of the CTs and PTs for input to the SA or NMS.

CAUTION

Extreme care is necessary to avoid causing relay misoperation and to avoid open-circuiting the secondary of a CT. Connections to CTs and PTs should only be done by a competent power relay technician or relay engineer.

4.3.2 Determining the source of power interference

Having determined the nature and severity of the influence from the power system, the ICEP engineer's next task should be to seek an explanation for the high influence, and to request help from the power engineer.

4.3.2.1 Fundamental frequency interference

Fundamental frequency interference is usually associated with the following:

- Unbalanced loads
- Too small, open, or defective neutrals
- Open-wye or open-delta transformer connections
- Long, single-phase buried cable taps
- Open capacitor fuses, capacitor switches, or defective capacitors

4.3.2.2 Harmonic frequency interference

Harmonic frequency steady-state interference can result from a number of diverse sources and is often modified or enhanced by power system impedance. Some of those sources are as follows:

- a) Over excitation of transformers. If the system voltage is too high, the cores of the transformers will be driven too far into saturation. The resulting exciting current will have a sharply-peaked non-sinusoidal wave shape, rich in the odd harmonics of the fundamental frequency. An over-excited transformer is modeled as a voltage source of harmonics.
- b) Slot harmonics from motors and generators. Older machines were sometimes constructed in a manner that resulted in the production of a pair of odd harmonics of the fundamental frequency (e.g., the 17th and 19th harmonics).
- c) Grounded neutral generators. These provide a low-impedance path-to-ground for any harmonics on the system. Their use is not advisable.
- d) Converters (inverters or rectifiers). These devices, which change ac to dc, or dc to ac, are modeled as current sources of harmonics. Three-pulse converters produce all odd harmonics on the ac side of the transformers. Six-pulse converters produce only the 5th, 7th, 11th, 13th, etc. “characteristic” harmonics. Twelve-pulse systems produce only 11th, 13th, 23rd, 25th, etc. “characteristic” harmonics. On the dc side of a rectifier or converter, even harmonics are present. High voltage direct current

(HVDC) converters sometimes produce some odd harmonics also, on the dc side, due to unbalances within the converter. Harmonics are determined as follows (see [Equation \(2\)](#) or [Equation \(3\)](#)):

$$H_{(ac)} = a \times n \pm 1 \quad (2)$$

$$H_{(dc)} = a \times n \quad (3)$$

where

H is the order of harmonic

a is the number of pulses

n is any integer

- e) Defective or missing filters at converters.
- f) Resonance involving grounded shunt capacitors. Sometimes, the capacitive reactance of a grounded capacitor bank and the inductive reactance of the power system form a resonant circuit at some harmonic frequency. Many 9th harmonic interference problems can be traced to such a resonant condition.
- g) Wye-wye connected transformer connections without a delta tertiary or wye-delta grounding bank.

5. Mitigation theory and philosophy

5.1 General

As the number of subscribers, the demand for power and communication service, and the lengths of exposure have increased during the past 100 years, inductive interference problems have become more prevalent. Major efforts began in the 1920s between the National Electric Light Association (which became the Edison Electric Institute in 1933) and the Bell Telephone System to study, identify, and resolve the main causes of incompatibility. See Joint Subcommittee on Development and Research of the National Electric Light Association and the Bell Telephone System report [B4] for additional information. Numerous advances and innovations such as balanced circuits, metallic shielded cables for communications, drainage reactors, longitudinal chokes, neutralizing transformers, and isolation transformers resulted from this cooperation. Advancement in technology since the 1960s has introduced new, challenging problems in the area of mitigation due to the introduction of solid-state devices.

5.2 Definition

Mitigation is defined as the engineering approach of reducing, suppressing, controlling, and/or eliminating inductive interference through long-term cost-effective solutions. The mitigation process involves controlling the three following factors:

- Influence
- Coupling
- Susceptiveness

Ways of approaching mitigation are associated with the factors as follows:

- a) Influence
 - 1) Identifying and correcting the source of the problem
 - 2) Installing controlling devices in the power system
- b) Coupling
 - 1) Avoiding exposure between power and communication facilities
 - 2) Improving shielding characteristics
- c) Susceptiveness
 - 1) Identifying and correcting the source of the problem
 - 2) Installing controlling devices in the communications system
 - 3) Using equipment with reduced susceptiveness

5.3 Application theory

The mitigation process can be achieved as identified under the following categories:

- a) Influence
 - 1) Reduction of distributed residual current
 - i) Amplitude
 - ii) Phase angle
 - 2) Reduction of distortion in voltage waveform
- b) Coupling
 - 1) Reduction of mutual impedance
 - 2) Improvement of shielding/grounding
- c) Susceptiveness (susceptibility)
 - 1) Increase longitudinal impedance (e.g., longitudinal chokes)
 - 2) Reduce longitudinal voltage (drainage or cancellation)
 - 3) Improve longitudinal balance
 - 4) Reduce equipment susceptibility

5.4 Application risks

Applying mitigation may introduce the following risks:

- A new problem is created.
- Reliability is reduced and maintenance increased.
- Additional personnel training is required.
- Additional expenses are incurred due to administrative and policy procedures having to be established.