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IEEE Guide for Power System Protective Relay Applications of Audio Tones over Telephone Channels

Sponsor

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of the
Power System Relaying Committee
of the
IEEE Power Engineering Society**

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Foreword

(This foreword is not a part of ANSI/IEEE C37.93-1987, IEEE Guide for Power System Protective Relay Applications of Audio Tones over Telephone Channels.)

This guide, last revised in 1976, recognized the reliability demands placed on audio tone relaying equipment and the associated telephone facilities. The challenges for providing reliable (secure and dependable), high-speed pilot protection have increased enormously over the years. These challenges have occurred as power systems are operated closer to design limits due to economic, environmental, and regulatory considerations.

This revision retains the original intent of providing a reference for manufacturers, designers, and users of audio tone equipment and for providers of the telecommunication channels employed with the audio tone protective relay schemes. It was prepared not only for those using an audio tone relay system for the first time but also as a reference for the experienced user.

This revision provides a basic introduction and description of leased telephone channels. Also included are typical interface requirements and the transmission line characteristics of three channel offerings along with examples. Since other IEEE standards cover the subject of protection more comprehensively, a brief description of special protection devices is provided for informational purposes. Sections have been revised to be consistent with current telephone company practices and the section concerning periodic maintenance has been expanded.

Acknowledgment

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IEEE Guide for Power System Protective Relay Applications of Audio Tones over Telephone Channels

1. Scope and References

1.1 Scope

1.1.1

This guide contains information and recommendations for applying audio tones over telephone channels for power system relaying. Included are sections on transmitting and receiving equipment, leased telephone channels, application principles, installation, and testing. Reflected in this work is the knowledge and experience of equipment manufacturers and telephone companies as well as that of power utility users.

1.1.2

This guide is not intended to supplant specific or general instructions contained in the manufacturers' instruction books or in any contractual agreement between a manufacturer or telephone company(s) or both and a purchaser of a given relaying system. The illustrations in 5.7 are used for illustrative purposes only and do not represent the preferred protection under all conditions.

1.2 References

The following publications shall be used in conjunction with this standard:

- [1] ANSI/IEEE C37.90-1978, IEEE Standard Relays and Relay Systems Associated with Electric Power Apparatus.
- [2] ANSI/IEEE C37.90.1-1974 (Redesignation of ANSI C37.90a-1974/IEEE Std 472-1974), IEEE Guide for Surge Withstand Capability (SWC) Tests.
- [3] ANSI/IEEE Std 281-1984, IEEE Standard Service Conditions for Power System Communication Equipment.¹
- [4] ANSI/IEEE Std 367-1979, IEEE Guide for Determining the Maximum Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault.
- [5] ANSI/IEEE Std 487-1980, IEEE Guide for the Protection of Wire-Line Communication Facilities Serving Electric Power Stations.

¹ANSI/IEEE publications can be obtained from the Institute of Electrical and Electronics Engineers Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, or from the American National Standards Institute, Sales Department, 1430 Broadway, New York, NY 10018.

2. Purpose

2.1

The primary purpose of this document is to guide the power system user in applying, installing, and operating audio-tone protective relaying systems over telephone channels. Secondly, it is to provide a reference for equipment manufacturers engaged in the design and application of relaying equipment and for telephone personnel engaged in providing telecommunications channels for audio-tone protective relay schemes. The guide has been prepared not only for those considering audio-tone relaying for the first time, but as a reference for the experienced.

3. Transmitting and Receiving Equipment

3.1 Relaying Requirements

3.1.1

Receiver response is very essential in ensuring correct operation of an audio-tone relay scheme. It is most important that receivers be capable of discriminating between valid signals and spurious signals which may be introduced into the telephone lines particularly during power system disturbances.

3.1.2

Extremely high on the list of desirable system objectives is security — the assurance that false tripping will not occur. Here the goal is no false operations under any and all operating conditions. A trip signal should provide satisfactory operation down to a signal-to-noise ratio of zero decibel (0 dB) using a C-message weighted noise measurement. However, a proper balance between security and dependability — the assurance that valid tripping will occur — should be accepted.

3.1.3

Equipment designed for relaying functions and for use with available types of telephone communication circuits should meet the following requirements:

- 1) The operate time should be consistent with the relay application requirements but in the interest of security the tone operate time should not be any faster than necessary, typically 10–16 ms. This includes tone transmitter operation time (after being keyed), tone receiver response time, and operate time of an output device. This does not include telephone channel delay time, which may vary from a few milliseconds to over 10 ms. Accordingly, in writing audio-tone terminal equipment specifications, the user should exclude telephone channel delay time when specifying required speed, since this time is not under the control of the tone equipment manufacturer.
- 2) Highest dependability possible.
- 3) Highest possible security for conditions such as:
 - a) steady state noise equal in magnitude to the signal over the voice frequency bandwidth
 - b) failure of the monitoring signal
 - c) intermittent shorting, opening, or grounding of the communication circuit
 - d) complete interruption of the communication circuit
 - e) cross talk from an adjacent circuit
 - f) inadvertent application of test signals normally encountered in channel testing
 - g) power system disturbances
 - h) removal and application of power supply

- i) multiplex or carrier frequency translations
- j) single component failure
- k) voltage transients in power supply and output circuits
- l) electromagnetic interference (EMI) and radio frequency interference (RFI) effects
- m) physical substation environment

3.2 Basic Types of Audio-Tone Systems

3.2.1 General

Equipment to meet the relaying requirements may take any of several forms. The importance of the function requires that the user be assured of a workable system on a continuous basis with an alarm to indicate an inoperative condition. Each type of equipment has both advantages and disadvantages.

3.2.2 Frequency Shift Modulated Equipment

This equipment is the type most frequently used. A signal is always present under normal conditions on one of two possible frequencies, guard or trip. Frequency shift equipment is inherently self monitoring when the design is such that the same components generate, amplify, and receive both frequencies. Some frequency shift equipment also employs an enhanced trip signal so that the signal to noise ratio is improved at the time of trip signal transmission. (See 4.3.2.1.) This increase in signal power during enhanced signaling trip typically lasts for 50 to 100 ms.

3.2.3 ON-OFF Modulated Equipment

ON-OFF equipment is not inherently self-monitoring because many components are inactive in their quiescent state. If the scheme utilizes more than one tone signal, the circuit can be designed for periodic in-service testing. This type of equipment is presently applicable only to blocking type relaying systems.

3.2.4 Coded Pulse Signaling

Coded pulse signaling is another mode of signal applicable to relay functions employing one of the above types of signal transmission. The signal is keyed in a time sequence to form a code composed of marks and spaces.

Coded pulse equipment appears to offer great security against false operation due to interference. Coded pulse systems require greater channel bandwidths for the same operating speed than do the basic frequency shift or ON-OFF systems. This factor should be considered in view of the frequency range of the telephone channel and the overall function of the equipment.

3.2.5 Phase Shift Keying Modulated Equipment

The form of phase modulation in which the modulating function shifts the instantaneous phase of the modulated wave between predetermined discrete values is called phase shift keying. One predetermined phase of the signal may be guard and another may be trip; or, a combination of keying between two or more phases can be guard and another combination trip. The band-width of the channel is dependent on the channel time required and the keying rate (frequency of keying between phases).

3.3 Power Supplies

3.3.1 General

Solid state audio-tone equipment operates at voltages typically below 24 V direct current. This is not usually the concern of the power application engineer because of the integral power supplies that go with these equipments. Practically all such power supply units are designed with regulators to maintain output voltage to assure performance

of the tone equipment within its specified limits. These supplies operate from standard power station sources: 120 V alternating current, 24, 48, 125, and 250 V direct current (ANSI/IEEE Std 281-1984) [3].² In applying solid state equipment, care should be taken to insure that the power supply ratings are adequate for battery equalizing overvoltages.

Power supplies in newer type audio-tone equipment are of the DC-DC converter type. The isolation afforded by this type of supply reduces the effects of surges appearing at the power supply input, and is of particular benefit when the station battery is used as the source. Converter type power supplies are preferred over the less effective dropping resistor and tapped station battery techniques.

3.3.2 Station Battery Source

From an operating point of view, the use of the station battery may be preferable to a separate battery since it reduces maintenance.

3.3.3 Separate Battery Source

For solid state equipment, there are advantages to separate battery sources since this equipment usually operates below 48 V. This method of supply has the advantage of being independent of the station battery source, thus minimizing exposure to surge phenomena originating in the station battery circuits.

3.3.4 Alternating Current Source

Alternating current as a source of power is suitable only when supplied from an uninterruptible power source (UPS).

3.3.5 Telephone Company Power Requirements

Particular attention should be given to the power requirements for any on-site active network channel terminating equipment owned by the telephone company. If this equipment is essential to the proper operation of relay schemes, the same considerations listed in this section must apply.

3.4 Equipment Protection from Surge Phenomena

3.4.1

The manufacturer of the terminal equipment normally includes all necessary components for suppression of surges in the power supply and output circuits. Such components are provided to reduce the effect of surges in the signal channels and include those necessary to prevent damage to components. Suitable surge reducing components should be applied to the communications channel and to the power supply connections. Such surge isolation and protective equipment should be coordinated with that of the communications facilities and tested in accordance with capability (SWC) Test, ANSI/IEEE C37.90.1-1978 [1].

3.5 Noise Suppression Circuits or Devices

3.5.1 General

Most commercial equipment contains circuits to sort the incoming signals and yield the desired output. These circuits provide a measure of protection against false operation from spurious frequencies or noise.

²The numbers in square brackets correspond to those of the references listed in 1.2 of this guide; when preceded by the letter B, they refer to bibliographic selections listed in Section 7

3.5.2 Circuit Arrangement

In frequency shift keyed systems, the tripping circuits are usually arranged to operate upon loss of guard tone and reception of a trip tone. The condition of loss of guard tone output may result from or be coincident with the presence of noise. If a trip frequency or trip frequencies appear under these conditions, an undesired trip may occur. Protection against this is difficult.

3.5.3 Noise Presence

The presence of noise offers a degree of information that can be used to block the receiver if desired:

- 1) A filter can be used to detect broad band noise which, through suitable amplification, can be used to prevent receiver operation. The noise filter should have a sufficiently wide passband (wider than the receiver filter) so that the response time of this “squench” circuit is rapid enough to block the receiver output circuits before an impulse can travel through the tone receiver. The frequency of the noise filter shall fit into the spectrum of the system at a point not utilized for information transfer.
- 2) If the noise to be protected against is not broad band or the frequency spectrum for a noise filter is not available, some means shall be found to operate successfully with the information available through the receive filter. This may be accomplished through the use of a discriminator or logic.

3.5.4 Signal-to-Noise Ratio Comparison Circuits

Such circuits have performed with a satisfactory history of security. It is necessary that a true comparison be made between noise and signal and that trip blocking be performed rapidly. A second area of importance is the time delay in restoration of tripping to permit all residual noise components to clear the equipment.

3.5.5 Loss-of-Tone Monitoring

A loss-of-tone squelch feature improves the security of the toner receiver in the presence of noise. This feature is provided to prevent false operation of the receiver output relays whenever low-level noise is received in the absence of tone.

3.5.6 Tone Level Meter

Tone level meters may be used to provide a visual indication of the relative operating condition of tone receivers and channel attenuation.

3.6 Frequency Translation Protection

- 1) Tripping can be blocked during a frequency translation caused by multiplex or carrier equipment switching with the use of a pilot tone in conjunction with a “notched” noise squelch bandpass filter. The pilot tone is selected to fall within the “notch” or rejection band of the noise squelch receiver. Should the telephone channel translate the relaying frequencies, it will also translate the pilot tone out of the rejection band to allow the pilot tone to activate the noise squelch receiver.
- 2) By using two frequency shift tones, one can be made to shift up for trip and the other down to trip. This will permit in-band noise monitoring and with proper logic protects against the effects of frequency translation.

4. Leased Telephone Channels

4.1 Introduction

4.1.1

Leased telephone channels as referred to in this guide are dedicated (that is, private line, nonswitched) voiceband communication paths that interconnect two or more locations for the purpose of transmitting electrical signals from one location to another. These channels, which have usable bandwidths from approximately 300 to 3000 Hz, are provided over a variety of transmission media including paired wire, multipaired cable, coaxial cable, microwave radio, and optical fibers. Voiceband signals may be transmitted from one location to another entirely as voice frequency signals, or they may be converted to equivalent electrical signals for transmission on analog or digital carrier systems. Combinations of various transmission media and transmission systems are frequently employed by telephone companies so that customer demand for telecommunication services might be met in the most cost effective manner.

Channel characteristics described in this section are for two types of voiceband telephone channels:

- 1) Typical widely available voiceband channels, either basic (nonconditioned) or conditioned, which can be used for a variety of voiceband applications, including audio-tone protective relaying.
- 2) A voiceband channel specifically designed for audio-tone protective relaying applications. This channel is intended to provide increased reliability for protective relaying systems through improved signal to noise performance in that portion of the circuit in the immediate vicinity of the power station (between the power station and the serving telephone company central office).

4.2 Need for Joint Discussions

4.2.1

When leased telephone channels are contemplated for highly critical audio-tone protective relaying applications, consideration should be given to joint discussions so that those involved may have a mutual understanding of the system requirements and have ample opportunity to work out any problems prior to initiation of service. Such discussions should include responsible engineering representatives from the telephone company and the power utility, and where appropriate, the audio-tone equipment manufacturer or supplier. The discussion should include the following items:

- 1) audio-tone terminal equipment operation and performance
- 2) special high voltage protection requirements at the power station(s) and any other protection requirements throughout the length of the channel
- 3) reliability requirements (including the possibility of dual alternate routed channels)
- 4) telephone channel characteristics (such as covered in 4.3)
- 5) channel testing and maintenance arrangements (including special services maintenance concepts)
- 6) equipment compatibility
- 7) tariff offerings and requirements
- 8) central office termination markings (including joint inspections)
- 9) power requirements for the telephone company's network channel terminating equipment
- 10) use of sealing current (a circulation of approximately 1 mA of dc current) by the telephone company to prevent circuit noise caused by small accumulations of oxides at splices and other connection points.

This is not an all inclusive list but represents items that should be mutually understood to increase the likelihood of successful operation.

4.3 Characteristics of Telephone Channels

4.3.1 Voiceband Channel Offerings

Table 1 gives typical interface requirements and transmission characteristics for two leased voiceband telephone channels that can be employed for audio-tone protective relaying. These typical specifications are representative of specifications for telecommunication channels that are provided under both interstate and intrastate tariffs in the United States. Since the channel specifications in Table 1 are only representative, it is recommended that actual specifications be obtained from the local telephone company serving a particular area or jurisdiction.

It is anticipated that the requirements for most audio-tone protective relaying systems will be met by one of the channels described in Table 1. If there are unusual transmission requirements, or if special engineering considerations are involved, those should be fully discussed with the telephone company so that they can be provided on a custom engineering basis.

4.3.2 Interface Requirements

Requirements at the customer-telephone company interface are established for the electrical protection of the telephone network, for the proper functioning of the protective relaying channel and the terminal equipment, and for purposes of standardization in private line channel design.

4.3.2.1 Transmitted Signal Power

For the leased voiceband telephone channels listed in Table 1, the maximum allowable composite transmitted signal power at the customer-telephone company interface, averaged over any three second interval, is 0 dBm (0 dB referred to 1 mW). The Special Audio-Tone Protective Relay Channel, described in the Bell publication PUB 41011 [B1] and shown in Table 1, permits a short term enhanced trip signal up to +16 dBm at the transmitting interface. This is so that the transmitted trip signal might override the fault coincident noise often introduced onto telephone facilities at times of power system faults. The duration of the enhanced trip signal is typically 50 to 100 ms, depending upon the terminal equipment design. If enhanced trip is used, the steady state transmitted power must be less than 0 dBm by the amount necessary to permit the three second intervals, including the enhanced trip signal and the three seconds before and afterwards, to meet the three second average power limitation. For example, if an enhanced signal of +16 dBm is sent for a duration of 50 ms, the maximum permissible steady state power before and after the enhanced signal would be -4.7 dBm. This is determined as follows:

- 1) 0 dBm for three seconds is equal to 3 mW-s per three second interval
- 2) +16 dBm for 50 ms is equal to $40 \text{ mW} \cdot 0.05 \text{ seconds}$ or 2 mW-s
- 3) 3 mW-seconds total for any three second interval minus 2 mW-s of enhanced trip signal is equal to 1 mW-s available for the remaining 2.95 s
- 4) $1 \text{ mW-s} \div 2.95 \text{ s} = 0.34 \text{ mW}$ or -4.7 dBm

When more than one protective relaying tone transmitter is connected to the same telephone channel, the power limitations apply to the total signal at the customer-telephone company interface. (See example in the Annex.)

4.3.2.2 Terminal Impedance and Balance

For the channels listed in Table 1, the nominal impedance of the protective relaying terminal equipment should be 600 Ω resistive $\pm 10\%$ and balanced to ground over the 300 to 3000 Hz band. The impedance of telephone company test equipment used for installation and maintenance tests is ordinarily 600 Ω resistive. Therefore, channels whose transmission characteristics were adjusted using 600 Ω test equipment should also employ protective relaying terminal equipment that has the same impedance to ensure that channel transmission performance is as specified.