ANSI CANVASS LETTER BALLOT

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Question: Should this standard, developed by the National Electrical Contractors Association (NECA), be approved as an American National Standard?

XX Approve
XXXX Approve With Comment (see attached Comment Matrix)

XXXX Disapprove In accordance with ANSI procedures, objections must be accompanied by supporting written reasons, and, where possible, proposals for a solution to the problem raised. (see attached Comment Matrix)

XXXX Abstain If you find you cannot vote “yes” or “no” and want to be recorded as abstaining, please explain the reasons for your abstention (see attached Comment Matrix)

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# Table of Contents

## 1. Scope

1.1 Products and Applications Included .................................
1.2 Products and Applications Excluded ............................... 
1.3 Regulatory and Other Requirements ............................... 
1.4 Mandatory Requirements, Permissive Requirements, Quality and Performance Recommendations, Explanatory Material, and Informative Annexes ............................................

## 2. Definitions

## 3. Introduction

3.1 Overview ........................................................................ 
3.2 Sources of Power Quality Problems ............................... 
3.3 Power Quality Audit ....................................................

## 4. Grounding and Bonding

4.1 Overview ........................................................................ 
4.1.1 Personnel Safety ................................................... 
4.1.2 Overcurrent Protective Device Operation ................... 
4.1.3 Voltage Reference ................................................ 
4.2 Causes of Grounding Problems ..................................... 
4.2.1 Grounding Connections and Terminations .................
4.2.2 Open or Missing Grounding Conductor ...................... 
4.2.3 Undersized Grounded or Neutral Conductors .............. 
4.2.4 Improper Neutral-to-Ground Bonding ....................... 
4.2.5 Multiple, Separate Grounding Electrodes ....................
4.2.6 Improper Isolated Ground Systems ..........................

## 5. Transient Voltage or Current

5.1 Overview ........................................................................ 
5.1.1 Impulsive transients .............................................. 
5.1.2 Oscillatory transients ............................................. 
5.2 Sources of Transient Voltages and Currents ....................
5.2.1 Lightning .............................................................
5.2.2 Motor Starting ..................................................... 
5.2.3 Power Capacitor Switching ..................................... 
5.2.4 Fault Clearing ..................................................... 
5.2.5 Transformer Energization and Ferroresonance .............. 
5.3 Mitigating Transient Voltages and Currents ....................

## 6. Voltage Distortion

6.1 Overview ........................................................................ 
6.2 Interruptions ............................................................... 
6.3 Voltage Sags or Dips ....................................................

### Foreword
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.4</td>
<td>Undervoltage</td>
<td>81</td>
</tr>
<tr>
<td>6.5</td>
<td>Voltage Swells</td>
<td>82</td>
</tr>
<tr>
<td>6.6</td>
<td>Overvoltage</td>
<td>83</td>
</tr>
<tr>
<td>6.7</td>
<td>Voltage Imbalance</td>
<td>84</td>
</tr>
<tr>
<td>6.8</td>
<td>Variations in Power System Frequency</td>
<td>85</td>
</tr>
<tr>
<td>6.9</td>
<td>Mitigating Voltage Distortion</td>
<td>86</td>
</tr>
<tr>
<td>6.9.1</td>
<td>Fast Transfer Switches</td>
<td>87</td>
</tr>
<tr>
<td>6.9.2</td>
<td>Uninterruptible Power Supplies (UPSs)</td>
<td>88</td>
</tr>
<tr>
<td>6.9.3</td>
<td>Interconnected Distributed Generation</td>
<td>89</td>
</tr>
<tr>
<td>6.9.4</td>
<td>Energy Storage Systems (ESS)</td>
<td>90</td>
</tr>
<tr>
<td>6.9.5</td>
<td>Compensators</td>
<td>91</td>
</tr>
<tr>
<td>7.</td>
<td>Waveform Distortion</td>
<td>93</td>
</tr>
<tr>
<td>7.1</td>
<td>Overview</td>
<td>94</td>
</tr>
<tr>
<td>7.2</td>
<td>Harmonics</td>
<td>95</td>
</tr>
<tr>
<td>7.2.1</td>
<td>Effects of Harmonic Distortion</td>
<td>96</td>
</tr>
<tr>
<td>7.2.2</td>
<td>Mitigating General Harmonic Distortion Effects</td>
<td>97</td>
</tr>
<tr>
<td>7.2.3</td>
<td>Arcing Harmonic-Generating Loads</td>
<td>98</td>
</tr>
<tr>
<td>7.2.4</td>
<td>Harmonic Filters</td>
<td>99</td>
</tr>
<tr>
<td>7.2.5</td>
<td>Harmonic Resonance</td>
<td>100</td>
</tr>
<tr>
<td>7.3</td>
<td>Even Harmonics and Interharmonics</td>
<td>101</td>
</tr>
<tr>
<td>7.4</td>
<td>Notching</td>
<td>102</td>
</tr>
<tr>
<td>7.5</td>
<td>Noise</td>
<td>103</td>
</tr>
</tbody>
</table>

Annex A: Reference Standards

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(This foreword is not a part of the standard)

Foreword

National Electrical Installation Standards™ (NEIS™) are designed to improve communication among specifiers, purchasers, and suppliers of electrical construction services. They define a minimum baseline of quality and workmanship for installing electrical products and systems. NEIS™ are intended to be referenced in contract documents for electrical construction projects. The following language is recommended:


Use of NEIS™ is voluntary, and the National Electrical Contractors Association (NECA) assumes no obligation or liability to users of this publication. Existence of a standard shall not preclude any member or non-member of NECA from specifying or using alternate construction methods permitted by applicable regulations.

This publication is not intended as a substitute for qualified design professionals. Proper operation of electrical systems and equipment requires the analysis, comparison, selection, and coordination of electrical power distribution system equipment and components, and should be performed under the supervision of qualified individuals, such as by qualified professional engineers.

This publication is intended to comply with the National Electrical Code (NEC). Because they are quality standards, NEIS may in some instances go beyond the minimum safety requirements of the NEC. It is the responsibility of users of this publication to comply with state and local electrical codes and Federal and state OSHA safety regulations as well as follow manufacturer installation instructions when installing electrical products and systems.

Suggestions for revisions and improvements to this standard are welcome. They should be addressed to:

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1. Scope

This publication describes recommended practices for identifying possible causes of electrical equipment mis-operation due to poor power quality, and methods of improving overall system power quality and equipment operation.

1.1 Products and Applications Included

This recommended practice covers the following symptoms of poor power quality and addresses methods of addressing the root causes of poor power quality:

- Grounding and Bonding
- Transient voltage or current phenomenon
- Voltage distortion
- Waveform distortion

1.2 Products and Applications Excluded

This standard does not apply to:

- Electric power supply reliability
- Static electricity
- Voltage flicker

1.3 Regulatory and Other Requirements

All information in this publication is intended to conform to the National Electrical Code (ANSI/NFPA 70). Installers shall follow the NEC, applicable state and local codes, manufacturer instructions, and contract documents when installing electrical equipment and systems.

Only qualified persons as defined in the National Electrical Code familiar with the construction, installation, and operation of electrical power distribution equipment shall perform the technical work described in this publication. Administrative functions such as receiving, handling, and storing of electrical equipment and components and other tasks shall be performed under the supervision of a qualified person. All work shall be performed in accordance with NFPA 70E, Standard for Electrical Safety in the Workplace.

General requirements for installing electrical products and systems are described in NECA 1, Standard Practices for Good Workmanship in Electrical Construction (ANSI). Other NEIS provide additional guidance for installing particular types of electrical products and systems. A complete list of NEIS is provided in Annex A.

1.4 Mandatory Requirements, Permissive Requirements, Quality and Performance Recommendations, Explanatory Material, and Informative Annexes

Mandatory requirements in manufacturer instructions, Codes or other mandatory Standards that may or
may not be adopted into law, are those that identify actions that are specifically required or prohibited and are characterized by the use of the terms “must” or “must not,” “shall” or “shall not,” or “may not,” or “are not permitted,” or “are required,” or by the use of positive phrasing of mandatory requirements.

Examples of mandatory requirements may equally take the form of, “equipment must be protected . . .,” “equipment shall be protected . . .,” or “protect equipment . . .,” with the latter interpreted (understood) as “(it is necessary to) protect equipment . . .”

Permissive requirements of manufacturer instructions, Codes or other mandatory Standards that may or may not be adopted into law, are those that identify actions that are allowed but not required, or are normally used to describe options or alternative means and methods, and are characterized in this Standard by the use of the terms “may,” or “are permitted,” or “are not required.”

Quality and performance recommendations identify actions that are recommended or not recommended to improve the overall quality or performance of the installation and are characterized by the use of the terms “should” or “should not.”

Explanatory material, such as references to other Codes, Standards, documents, references to related sections of this Standard, information related to another Code, Standard, or document, and supplemental application and design information and data, is included throughout this Standard to expand the understanding of mandatory requirements, permissive requirements, and quality and performance recommendations. Such explanatory material is included for information only, and is identified by the use of the term “NOTE,” or by the use of italicized text.

Non-mandatory information and other reference standards or documents relative to the application and use of materials, equipment, and systems covered by this Standard are provided in informative annexes. Informative annexes are not part of the enforceable requirements of this Standard, but are included for information purposes only.

2. Definitions

Active Harmonic Filter: Any number of sophisticated power electronic devices that reduce or eliminate harmonic distortion from the power system by monitoring changes in the harmonic content of the load current and automatically injecting harmonic current into the system in response to those changes. Active harmonic filters supply some or all of the harmonic currents drawn by the non-sinusoidal load, while the utility power source supplies the balance of the load current, which has greatly reduced harmonic distortion from the contribution of the active filter. Newer active harmonic filters can also address the reactive power needs of the load.

Automatic Transfer Switch (ATS): A device that continuously monitors electrical operating parameters (such as voltage magnitude, phase angle displacement, and frequency) of two sources (one primary source, one backup or alternate source), that automatically transfers the load from the primary source to the backup source using mechanical means in the event that the operating parameters of the primary source fall outside of the tolerances of the operating characteristics of the load that are programmed into the device.

Bonding: The permanent joining of metallic parts to form an electrically conductive path which will assure electrical continuity and the capacity to conduct safely any current likely to be imposed.
**Bonding Jumper, Main:** The connector between the grounded circuit conductor (neutral) and the equipment-grounding conductor at the service entrance.

**Brownout:** A reduction of voltage by the utility for a long duration (hours).

**Current Distortion:** Deviation from the normal sine wave in the AC line current.

**Distortion:** Any deviation from a perfectly sinusoidal wave.

**Disturbance:** Any sudden change in the intended power, voltage, or current supply.

**Dropout:** A loss of equipment operation (discrete data signals) due to noise, sag, or interruption.

**Dropout Voltage:** The voltage at which a device fails to operate due to an undervoltage condition.

**Duration, Long:** A length of time greater than 1 minute.

**Duration, Short:** A length of time greater than 0.5 cycles of the power frequency but less than or equal to 1 minute.

**Electromagnetic Compatibility:** The ability of a device, equipment, or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

**Equipment Grounding Conductor:** The conductor used to connect the normally non-current-carrying parts of conduits, raceways, and equipment enclosures to the grounded conductor (neutral) and the grounding electrode at the service equipment (main panel) or secondary of a separately derived system, such as a transformer.

**Fault:** Generally refers to a short circuit on the power system.

**Fault, Transient:** A short circuit on the power system usually induced by lightning, tree branches, or which can be cleared by momentarily interrupting the current.

**Ferroresonance:** An irregular, often chaotic type of resonance that involves the non-linear characteristic of iron-core (ferrous) inductors. It is nearly always undesirable when it occurs in the power delivery system, but it is exploited in technologies such as constant-voltage transformers to improve the power quality.

**Filter:** A generic term used to describe those types of equipment or devices whose purpose is to reduce the harmonic current of an electrical power system.

**Frequency Deviation:** The change of supply frequency above or below the nominal value. The duration of frequency deviation may be from several cycles to several hours.

**Ground:** The earth.
**Ground Loop:** A potentially detrimental loop formed when two or more points in an electrical system that are nominally at ground potential are connected by a conducting path such that either or both points are not at the same ground potential.

**Grounded (Grounding):** Connected (connecting) to ground or to a conductive body that extends the ground connection.

**Grounded Conductor:** A system or circuit conductor that is intentionally grounded.

**Grounded, Solidly:** Connected to ground without inserting any resistor or impedance device.

**Grounded System:** A system of conductors in which at least one conductor or point (usually the middle wire or neutral point of transformer or generator windings) is intentionally grounded, either solidly or through an impedance.

**Grounding:** A conducting connection, whether intentional or accidental, by which an electric circuit or equipment is connected to the earth, or to some conducting body of relatively large extent that serves in place of the earth used for establishing and maintaining the potential of the earth (or of the conducting body), or approximately that potential, on conductors connected to it; and for conducting ground current to and from the earth (or the conducting body).

**Grounding Conductor:** A conductor used to connect equipment or the grounded circuit of a wiring system to a grounding electrode or electrodes.

**Grounding Conductor, Equipment (EGC):** The conductor used to connect the non-current-carrying metal parts of equipment, raceways, and other enclosures to the system grounded conductor and/or the grounding electrode conductor at the service equipment or at the source of a separately derived system.

**Grounding Electrode:** A conductor or group of conductors in intimate contact with the earth for the purpose of providing a connection with earth.

**Grounding Electrode Conductor (GEC):** The conductor used to connect the grounding electrode to the equipment-grounding conductor and/or to the grounded conductor of the circuit at the service equipment or at the source of a separately derived system.

**Grounding Electrode System:** A conductor used to connect the system grounded conductor or the equipment to a grounding electrode or to a point on the grounding electrode system.

**Harmonic Distortion:** Periodic distortion of the sine wave caused by power system frequencies that are multiples of the fundamental frequency. The frequencies involved are created by non-linear loads, or loads in which the current waveform does not conform to the waveform of the supply voltage.

**Harmonic Filter:** A device for reducing or eliminating one or more harmonics from the power system. Also see active harmonic filter and passive harmonic filter.
Harmonic Resonance: A condition in which the power system is resonating near one of the major harmonics being produced by non-linear elements in the system, thus exacerbating the harmonic distortion.

Harmonics: Periodic sinusoidal distortions of the supply voltage or load current caused by non-linear loads. Harmonics are measured in integer multiples of the fundamental supply frequency.

Harmonic Voltage: A sinusoidal voltage with a frequency equal to an integer multiple of the fundamental frequency of the supply voltage.

Impulse Transient: A sudden, non-power frequency change in the steady-state voltage or current that is unidirectional in polarity (either positive or negative). Typical duration is nanoseconds to milliseconds with high amplitudes. Often associated with lightning strikes or switching surges.

Instantaneous: When used to quantify the duration of a short-duration variation as a modifier, this term refers to a time range from one-half cycle to 30 cycles of the power frequency.

Instantaneous Reclosing: A term commonly applied to reclosing of a utility breaker as quickly as possible after an interrupting fault current. Typical times are 18 to 30 cycles.

Interharmonics: Distorted voltage or current waveforms containing periodic distortions of a sinusoidal nature that are not integer multiples of the fundamental supply frequency.

Interharmonic Voltage: A sinusoidal voltage with a frequency that is not an integer multiple of the fundamental frequency.

Interruption: A reduction in the supply voltage to a level less than 10 percent of the nominal system voltage. Interruptions can be caused by system faults, system equipment failures or control and protection malfunctions. Typical duration of an interruptions is:

- Instantaneous: from 0.5 cycle to 30 cycles in duration.
- Momentary: from 30 cycles to three seconds in duration.
- Temporary: between three seconds and one minute in duration.
- Sustained: greater than 1-minute in duration.

Linear Load: An AC electrical load in which, in steady-state operation, the current at any time is proportional to the voltage of the electric supply with or without phase angle displacement. For a linear AC load with a sinusoidal supply voltage, the current waveform is also sinusoidal.

Long-Duration Voltage Variation: A variation of the RMS value of the line voltage from normal voltage for a time greater than 1 minute, such as undervoltage, overvoltage, or voltage interruption.

Low Frequency Oscillatory Transient: Sudden, non-power frequency change in the steady-state voltage or current, that includes both positive and negative polarity values, usually caused by utility capacitor switching. Distribution capacitor switching will typically produce a transient between 300 Hz and 900 Hz. Many utility distribution systems will have a common “ring” frequency due to fact that many utilities reuse construction details such as structure type or conductor type. In theory, the peak magnitude can be 200 percent, but in reality, it tends to fall between 130 and 180 percent with a duration between 0.5 to 3 cycles. 140 percent is a typical value. Transients below 300 Hz are generally the result of transformer energization or ferroresonance.
Noise: Unwanted electrical signals that produce undesirable effects in the circuits of the equipment and systems in which they occur.

Non-linear Load: An electrical load which draws current discontinuously or whose impedance varies throughout the cycle of the input AC voltage waveform.

Notching: A switching (or other) periodic disturbance of the normal power voltage waveform, lasting less than one half-cycle. This disturbance is initially the opposite polarity of the normal waveform and is thus subtractive from the normal waveform in terms of the peak value of the disturbance voltage. A complete loss of voltage for up to one-half-cycle is also considered notching.

Nominal Voltage ($V_n$): A nominal value assigned to a circuit or system for the purpose of conveniently designating its voltage class (as $208Y/120$ and $480Y/277$).

Oscillatory Transient: Sudden, non-power frequency change in the steady-state voltage or current, that includes both positive and negative polarity values. Typical duration can range from 5 microseconds to 3 milliseconds.

Overvoltage: An increase in the RMS AC voltage, at the power frequency, for a duration greater than a few seconds.

Passive Harmonic Filters: A combination of inductors, capacitors, and resistors designed to reduce or eliminate one or more harmonics from the power system. The most common variety is simply an inductor in series with a shunt capacitor, which short-circuits the major distorting harmonic component from the system.

Phase Shift: Sinusoidal waveforms that are displaced from each other with respect to time.

Point of Common Coupling (PCC): The point in the interconnected power system where loads are connected to the network (point at which load interacts with other loads and the network itself).

Power Factor: The ratio of active power (watts) to apparent power (volt-amperes).

Power Quality: The concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment.

Separately Derived System: Premises wiring system whose power is derived from generator, transformer, or converter windings and has no direct electrical connection, including a solidly connected grounded circuit conductor, to supply conductors originating in another system.

Service: The conductors and equipment for delivering electric energy from the serving utility to the wiring system of the premises served.

Short-Duration Voltage Variations: A variation of the RMS value of the line voltage from nominal voltage for a time greater than 0.5 cycles of the power frequency but less than or equal to 1 minute, such as a sag, swell, or interruption.
Static Transfer Switch (STS): A device that continuously monitors electrical operating parameters (such as voltage magnitude, phase angle displacement, and frequency) of two sources (one primary source, one backup or alternate source), that automatically transfers the load from the primary source to the backup source using power electronic switching means in the event that the operating parameters of the primary source fall outside of the tolerances of the operating characteristics of the load that are programmed into the device.

Total Harmonic Distortion: The ratio of the root mean squared (RMS) of the harmonic content to the RMS of the fundamental quantity, expressed as a percent of the fundamental.

Transient: An undesirable momentary deviation of the supply voltage or load current. A transient can be a unidirectional impulse of either polarity or a damped oscillatory wave from the first peak occurring in either polarity.

Transient Fault: A short circuit on the power system usually induced by lightning, tree branches, or animals, which can be cleared by momentarily interrupting the current.

Transient Overvoltage: A short duration oscillatory or non-oscillatory overvoltage usually highly damped and with a duration of a few milliseconds or less.

Undervoltage: A decrease in the RMS AC voltage, at the power frequency, for a duration greater than a few seconds.

Ungrounded System: A system, circuit, or apparatus without an intentional connection to ground, except through potential indicating or measuring devices or other very high impedance devices.

Uninterruptible Power Supply (UPS): A system consisting of a rectifier/charger or rectifier and battery charger, a battery source, an inverter, usually an internal static bypass switch, and control equipment designed to provide power to the load that continues without interruption for a finite period of time after the loss, failure, or degradation of the normal AC power source.

Voltage Distortion: Any deviation from the nominal sine waveform of the AC line voltage.

Voltage Imbalance: A deviation in the magnitude and/or phase angle of one or more phases in a three-phase system with respect to the magnitude of the other phases and the normal phase angle.

Voltage Sag: A short duration reduction in RMS voltage that can be caused by a short circuit, overload, or starting of electric motors. A voltage sag happens when the RMS voltage decreases between 10 and 90 percent of nominal voltage, at the power frequency, for one-half cycle to one minute. Voltage sag is a three-phase phenomenon where all three phases are simultaneously affected.

Voltage Swell: A short duration increase in the RMS voltage level to between 110% and 180% of nominal voltage, at the power frequency, for one-half cycle to one minute.

Waveform Distortion: A steady-state deviation from an ideal sine wave of power frequency principally characterized by the spectral content of the deviation.
3. Introduction

3.1 Overview

Power quality is defined as the concept of powering and grounding electrical equipment in a manner that is suitable for the proper operation of that equipment. In other words, power quality is a subjective measure of the electrical characteristics of the supply of power that enables electrical equipment to work properly.

Ideally, electric power should be supplied at constant voltage and constant frequency without interruption, and with perfectly sinusoidal and symmetrical waveforms. In reality, electric power is affected by variations in the electric supply voltage and waveform, continually changing system loading, and influences of significant loads on other loads and on the system. Power quality problems arise when voltage, current, and/or frequency deviations result in the mis-operation or failure of equipment supplied by the system.

Power quality is further complicated by the fact that the load determines the current drawn from the supply voltage. Some electrical equipment draws current from the supply bus in a manner than degrades the ideal supply voltage magnitude, frequency, and/or sinusoidal waveshape.

Power quality in a practical sense involves the quality of the electric power supply along with the interaction of the electrical loads with other electrical loads on the electrical power distribution system, and with the electric power supply.

3.2 Sources of Power Quality Problems

Power quality problems are manifested in voltage, current, and/or frequency deviations that can be momentary, temporary, or long-duration, and that results in the failure or mis-operation of end-user equipment, and include:

- Undervoltage or overvoltage – typically caused by poor voltage regulation, incorrect transformer tap settings, overloaded feeder, and utility equipment
- Voltage sag, swell, or interruption – typically caused by faults, motor starting, and utility protective relay operation
- Under-frequency and over-frequency – typically caused by poor generator frequency or speed control
- Transient overvoltage – typically caused by lightning or switching loads
- Voltage imbalance – typically caused by unbalanced loads or equipment failure
- Waveform distortion, such as harmonics, interharmonics, resonance, and notching – typically caused by electronic loads

3.3 Power Quality Audit

While the methodology for troubleshooting and evaluating power quality is beyond the scope of this Recommended Practice, the pages that follow provide guidance for addressing power quality issues. Many times, isolated operational issues with one malfunctioning piece or one type of equipment is
perceived as a facility-wide power quality problem that does not truly exist. Identifying issues with power quality is accomplished through a power quality audit. Tasks required during a power quality audit include:

- A review of electrical as-built drawings and one-line diagrams
- A site survey to verify documentation with actual field conditions
- A review of load information including classifying loads into categories of sensitivity or risk to power quality problems
- A review of maintenance records to identify trends in equipment mis-operation and failure
- Inspecting electrical connections and terminations
- Verifying proper grounding and bonding connections of electrical equipment
- Direct electrical testing, such as measuring voltage, current, and harmonic content (spectrum analysis), during equipment operation. Frequently, monitoring electrical equipment operation over time (from hours to weeks) is necessary to determine cyclic load patterns for equipment, and to detect intermittent operational and power quality anomalies.

The information obtained by performing a power quality audit will provide insight into what equipment is at risk and what electrical parameters may be causing power quality issues within a facility. Mitigating power quality problems is somewhat subjective, and qualified personnel with experience and expertise in identifying and resolving power quality issues are frequently needed to interpret the data gathered and to recommend effective corrective actions.

4. Grounding and Bonding

4.1 Overview

The grounding system is the first line of defense in protecting equipment and personnel during abnormal operating conditions, including short-circuits, ground-faults, voltage sags and surges, and lightning strikes. All grounding system components must be properly installed and properly connected to provide the intended protective and operational functions.

All electrical distribution systems must be grounded (connected to the earth, or to a conductive body that extends the ground connection) and bonded (connected to establish electrical continuity and conductivity). Grounding and bonding of electrical distribution systems and equipment provides a low-impedance path for fault current and limits the voltage rise on non-current-carrying components during fault conditions, which provides for personnel safety, facilitates overcurrent protective device operation, and establishes a voltage reference for equipment operation.

4.1.1 Personnel Safety

A low-impedance path for fault current created by grounding and bonding the electrical power distribution system in accordance with the NEC limits the voltage rise on non-current-carrying components, such as raceways, boxes, and enclosures, in accordance with Ohm’s law. Consequently, the shock hazard associated with a short circuit or ground-fault is reduced on the system, improving safety for personnel.

If the grounding and bonding is compromised, a short circuit or ground-fault could energize raceways,
10 boxes, and enclosures as high as the line voltage, creating a shock hazard for personnel coming into contact with the energized equipment.

4.1.2 Overcurrent Protective Device Operation

Low-impedance paths for fault current created by grounding and bonding the electrical power distribution system in accordance with the NEC facilitates high-speed operation of overcurrent protective devices. Overcurrent protective devices, such as fuses and circuit breakers, are inverse-time devices, meaning that they operate faster for higher levels of current. In accordance with Ohm’s law, the low-impedance path for fault current created by grounding and bonding causes high fault current levels for the given source voltage, which results in overcurrent protective devices operating quickly to remove the faulted equipment from the system.

4.1.3 Voltage Reference

Grounding and bonding the electrical power distribution system provides a reference voltage for safe and stable equipment operation. By grounding the system, the voltage rise on the phase conductors can be limited to the reference voltage, which can relieve stress on the electrical insulation of conductors and equipment. Additionally, grounding and bonding provides a path to shunt unwanted voltages and currents onto ground, toward the electrical supply source, and away from equipment.

4.2 Causes of Grounding Problems

Typical causes of power quality issues related to grounding and bonding include:

- Loose or missing grounding connections and terminations
- Open or missing grounding conductors
- Undersized neutral conductors
- Improper neutral-to-ground bonding, including multiple neutral-to-ground bonds, or ground loops
- Multiple or separate grounding electrodes
- Improper isolated ground systems

4.2.1 Grounding Connections and Terminations

Loose, missing, or damaged grounding and bonding connections and terminations can cause the following power quality issues:

- Extreme voltage fluctuations caused by high impedance in the neutral circuit or in the neutral-to-ground bond
- High neutral to ground voltage due to high impedance to ground
- Burning or burnt smell at the panel, junction box, or load cause by overheated connections or arcing
- Equipment, panel, or junction box that is warm or hot to the touch due to arcing
- Buzzing sound due to arcing
- Thermal damage to equipment or conductor insulation due to a poor connection
- Intermittent voltage or loss of voltage due to poor connections
To ensure proper grounding connections and terminations, check the continuity of grounding and bonding conductors. Inspect all grounding and bonding connections and terminations for evidence of loose connections, thermal damage, arcing, corrosion, and physical damage. Verify the torque of grounding and bonding connections and terminations in accordance with manufacturer published torque-tightening values using a calibrated torque wrench or torque screwdriver. After applying proper torque, re-torque hardware after a period of several minutes. Re-terminate, repair, or replace loose, damaged, or corroded conductors and connections.

**NOTE:** Infrared scanning of conductors under load is typically used to identify loose or damaged connections in current-carrying conductors as the resulting high impedance causes hot spots that are easily detected by the infrared scan. Because grounding and bonding conductors that are properly designed and installed are not current-carrying conductors in steady-state, but are intended to only carry current during abnormal operating conditions, such as a ground-fault, infrared scanning is not used to identify loose or damaged grounding and bonding connections.

### 4.2.2 Open or Missing Grounding Conductor

An open or missing equipment grounding conductor poses a serious safety hazard. Equipment grounding conductors may be open or missing due to the age of the building (as equipment grounding conductors have not always been required to be installed), because of poor connections or terminations (see Section 4.2.1), or because ground connections have been intentionally removed.

For existing two-wire (phase and neutral) branch circuit receptacles, use a three-prong cord plug to two-prong receptacle adapter only when there is an equipment grounding conductor installed in the outlet box to provide grounding for the adapter and connected load. Alternatively, replace the existing two-prong (non-grounding) receptacle with a three-prong (grounding-type) receptacle when the equipment grounding conductor is available in the outlet box.

For existing two-wire (phase and neutral) branch circuit wiring where the equipment grounding conductor is missing in its entirety, do not connect equipment that requires a grounding connection (three-prong cord plug). Upgrade the existing two-wire (phase and neutral) branch circuit wiring systems to three-wire, (phase, neutral, and ground) branch circuits in accordance with recommended wiring methods in the NEC.

Identify and correct loose, missing, or damaged grounding connections and terminations in accordance with Section 4.2.1.

Identify and correct grounding and bonding connections that have been intentionally removed or disconnected. Check the plug connector of all equipment and extension cords for a missing equipment ground prong. Remove any cord-and-plug equipment and extension cords that are missing the equipment ground prong from service until the cord plug is replaced.

### 4.2.3 Undersized Grounded or Neutral Conductors

The grounded or neutral conductor in three-phase, four-wire, wye-grounded systems carries return currents from unbalanced loads, unbalanced phase voltages, or both, and harmonic currents that are in...
phase and do not cancel (triplen harmonics).

For balanced linear loads on a three-phase system, there is zero current flowing in the neutral conductor, as the out-of-phase return currents from each phase mathematically cancel. For this reason, the NEC has, under certain design conditions, permitted the neutral conductor of three-phase, four-wire, wye-grounded systems to be reduced in size from the phase conductors, such as permitting multi-wire branch circuits where two or three line-to-neutral branch circuits share a common neutral conductor.

Over time, with greater applications of electronics into everyday electrical equipment and appliances, harmonics have impacted the magnitude of current flowing on the neutral conductor (see Section 7.2). Consequently, historically NEC-compliant electrical systems have begun to demonstrate symptoms of poor power quality from apparently undersized neutral conductors.

For three-phase, four-wire, wye-grounded electrical distribution systems, overloaded or undersized grounded or neutral conductors that supply unbalanced or non-linear line-to-neutral connected loads can lead to equipment and conductor overheating, loose connections and terminations, thermal damage, and excessive neutral-to-ground voltage as measured at the receptacle (due to voltage drop over the length of the overloaded neutral conductor), which can lead to the mis-operation of electronic equipment.

When overloaded (undersized) neutral conductors are suspected, measure the load current in phase and neutral conductors using a true-RMS ammeter, which is capable of measuring harmonic current contribution to the load current. Compare the measured current with the ampacity of the neutral conductor.

If the neutral conductor is overloaded (undersized), identify the harmonic content of the load current, and measure the phase-to-phase, phase-to-neutral, and neutral-to-ground voltages. If there is a significant variation in voltage measurements between phases, between phase-to-neutral, and from neutral-to-ground, see Section 6.7 for guidance in addressing voltage imbalance. If the neutral current predominately consists of harmonics, see Section 7.2 for guidance in mitigating harmonic-related power quality issues.

If the neutral current does not predominately consist of harmonics, either more closely balance the loads between the phases, reduce the loads on the circuits, and/or replace neutrals conductors with conductors of higher ampacity. For multi-wire branch circuits, install separate, dedicated neutral conductors that are the same ampacity as the phase conductors for all line-to-neutral branch circuits.

### 4.2.4 Improper Neutral-to-Ground Bonding

For services and for separately-derived systems, the NEC requires that the neutral conductor be bonded to ground at one location, from the source of the supply up to the first overcurrent protective device for the circuit. From that neutral-to-ground bonding location, the neutral (grounded conductor) must be insulated and isolated from the equipment grounding conductor its entire length, including panelboards, junction boxes, and all connections and terminations.

When the neutral conductor is not bonded to ground at all, the electrical system operates as an ungrounded system. In an ungrounded system, the neutral is capacitively-coupled to ground, and the neutral-to-ground voltage will be affected by any load imbalance on the system. The first symptom of no neutral-to-ground bond may be the mis-operation of electronic equipment due to excessive neutral-to-ground voltage at receptacles from the floating neutral-to-ground voltage.
More frequently, a missing neutral-to-ground bond is identified after a ground-fault on the system establishes a connection with a voltage reference that is significantly different than expected, and the measured neutral-to-ground voltage is significantly greater than zero. Overcurrent protective devices, such as circuit breakers and fuses, do not operate because there is only one grounding connection of the system, the ground-fault location, which establishes the electrical reference for the system, but does not permit fault current to flow.

To identify a missing neutral-to-ground bond, measure the phase-to-phase, phase-to-neutral, phase-to-ground, and neutral-to-ground voltages. A floating or ungrounded system will have different values of phase-to-ground and neutral-to-ground voltages at different times with different loadings. A system with a ground-fault will have stable phase-to-ground and neutral-to-ground voltages that vary significantly from nominally expected values when the faulted load is in operation, and will float as described above when the faulted load is OFF.

If more than one neutral-to-ground bond exists, the neutral and the equipment grounding conductor are electrically connected in parallel, which creates a ground loop that permits neutral currents to flow on the equipment grounding conductor and the grounding electrode system. Symptoms of multiple neutral-to-ground bonds include load currents flowing on equipment grounding conductors, unexplained damage on mechanical and plumbing systems, such as pin-hole leaks in water pipes (grounding electrode) that are carrying current in steady-state, mis-operation of low-voltage systems and data and communication systems from ground shield conductors carrying current, and arcing when disconnecting equipment grounding conductors.

Other causes of neutral current flow on the grounding system include an inadvertent cross connection between a neutral conductor to ground, and between an equipment grounding conductor to the neutral.

To identify multiple neutral-to-ground bonds, measure the current on equipment grounding conductors, grounding electrode conductors, and bonding jumpers. Review original and renovation construction drawings to identify locations where neutral-to-ground bonds may exist in the system. Visually inspect transformers, panelboards, generators, and transfer equipment to identify locations of neutral-to-ground bonding and any neutral or grounding conductors that are cross-connected. Identify the one neutral-to-ground location for each service and each separately-derived system.

During times of light system loading, install the one identified neutral-to-ground connection if it does not already exist, and systematically remove all other neutral-to-ground bonds throughout the system. Measure the current on equipment grounding conductors before and after removing each connection to verify that all additional neutral-to-ground bonds have been removed. After removing all supplemental neutral-to-ground bonds, measure the phase-to-phase, phase-to-neutral, phase-to-ground, and neutral-to-ground voltages and check continuity of the neutral to ground at each panelboard to ensure that the system is properly grounded.

### 4.2.5 Multiple, Separate Grounding Electrodes

The NEC requires that all available grounding electrodes be bonded together to form one grounding electrode system. Multiple separate (electrically isolated) grounding electrodes, such as additional or supplemental ground rods that are not bonded to the overall grounding electrode system, can cause power quality problems from different voltage potentials between circuits and systems that are common between the two or more electrically isolated grounding electrodes, such as low-voltage power, data, or communication systems.
When equipment and systems have one interconnected grounding electrode system, the voltage potential over the entire grounding system rises and falls at the same potential, such as during a ground-fault or lightning strike. When equipment and systems have multiple separate (electrically isolated) grounding electrodes, a ground-fault or lightning strike will result in different voltage potentials across the different grounding electrodes, with the common connections between equipment and systems being the only path to normalize the voltage on the grounding system.

The symptoms of multiple, isolate grounding electrodes include repetitive damage to power supplies, printed circuit boards, and communication and data conductors of low-voltage systems, such as fire alarm systems, CCTV, security, and access control systems, and data and communication systems, such as computers and telephone systems, from transient overvoltages and overloaded ground and shield conductors during or after ground-faults, thunderstorms, and lightning strikes.

To identify multiple, separate grounding electrodes, review original and renovation construction drawings to identify locations for installing and bonding grounding electrodes throughout the facility. Visually inspect grounding electrode connections to identify grounding electrode bonding connections. Where grounding electrodes are isolated, install grounding electrode bonding jumpers in accordance with the NEC.

### 4.2.6 Improper Isolated Ground Systems

Isolated ground branch circuits are installed to provide a “clean” voltage signal reference to ground for sensitive electronic loads. An isolate ground branch circuit is comprised of one phase conductor, one grounded or neutral conductor (typically white in color), an equipment grounding conductor (typically green in color), and an isolated ground conductor (typically green in color with one or more yellow stripes), that are connected to an isolated ground receptacle (denoted by a triangle on the face of the receptacle).

The ground connection (third-prong) of an isolated ground receptacle is isolated from the yoke of the receptacle. The isolated ground conductor is terminated on the ground connection of the receptacle, and the yoke of the receptacle is separately bonded to the equipment grounding conductor for electrical safety.

The isolated ground conductor is bonded to ground at the same location as the neutral. Similar to the neutral conductor, the isolated ground conductor is insulated and isolated from ground from the neutral-to-ground bonding location to its point of connection on the isolated ground receptacle. Similar to the neutral, isolated ground connections that are made within a panelboard must be made on terminal bars that are insulated and isolated from the panelboard cabinet.

Unlike the equipment grounding conductor that is intended to carry fault current, the isolated ground conductor is intended to never carry current. As such, there should be no voltage drop to ground across an isolated ground conductor, which provides a stable voltage reference to ground for the equipment supplied from the isolated ground branch circuit.

Power quality problems arise with isolated ground systems when the isolated ground conductor is not insulated and isolated from the ground from the neutral-to-ground bonding location to its point of connection on the isolated ground receptacle, and the isolated ground conductor has an inadvertent connection to the equipment grounding conductor, or worse, carries current from an inadvertent connection to the neutral.
Inadvertent cross-connections between the isolate ground and the neutral and/or the equipment grounding conductor can happen over time as new circuits are installed or when changes are made to existing circuits. An isolated ground cross-connection with the equipment grounding conductor can introduce fault currents to the isolated ground system, and will introduce unwanted currents and signals that are typically carried on the equipment grounding system back toward the source. An isolated ground cross-connection with the neutral conductor will introduce steady-state neutral load current to the isolated ground system. Both conditions are disruptive to the intended purpose of the isolated ground to never carry current and to be a stable voltage reference to ground for equipment.

Check for inadvertent connections between the isolated ground conductor and the neutral or the equipment grounding conductor by disconnecting the isolated ground connection at the neutral-to-ground bonding location and checking continuity from the isolated ground to the neutral and to the equipment grounding conductor at each isolated ground receptacle. Disconnect any connections found between the isolated ground conductor and the neutral and equipment grounding conductor at any point from the neutral-to-ground bonding location to its point of connection on the isolated ground receptacle. Additionally, verify that isolated ground branch circuits are only connected to isolated ground receptacles, denoted by having a triangle on the face of the device.

Ideally, isolated ground circuits should not share raceways or outlet boxes with non-isolated ground circuits. Additionally, isolated ground circuits should be routed in metallic raceways and outlet boxes, or should have metallic cable armor.

5. Transient Voltage or Current

5.1 Overview

Transient voltages and currents are high-energy pulses of relatively short duration that are caused by sudden changes in the electrical power distribution system. Transients are momentary disturbances rather than steady-state variations such as harmonic distortion or voltage imbalance, and can originate on either the customer or utility side of the system.

Transient overvoltages can be categorized by time as either surges, with a duration in the range of milliseconds, or spikes, with a duration in the range of seconds. Surges are high-energy pulses arising from power system switching disturbances, either directly or as a result of resonating circuits associated with switching devices and step load changes. Spikes result from direct or indirect lightning strikes, arcing, insulation breakdown, and fault clearing, among other causes.

Transients are either impulsive (unidirectional impulse of either polarity) or oscillatory (damped oscillatory wave with the first peak occurring in either polarity).

5.1.1 Impulsive transients

An impulsive transient is a fast (short duration) variation of the voltage value. Impulsive transients may reach thousands of volts, even on low voltage power distribution systems and equipment. Typical causes of impulsive transients include lightning, utility line-level switching, switching of power capacitors, and the disconnection of loads with high current levels. The result of impulsive transients can include data errors and loss, failure and destruction of electronic components, degradation and failure of electrical
insulation, and flashover.

Impulsive transients are damped quickly by resistive circuit components, and are not conducted far from
their source. Consequently, there can be significant differences in the transient characteristic away from
the source of the transient. Impulsive transients can also excite power systems components whose
resonance corresponds to the frequency of the transient, producing oscillatory transients.

5.1.2 Oscillatory transients

An oscillatory transient is a sudden, non-power frequency change in the steady state condition of voltage,
current, or both, that includes both positive and negative polarity values. An oscillatory transient consists
of a voltage or current of relatively high frequency, meaning that its instantaneous value changes polarity
rapidly.

Oscillatory transients are described by their spectral content (predominant frequency), duration, and
magnitude. The spectral content subclasses are high, medium, and low frequency. The frequency ranges
for these classifications are chosen to coincide with common types of power system oscillatory transient
phenomena.

Oscillatory transients with a primary frequency component greater than 500 kHz and a typical duration
measured in microseconds (or several cycles of the principal frequency) are considered high frequency
oscillatory transients. These transients are almost always due to some type of switching event. High
frequency oscillatory transients are often the result of a resonance condition, or the local system response
to an impulsive transient.

A transient with a primary frequency component between 5 kHz and 500 kHz with duration measured in
the tens of microseconds (or several cycles of the principal frequency) is considered to be a medium
frequency transient. Medium frequency oscillatory transients are typically the result of utility line-level
switching, back-to-back switching of power capacitors, or a system response to an impulsive transient.

A transient with a primary frequency component less than 5 kHz, and a duration from 0.3 ms to 50 ms, is
considered to be a low frequency transient. Low frequency oscillatory transients are typically the result
of switching power capacitors on the utility distribution or sub-transmission system.

Oscillatory transients with principal frequencies less than 300 Hz are generally associated with
transformer energization, ferroresonance, or series-connected power capacitors. Low-frequency
oscillatory transients can occur when the resonance results in magnification of low frequency components
in the transformer inrush current, such as the 2nd or 3rd harmonic, when unusual conditions result in
ferroresonance. See Section 5.2.5.

5.2 Sources of Transient Voltages and Currents

Sources of transients in power systems include lightning, load switching, power capacitor switching, fault
clearing, and transformer energization and ferroresonance.

5.2.1 Lightning
Lightning is a leading cause of impulsive transient overvoltages on electrical power distribution systems. Lighting produces high voltage and current magnitudes that can cause catastrophic damage from a direct strike. But because of the high voltage magnitudes associated with lighting, an indirect lightning strike in close proximity to conductors or equipment can also induce transients on the system.

Lightning will damage whatever it strikes directly. Lightning striking roof-mounted equipment or overhead lines often causes flashovers to adjacent conductors and equipment as insulators break down or the high voltage potential jumps air gaps. In these instances, the impulsive transient with be accompanied by fault clearing and voltage dips on the system. See Section 5.2.4.

When the system is not properly grounded and bonded, the ground potential in a localized segment of the electrical power distribution system will be raised by a nearby lightning strike while the balance of the system remains at a lower ground potential. See Section 4.2.5. In this circumstance, the impulsive transient voltage will be shunted to ground through the grounding circuits of common systems between the segmented electrical power distribution system, such as data, communication, access control, CCTV, and fire alarm systems, causing damage to those systems.

Additionally, high levels of neutral currents can flow between the segmented grounding system as the impulsive transient is shunted to ground among the segmented grounding system. Improper grounding and bonding can result in consistent, repetitive damage to sensitive electronic equipment and low voltage systems caused by lightning-induced impulsive transients.

### 5.2.2 Load Switching

Impulsive transients due to switching off loads with relatively high load current typically exhibits high voltage magnitude typical of an arc or fault clearing, but are of short duration, having very little energy and only affecting other equipment in relatively close proximity to the load being switched off.

### 5.2.3 Power Capacitor Switching

Capacitor switching is a significant source of transients on the electrical power distribution system. Capacitors are used to regulate system voltage and to reduce reactive power requirements and line losses on the system by providing reactive power (VAR) compensation for inductive loads, such as transformers, motors, and reactors. Some capacitors are static, meaning permanently connected and not switched. Other capacitors are switched in response to system conditions.

Capacitor switching to support distribution voltages can occur several times in a day. While capacitors are typically switched on early in the morning and switched off in the evening, they may be switched at any time.

When capacitors are switched and initially energized, they can cause oscillatory voltage transients due to their interaction with the inductive elements and other capacitive elements on the electrical power distribution system.

Capacitor switching can also cause resonant oscillations leading to overvoltages or overcurrents of several times the nominal ratings, causing overcurrent protective device operation or equipment damage. See Section 7.2.5. Electronically based controls for industrial motors are particularly susceptible to these
transients, as are variable-frequency drives (VFDs), personal computers, telephone and other communication systems, and television systems.

Back-to-back capacitor energization also results in oscillatory transient currents when power capacitors are energized in close electrical proximity to power capacitors already in service. Upon energization, the de-energized capacitors are a low-impedance path to ground from the perspective of the energized capacitors, with the current flow limited only by the inductance of the bus between the two capacitors, which is typically low.

5.2.4 Fault Clearing

During a fault, the voltage drops at the point of the fault, and high levels of current flow throughout the electrical power distribution system, which typically results in the operation of one or more overcurrent protective devices, circuit breakers and/or fuses. Overcurrent protective device operation to clear a fault has a similar effect as switching off a significant load, which results in an impulsive voltage transient on the system when the fault is cleared.

Automotive reclosers are frequently employed on overhead electrical distribution systems because many faults on overhead lines are temporary in nature, such as lightning and insulator flashover, tree limbs, and rodents, that can be cleared by interrupting the flow of current temporarily.

After a predetermined time delay that allows the fault to be cleared and all ionization in the air to dissipate, typically between 12 cycles and one minute, the circuit will be re-energized. If the fault has cleared, power has been fully restored. If the fault has not been cleared, the recloser will cycle again until either the fault is cleared or the recloser locks out the circuit for manual intervention, inspection, and repair. Each interrupting and reclosing action introduces impulsive transients to the electrical power distribution system.

5.2.5 Transformer Energization and Ferroresonance

Similar to motor starting, transformers experience an in-rush of starting current when initially energized. Energizing transformers can cause large oscillatory inrush currents that have an adverse effect on power quality each time a transformer is energized. Energizing a transformer can cause dynamic overvoltages for up to one second after it is energized, with a highly distorted in-rush current.

Ferroresonance can occur when transformers are energized concurrently with power capacitors, and the value of the magnetizing reactance of the transformer is close to the value of the system capacitance. 

*NOTE: The magnetizing flux of a transformer can change from cycle to cycle, and the resonant waveshape can also change from cycle to cycle. Because of the short duration, ferroresonance is classified as a transient overvoltage condition and not a harmonic (steady-state) power quality issue.*

Energizing transformers at a different rate than power capacitors can eliminate ferroresonance at transformer start-up. Additionally, power capacitors can be sized to de-tune the system from known resonant frequencies.

5.3 Mitigating Transient Voltages and Currents
Transient voltages and currents can be partly mitigated through design and installation that takes these phenomena into consideration, such as selecting and installing equipment that can withstand transients, using proper wiring methods, properly grounding and bonding the electrical power distribution system, and electrically isolating equipment from sources of transients.

Additionally, specific equipment can be installed to protect equipment from transient overvoltage by limiting the maximum voltage impulse introduced to the electrical system, such as lightning or surge protective devices (SPDs), such as metal oxide varistors or MOVs on high voltage circuits, SPDs such as avalanche diodes at low voltages, and isolation transformers to electrically isolate equipment.

Frequently, SPDs are installed at different levels of the electrical power distribution system, such as at the service entrance, at distribution equipment, at branch circuit panelboards, and at the point of use, to provide layered protection against transients.

Finally, a lightning protection system should be installed to mitigate the voltage and current transients from lightning. The goal of lightning protective systems, and proper grounding and bonding, is to prevent collateral damage away from the location of the lightning strike. While a separate system, the lighting protection system is required to be bonded to the building or facility grounding electrode system.

As a lightning strike is shunted to ground by the lightning protection system, the ground potential on the building or facility electrical power distribution system is raised to its maximum at the location where the impulse enters the system. Provided the building or facility electrical power distribution system is properly grounded and bonded (see Section 4), the entire electrical system rises with the introduction of the transient, and falls as the transient is dissipated. As a result, there is no collateral damage aside from the damage at the location of the lightning strike.

6. Voltage Distortion

6.1 Overview

Voltage quality is based on an ideal sinusoidal waveform of constant magnitude and constant frequency. Deviations in voltage quality include sinusoidal waveform distortion, including interruptions and imbalance between phases, variations in voltage magnitude above and below nominal, and variations in frequency. Distorted load current causes voltage distortion across the distribution system in accordance with Ohm’s law based on the impedance of the system.

Voltage distortion can also be caused by transient phenomena or the presence of non-linear components. See Section 5 for transient voltage conditions. See Section 7 for non-linear or harmonic distortion.

6.2 Interruptions

Interruptions are characterized by a reduction in the RMS voltage to 10% or less of the nominal voltage (essentially zero volts) on one or more phase conductors for a period of time. Interruptions are classified by duration as instantaneous, momentary, temporary, and sustained. NOTE: Interruption up to 0.5 cycle are classified as voltage notches. See Section 7.4. An instantaneous interruption is between 0.5 cycles and 30 cycles in duration. A momentary interruption is between 30 cycles and three seconds in duration. A temporary interruption is between three seconds and one minute in duration. A sustained interruption
is greater than one minute in duration, is often permanent in nature, and requires manual intervention to
restore power.

Causes of instantaneous, momentary, and temporary interruptions include overcurrent protection device
operation (blown fuse or circuit breaker opening), automatic circuit reclosers on overhead utility lines,
open transition (break-before-make) transfers between sources, and faults in close electrical proximity to
the load. Causes of sustained interruptions include events and equipment damage such as building fires,
insulation and equipment damage or failure, wildlife, trees and foliage, and snow and ice build-up,
saltwater spray in coastal areas, and downed overhead power lines, among others.

Methods of mitigating interruptions include redundant sources of power and automatic or static transfer
switches, uninterruptible power supplies (UPSs), on-site generation, and energy storage systems.

6.3 Voltage Sags or Dips

Voltage sages or dips are characterized by a reduction in the RMS voltage to between 10% and 90% of
the nominal voltage on one or more phase conductors for a period of time. Voltage sags are classified by
duration as instantaneous, momentary, and temporary. NOTE: A voltage sag of less than 0.5 cycle is
classified as a transient. See Section 5. An instantaneous voltage sag is between 0.5 cycles and 30 cycles
in duration. A momentary voltage sag is between 30 cycles and three seconds in duration. A temporary
voltage sag is between three seconds and one minute in duration.

Causes of voltage sags include lightning, system faults such as short circuits and ground-faults, switching
operations, energizing significant block loads, and motor starting. For system faults, once the fault is
cleared, the voltage will return to its original value. In this circumstance, the sag duration is slightly
longer than the fault clearing time due to re-energizing and re-accelerating inductive motor loads, which
can take several seconds to recover. Methods of mitigating voltage sags due to faults include fast-acting
overcurrent protective devices, such as current-limiting fuses and suitable instantaneous overcurrent
settings of adjustable-trip circuit breakers, and other types of high-speed, high-sensitivity relaying, such
as differential relaying.

Devices that are sensitive to voltage sags include Variable-Frequency Drives (VFDs), personal
computers, programmable logic controllers (PLC), large motors and motor controls; and High-Intensity
Discharge (HID) lighting systems (metal halide, low- and high-pressure sodium, and mercury vapor).
Depending upon duration and magnitude, voltage sags can cause HID lamps to turn off, control devices
and systems to malfunction, motors to stop or change speeds, contactors and electromagnetic relays to
trip, and computers to experience data errors, among others, as various equipment reaches their respective
dropout voltage.

The effects of voltage sags range from individual equipment mis-operation to system-wide equipment
mis-operation. When a few pieces of equipment are affected, mitigation methods for voltage sags include
installing robust equipment that is more tolerant of voltage sags, installing phase-shifting transformers
(delta/wye) to electrically isolate and protect sensitive electronic equipment, or installing point-of-use
UPSs on specific sensitive equipment to ride through voltage sags.

Mitigation methods for more wide-spread effects of voltage sag include installing a Ferroresonant or
constant voltage transformer or power capacitors to provide voltage support and ride-through capability
for momentary sags up to three seconds in duration. For longer duration sags, larger scale static or rotary
UPSs can be sized and installed to maintain the system voltage for the duration of the sag from several
seconds to several minutes.

For voltage sags caused by motor starting, depending on the method of starting and the nature of the load, induction motors can draw starting currents as high as six times the normal rated current from start-up to full rated speed, which can take several seconds to achieve. The motor stator winding appears to the system as a short circuit until the electric and magnetic fields are established between the stator and rotor and the motor reaches its full rated speed.

The short duration motor start-up current causes a voltage dip on the distribution system which is dependent on the impedance of the system. Methods to reduce motor starting current, and subsequently to reduce voltage dips due to motor starting, include using solid state starters such as variable frequency drives, reduced current starters such as autotransformer, star-delta, and partial winding starters, and using capacitors or resistors to reduce the starting current.

6.4 Undervoltage

Undervoltage is characterized by a reduction in the RMS voltage to between 80% and 90% of the nominal voltage on one or more phase conductors for a period of time greater than one minute in duration. Undervoltage is caused by overloaded circuits, power capacitors that are switched off, and energizing a significant block load, among others. Undervoltages are typically controlled by utility voltage regulation equipment.

Methods to mitigate undervoltage can include automatic tap-changing transformers, load shedding, switching loads to a redundant utility source using automatic or static transfer switching with a closed transition (make-before-break) transfer, switching loads to one or more distributed energy resources, such as local generation or an energy storage system, or supplying loads from a larger scale static UPSs with a battery plant sized to supply critical loads during the undervoltage condition or long enough to transfer loads to a suitable alternate voltage source.

6.5 Voltage Swells

Voltage swells are characterized by an increase in the RMS voltage to between 110% and 180% of the nominal voltage on one or more phase conductors and are classified by magnitude and duration. An instantaneous voltage swell is between 0.5 cycles and 30 cycles in duration with a magnitude between 110% and 180% of the nominal voltage. A momentary voltage swell is between 30 cycles and three seconds in duration with a magnitude between 110% and 140% of the nominal voltage. A temporary voltage swell is between three seconds and one minute in duration with a magnitude between 110% and 120% of the nominal voltage.

Voltage swells can be caused by switching off large block loads or switching on a large power capacitor. Additionally, voltage swells can develop in the unfaulted phases of a three-phase circuit that experiences a single-phase ground-fault.

Voltage swells can cause the mis-operation of variable frequency drives (VFDs), and control systems and equipment. Swells can cause protective circuits of electronic equipment to operate, shutting down equipment. Additionally, voltage swells can stress the insulation of sensitive electronic equipment, damaging equipment or shortening its life expectancy.
Voltage swells are typically controlled by utility voltage regulation equipment. Methods to mitigate voltage swells includes installing voltage regulation equipment, or static or rotary UPSs sized to supply loads for the duration of the swell from several seconds to several minutes.

### 6.6 Overvoltage

Overvoltage is characterized by an increase in the RMS voltage to between 110% and 120% of the nominal voltage on one or more phase conductors for a period of time greater than one minute in duration.

Overvoltage can be the result of load switching, such as switching off a large block load, switching on a relatively large power capacitor, slow or poor voltage regulation capabilities or control, and incorrect tap settings on transformers. Overvoltages are typically controlled by utility voltage regulation equipment.

Methods to mitigate overvoltage can include switching loads to a redundant utility source using automatic or static transfer switching with a closed transition (make-before-break) transfer, switching loads to one or more distributed energy resources, such as local generation or an energy storage system, or supplying loads from a larger scale static UPSs with a battery plant sized to supply critical loads during the overvoltage condition or long enough to transfer loads to a suitable alternate voltage source.

### 6.7 Voltage Imbalance

Voltage imbalance is characterized by differences in the phase voltage magnitudes of a three-phase system of between 0.5% to 3% in RMS voltage magnitudes under steady-state conditions, or differences in the phase angles between the voltage waveforms, which should be 120 electrical degrees, or both.

Unbalanced voltage vectors can be resolved using symmetrical components into positive, negative, and zero sequence phasors. Zero sequence phasors cause circulating current in series-connected equipment, and negative sequence phasors cause reverse torque and heating in motors.

Voltage imbalance can be caused by unbalanced or significant single-phase loads on a three-phase system, power capacitors anomalies such as a blown fuse on one phase of a the three-phase capacitor bank, single-phasing of a three-phase system, damaged or defective transformers, a sustained ground-fault on an ungrounded or resistance-grounded system, and overhead lines that are not transposed.

Voltage imbalance only affects three-phase applications and three-phase devices, such as motors and transformers. Some equipment is designed to tolerate only small voltage imbalances. Voltage imbalances can cause premature failure of motors and transformers due to overheating, and can cause electronic equipment to malfunction.

For example, a three-phase induction motor operating on an unbalanced voltage source will draw current that is several times more unbalanced than the supply voltage imbalance. As a result, there will be a considerable temperature rise in the motor, potentially damaging thermal insulation and shortening the motor life expectancy. In extreme cases, the load current imbalance may be severe enough to activate single-phase motor protection, if installed.
Methods of mitigating voltage imbalance includes installing voltage balance protection on motors and generators, installing equipment that can withstand the voltage imbalance, such as motors that provide a margin for voltage imbalance to avoid overheating and motor damage, and de-rating equipment for voltage imbalance in accordance with manufacturer instructions, when applicable.

### 6.8 Variations in Power System Frequency

Power system frequency is directly related to the rotational speed of the connected generation that is supplying the system. At any point in time, frequency depends on the balance between the capacity of connected generation and the load. When significant changes in this balance occur, frequency can be affected. The magnitude and impact of the change in frequency, and its duration, depends on the characteristic of the load and the dynamic response of the connected generation to load changes.

Frequency variations are caused by large-scale faults, connection or disconnection of a large block of load, or the disconnection or interruption of a large source of generation. Frequency variations are rare because of the grid nature of modern interconnected power systems. Frequency variations are more likely to occur when a sub-set of electrical loads are supplied from one or more generations in isolation, such as an emergency generator or a microgrid, where the response of the generator(s) to changes in the load may affect equipment sensitive to frequency variations.

### 6.9 Mitigating Voltage Distortion

Methods of mitigating voltage sags include redundant sources of power and automatic or static transfer switches, uninterruptible power supplies (UPSs), on-site generation, energy storage systems coupled with dynamic voltage controls, or one of several types of voltage or reactive power compensators.

#### 6.9.1 Fast Transfer Switches

Transfer switches are used to transfer a load connection from one source of power to another. In the event of a disturbance to the connected source, the load will automatically be transferred to the alternate source, reducing the possibility of an interruption to the load.

To ensure high power quality, high speed operation is essential. High speed operation means that both sources of power to the transfer switch are on-line and available at all times. In short, transfer switches used to mitigate voltage waveform distortion must be supplied from redundant utility sources, minimally from separate distribution panelboards or switchboards supplied from the same utility source, but ideally from completely separate, redundant utility sources available within the facility.

An additional consideration for high-speed operation is for automatic transfer switches to use closed-transition (make-before-break) switching, where the contacts to the alternate source of power close before the contacts to the primary source of power open, transferring the load from one source to another without interruption.

A static transfer switch typically transfers the load from one source to another at the zero crossings of the voltage waveforms, meaning that switching is a sub-cycle event taking 240 electrical degrees, with the A-phase transferred between sources at 0 degrees, the B-phase transferred between sources at 120 degrees,
and the C-phase transferred between sources at 240 electrical degrees, with no switching transient and no interruption to the load.

6.9.2 Uninterruptible Power Supplies (UPSs)

An Uninterruptible Power Supply (UPS) is used to ensure supply continuity for critical loads. A double-conversion on-line UPS continuously supplies the load, and acts as a filter to isolate the load from any power quality issues that occur upstream of the UPS input. UPSs are intended to provide a finite period of operation, either on batteries (static UPS) or from a flywheel (rotary UPS), for the purpose of switching from one input source to another, or to allow for an orderly shutdown of the critical load.

The type of UPS and source of standby power should be carefully selected for the application. UPSs are typically used in systems with standby generation that are used to supply critical loads for the duration of a planned or unplanned utility interruption.

6.9.3 Interconnected Distributed Generation

Local generation that has the capability to independently control voltage and frequency, such as one or more diesel engine-generators with a synchronous alternator, can be installed for the purpose of providing power during longer-duration voltage degradation or utility interruptions. It is not economically feasible to have local generation running at all times in the event that utility power is degraded. Consequently, additional equipment, such as a UPS and an automatic transfer switch, must be installed to provide ride-through capability to allow local generation to start and reach operational status prior to supplying the load.

Renewable generation sources, such as photovoltaic power and wind turbines, typically do not have the capability to independently control voltage and frequency, and are not particularly suitable for maintaining power quality by providing power during longer-duration voltage degradation or utility interruptions unless integrated with an energy storage system.

6.9.4 Energy Storage Systems (ESSs)

Energy storage systems (ESSs) can be used to improve power quality on a short-term or instantaneous basis, such as providing energy capacity and voltage ride-through support for momentary outages, reducing harmonic distortions, and eliminating voltage sags and surges. See NECA 416 for additional guidance for ESSs and applications.

ESS technologies used to improve power quality include battery systems, flywheels, ultra-capacitors or super-capacitors, electric vehicle smart chargers (vehicle-to-grid or V2G), superconducting magnetic energy storage (SMES), compressed air energy storage (CAES), pumped hydro storage (PHS), and thermal energy storage (TES), among others.

6.9.5 Compensators

Compensators are typically one of several configurations of controls, power electronics, capacitors,
and/or reactors used to generate and/or control reactive power and/or voltage magnitude.

Static VAR compensators (SVCs) are comprised of fixed capacitors in parallel with thyristor-switched reactors. Dynamic voltage compensators (DVCs) are comprised of thyristor-switched capacitor banks. Compensators provide voltage support through reactive compensation with a reaction time of approximately one cycle. Compensators are most effective for loads where large changes in reactive power are the main contributor to voltage fluctuations.

SVCs can also be configured to limit voltage imbalance. SVC are relatively expensive and are typically used for individual large loads, such as an arc furnace.

Reactive power compensators are much less effective and can negatively affect voltage for fluctuations due to large changes in real power.

7. Waveform Distortion

7.1 Overview

Unlike transient distortion, waveform distortion is typically a periodic, steady-state phenomenon. Waveform distortion is a deviation from an ideal sine wave of power frequency principally characterized by the spectral content or harmonics/character of the deviation. There are four primary types of waveform distortion, namely harmonics, even harmonics and interharmonics, notching, and noise.

7.2 Harmonics

Harmonics are created by a load that draws current from the system supply source voltage in a non-linear or non-sinusoidal pattern, such as from switching the load on and off periodically during the sinusoidal voltage waveform. The current drawn by the load is “non-linear,” meaning that the load current is not proportional to the voltage waveform with or without phase displacement.

The non-linear or non-sinusoidal load current can be mathematically resolved into a sequence of harmonics, which are whole number (integer) multiples of the nominal fundamental frequency of the power system supply (e.g., 50 Hz or 60 Hz). The individual harmonics have varying magnitudes, but in general decrease exponentially with the square of the harmonic number.

From a mathematical perspective, harmonic content only contains either sine or cosine components, but not both, depending whether the supply source is modeled as a sine waveform or a cosine waveform. Additionally, because of the even symmetry of a cosine waveform about the y-axis, or the odd symmetry of the sine waveform about the x- and y-axes, generally, only odd-numbered harmonics are created by non-sinusoidal loads.

The exception to this generality is that arcing loads, such as arc furnaces, create even-numbered harmonics, and can also create interharmonics, which are waveforms containing periodic distortions of a sinusoidal nature that are not integer multiples of the fundamental supply frequency. See Section 7.3 for additional information regarding even harmonics and interharmonics.

Non-sinusoidal loads have become the rule rather than the exception with the proliferation of power
electronic devices, and include single-phase loads, such as fluorescent light ballasts, LED drivers, solid-state rectifiers used in welders, battery chargers, switch mode power supplies in computers and consumer electronic devices, and other conventional DC power supplies, and three-phase loads, such as arc furnaces, inverters, variable-frequency drives, and power electronics in uninterruptible power supplies and power conditioners. Non-sinusoidal loads also include saturable inductors and transformers, and solid-state power supplies, drives, and switching devices that use silicon-controlled rectifiers (SCRs), insulated gate bipolar transistors (IGBTs), and diodes.

Specific harmonics are associated with individual pieces of equipment, and manufacturers can typically provide the expected magnitude and order of harmonics generated by their equipment. Reducing or eliminating harmonics at their source is only an available option when originally installing or renovating the electrical power distribution system and when selecting and installing new harmonic-generating equipment. For existing facilities, installing harmonic filters is often the most cost-effective solution for large or aggregate harmonic generating loads.

Aggregate combinations of sinusoidal and non-sinusoidal loads within a facility are facility-specific. Developing mitigation for harmonics typically entails power quality monitoring to determine cyclic loading, and harmonic content at maximum, average, and minimum loading. Monitoring for power quality should last at least one complete business cycle of the facility. Ensure that monitoring captures typical individual and aggregate load profiles, as needed. Monitoring for longer periods are recommended to determine daily, weekly, monthly, and seasonal cyclic loading, along with maximum, average, and minimum loads and worst-case, average, and best-case harmonic content.

The system should be modeled for alternative source and load configurations, considering major equipment that may be out of service, such as alternate utility sources, on-site generation, power factor improvement capacitors, and harmonic filters, as applicable. It is also important to identify any facilities that are nearby that may be contributing significant harmonic distortion onto the utility.

### Effects of Harmonic Distortion

Harmonic current distortion causes several power quality related problems, including induced harmonic voltages, counter torque and heating in rotating machines, and conductor and equipment heating problems.

Harmonic load current drawn by non-linear or non-sinusoidal loads induces harmonic voltages across the electrical power distribution system due to system impedance in accordance with Ohm’s law. Because of the relatively low impedance of the electric utility grid from numerous sources connected in parallel, harmonic voltage distortion induced by harmonic current distortion in accordance with Ohm’s law is typically much less significant than voltage distortion directly caused by voltage wave-shaping power electronics.

For example, harmonic voltage distortion can be more pronounced in close electrical proximity to inverters, such as the output circuit from variable frequency drives or UPSs that do not have output filters or reactors to smooth the square steps of the output waveform. The deviation of the created voltage waveform from the ideal sinusoid means that sometimes significant voltage harmonics are present, which requires a different solution than voltage distortion induced by harmonic currents in accordance with Ohm’s law.

Rotating machinery is particularly susceptible to heating effects from harmonic load currents from
counter torque and from the skin effect. Periodic harmonic currents of the form $6N-1$, namely the $5^{th}$, $11^{th}$, $17^{th}$, and so on, have a reverse phase rotation (essentially negative sequence vectors) to the fundamental waveform, and create counter torque to the direction of positive motor rotation, creating greater internal stress and heating of motors.

Periodic harmonic currents of the form $6N+1$, namely the $1^{st}$ (fundamental), $7^{th}$, $13^{th}$, $19^{th}$, and so on, have a positive phase rotation (essentially positive sequence vectors), and create higher-frequency torque in the direction of positive motor rotation. Positive and negative rotating vectors in motors can cause pulsating or reduced torque, mechanical oscillations due to mechanical resonance, and higher audible noise from higher frequencies.

Additionally, harmonic load currents create heating in conductors, including motor winding conductors, from the skin effect. The skin effect is the tendency of current to flow on the outer ring of the conductor cross-section because the flux linkages at the center of conductors are not able to change polarity quickly at very high voltages or very high frequencies. Consequently, at higher order harmonic frequencies, conductors have a progressively smaller cross-sectional area to carry current as the skin effect becomes more pronounced. The result is that conductors have a progressively higher impedance at higher harmonic frequencies, which is the main reason why the magnitudes of harmonic currents decrease exponentially with harmonic order.

Finally, triplen harmonic currents (odd integer multiples of three) of the form $6N-3$, namely the $3^{rd}$, $9^{th}$, $15^{th}$, and so on, are in phase (essentially zero sequence vectors) and do not cancel, even for balanced single-phase load currents. Triplen harmonic currents, which are created by single-phase non-linear loads, are additive in common current-carrying components, such as the neutral conductor and in the delta-connected primary winding of delta-wye-grounded transformers, and can create unmitigated heating within common neutral conductors and delta-wye connected transformers.

The harmonic distortion from individual single-phase non-sinusoidal loads is insignificant, but because of the additive nature of triplen harmonic currents, the cumulative effect of numerous single-phase non-sinusoidal loads creates significant harmonic current distortion and the associated heating effects.

### 7.2.2 Mitigating General Harmonic Distortion Effects

IEEE Standard 519-1992, *IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*, considers harmonic current and voltage distortion limits at the point of common coupling, which is the interface between the customer and the electric utility. The customer is responsible for limiting harmonic currents that interfere with the power system. The utility is responsible for maintaining the quality of the voltage waveform at the point of common coupling.

Manufacturers are in the ideal position to identify and mitigate the harmonic contribution of their products. Select and install equipment and components with lower harmonic contribution, such as equipment with lower Total Harmonic Distortion (THD) ratings, when possible. Consult equipment manufacturers for design recommendations and for standard options and/or accessories that are used to mitigate harmonics, such as isolation transformers, input reactors or filters, and output reactors or filters for variable frequency drives (VFDs) and UPSs.

For larger equipment such as static power converters, selecting equipment with a higher number of pulse stages will reduce or eliminate lower-order harmonic currents. For example, because the harmonics created by 12-pulse converters are of the form $12N+/−1$ of the fundamental frequency, namely the $11^{th}$,
13th, 23rd, and 25th harmonics, and so on, selecting a 12-pulse converter in lieu of 6-pulse converter will completely eliminate the 5th, 7th, 17th, and 19th harmonics, and so on, inherent in 6-pulse converter operation in favor of higher-order harmonics (beginning with the 11th and 13th), whose magnitudes are naturally more attenuated due to the skin effect.

Some general overheating effects of small, distributed, single-phase, line-to-neutral non-sinusoidal loads can be mitigated by the design and installation of the premises wiring system which should include:

- Dedicated neutral conductors for single-phase, line-to-neutral branch circuits (no multi-wire branch circuits)
- Current-carrying conductors sized considering the heating effects of supplying harmonic load currents
- Additional or oversized neutral conductor bus bars in panelboards to accommodate the additional dedicated branch circuit neutral conductors
- A minimum of full-sized neutral conductors, or, preferably, double-capacity neutral conductors for feeders and services supplying concentrated single-phase, line-to-neutral non-sinusoidal loads
- A minimum of K-rated transformer to operate more efficiently while supplying non-sinusoidal load currents, or, preferably, zig-zag or harmonic mitigating transformers (HRTs) that provide a phase shift in the load currents that permit cancellation in the traditional triplen harmonic currents.
- NEC-compliant electrical power distribution system and equipment grounding and bonding.
- Use isolated grounding systems for sensitive electronic equipment, when required. See Section 4.2.6 for additional information.

### 7.2.3 Arcing Harmonic-Generating Loads

Arcing load devices are typically a stable source of harmonic distortion that can be modeled and mitigated. Arc welders commonly cause voltage transients due to their duty cycle and intermittent switching. Sensitive electronic equipment in close electric proximity to welders should be protected from the effects of these voltage transients.

Arc furnaces, however, present one of the more challenging scenarios for harmonic mitigation for several reasons. First, arc furnaces produce random variations of harmonic content which are difficult model and difficult to mitigate using with conventional harmonic filters. Second, the different operating modes of arc furnaces can create voltage imbalances between phases. Finally, arc furnaces can produce even harmonics and interharmonics (see Section 7.3), and voltage fluctuations.

Harmonic mitigation for arc furnaces includes connecting them to the highest possible operating voltage, and using series reactance as an input filter to reduce harmonic current contribution.

### 7.2.4 Harmonic Filters

Harmonic filters are devices that reduce or eliminate one or more harmonic current frequencies from the power system. Harmonic filters are either active or passive.

Active harmonic filters are any number of sophisticated power electronic devices that reduce or eliminate harmonic distortion from the power system by monitoring changes in the harmonic content of the load current and automatically injecting harmonic current into the system in response to those changes.
Active harmonic filters supply some or all of the harmonic currents drawn by the non-sinusoidal load, while the utility power source supplies the balance of the load current, which has greatly reduced harmonic distortion from the contribution of the active filter. Active harmonic filters are becoming commercially viable products for high-power applications. Active filters are used similarly to power factor improvement capacitors, which supply some or all of the reactive power required by loads with low power factor.

Passive harmonic filters are a combination of inductors, capacitors, and resistors (passive devices) that are specifically designed to reduce or eliminate one or more harmonics from the power system. The most common passive harmonic filter is an inductor in series with a shunt capacitor, which are both sized to tune the filter to a specific frequency. Passive filtering intentionally creates a controlled series resonance condition at a specific frequency to remove that specific harmonic from the composite load current. See Section 7.2.5.

Passive filters are typically more cost effective for high power applications or where capacitors are required for power factor improvement. Because of the overvoltage caused by series resonance, capacitors used for passive harmonic filters must have higher voltage ratings than the nominal operating voltage, such as using capacitors with a 600 V rating for filters applied on a 480 V nominal system.

Passive harmonic filters are typically tuned to one frequency, and several filters may be needed to address multiple harmonic frequencies. Due to the characteristics of capacitor aging, the resonant frequency of a passive filter tends to rise slightly as the capacitance changes over time. Consequently, a passive harmonic filter designed to mitigate the 5th harmonic (300 Hertz) is typically designed for harmonic resonance at the 4.7th harmonic (approximately 282 Hertz).

Passive filters, while composed of discrete components, can also be controlled and automatically switched on and off in stages as non-sinusoidal loads cycle on and off. NOTE: Automatic control of passive harmonic filters has historically been referred to as active harmonic filtering in the industry. Currently, power electronic devices that reduce or eliminate harmonic current content by monitoring harmonic load content and injecting harmonic currents into the power distribution system is known as active harmonic filtering. Keep in mind that passive harmonic filters create a series resonance on the electric power distribution system, and can draw harmonic load currents from other customers’ non-sinusoidal loads on the electric utility grid.

Consult qualified professionals, such as qualified professional engineers, for the design and application of active and passive harmonic filters.

### 7.2.5 Harmonic Resonance

Harmonic resonance is the condition in which the power system is resonating near one of the major harmonics being produced by non-linear elements in the system. Harmonic distortion is magnified when harmonic resonance occurs, meaning that damaging levels of voltage (parallel resonance) and/or current flow (series resonance) are possible.

Harmonic resonance causes increased equipment and conductor heating and the potential for insulation failure from overvoltage and/or excessive current flow causing increase voltage, dielectric stress, corona stress. Increase harmonic distortion can cause equipment malfunction, data errors, relay malfunction, and interference with telephone audio frequencies.
Harmonic resonance is typically a self-correcting phenomenon, as excessive currents will cause the
operation of overcurrent protective devices, and/or excessive voltage can cause capacitor and transformer
damage, causing the circuit to de-tune from the resonant frequency. Typically, overvoltage from
harmonic resonance exceeds the voltage rating of capacitors causing their rupture and failure.

Methods of mitigating harmonic resonance includes changing the method of kVAR compensation from
capacitors to synchronous condensers or other source of reactive compensation, adding either passive or
active harmonic filters, and/or changing the size of capacitor banks, and enduring one of the
disadvantages of either over-compensation and overvoltage on the system, or under-compensation on the
system with or without a financial PF penalty from the electric utility.

7.3 Even Harmonics and Interharmonics

Arcing loads and other large non-sinusoidal loads can produce uncharacteristic harmonics, namely even
harmonics (such as the 2nd, 4th, 6th, and so on) and interharmonics (harmonics that are not integer
multiples of the fundamental supply frequency). The main sources of interharmonic waveform distortion
are static frequency converters, cyclo-converters, induction motors, and arcing devices such as arc
furnaces. Power line carrier signals are also considered interharmonics. Even harmonics and
interharmonics can become more pronounced when the supply source voltage is less stable, and/or the
voltage waveform is not symmetrical.

Even harmonics are very disruptive to power electronic devices and motors. The 2nd harmonic can have a
relatively high magnitude because the skin effect is less pronounced at lower frequencies, and has a
reverse phase rotation (essentially reverse sequence phasor) that can cause a significant counter torque for
motors.

Even harmonics and interharmonics are mitigated in the same manner as the more characteristic odd
integer multiple harmonics. Perform power quality monitoring, including a spectrum analysis or
harmonic study, in accordance with Section 3.3 and Section 7.2. Consult a qualified electrical design
professional for the design and application of active and passive harmonic filters. See Section 7.2.4.

7.4 Notching

Notching is a steady-state switching (or other) periodic disturbance phenomena occurring in each cycle of
the normal voltage waveform in a similar manner for a period of time that is much greater than one
minute. Notching of the voltage waveform lasts for one-half cycle or less within each waveform cycle.

*NOTE:* If a phenomenon that has the characteristics of a notch occurs for only one cycle, it is termed an
impulsive transient. Also, a complete loss of voltage for up to one-half-cycle is also considered notching.

Notching is caused by the normal operation of power electronics devices when current is commutated
from one phase to another, causing a momentary short circuit between two phases that affects the source
voltage waveform. Three-phase converters or drives that produce continuous DC current are the most
significant source of voltage notching.

The duration of the notch, or the commutation period, is determined by the source inductance to the drive,
and the current magnitude. Most of the source inductance is from the step-down or isolation transformer
Severe notch depth can be mitigated by installing an input reactor (series inductor) in the AC supply circuit to the converter or drive to reduce the depth of the notch. A typical inductance size is 3% based on the rating of the converter or drive.

7.6 Noise

Noise is unwanted electrical signals with broadband spectral content lower than 200 kHz superimposed on the power system voltage waveform or phase currents in conductors, or found on neutral conductors or signal lines. Noise in power systems can be caused by power electronic devices, control circuits, arcing equipment, loads with solid-state rectifiers, and switching power supplies. Noise problems are often exacerbated by improper grounding.

The frequency range and magnitude level of noise depends on the source which produces the noise and the system characteristics. A typical magnitude of noise is less than one percent of the voltage magnitude. Noise disturbs electronic devices such as microcomputer and programmable controllers.

Noise problem can be mitigated by using filters, isolation transformers, and certain types of line conditioners.
Annex A: Reference Standards


A complete list of NEIS will be included