# Guide for Source Inspection and Quality Surveillance of Electrical Equipment

# Foreword

This guide has been developed to identify references in the existing Body of Knowledge (BOK) as a resource for individuals studying to take the API Source Inspector Certification examination. Source inspectors wishing to take the exam for API certification are responsible for being familiar with the entire published BOK, including provisions not found in this study guide. In the event of any discrepancy or conflict between the contents of this study guide and the contents of any referenced materials or the BOK, the requirements of the referenced materials will be controlling. API-certified inspectors are required to be proficient in all applicable API standards, specifications, and recommended practices. All questions and comments regarding individually referenced works should be addressed to the publishers of the works.

This study guide was not adopted according to API's *Procedures for Standards Development*, does not reflect a formal industry consensus, and may not be referenced separately as an industry consensus standard or recommended practice.

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# Guide for Source Inspection and
# Quality Surveillance of Electrical Equipment

## 1.0 Scope/Purpose

This document describes the process of providing quality surveillance of electrical materials and equipment being supplied for use in the oil, petrochemical and gas industry, including upstream, midstream and downstream segments. This guide may be used as the basis for providing a systematic approach to risk-based source inspection in order to provide confidence that materials and equipment being purchased meet the minimum requirements as specified in the project documents and contractual agreements. The activities outlined in this study guide do not intend to replace the manufacturer's/fabricator's own quality system, but rather are meant to guide source inspectors acting on behalf of purchasers to determine whether manufacturers/ fabricators own quality systems have functioned appropriately, such that the purchased equipment and materials will meet contractual agreements.

This study guide focuses primarily on the inspection of electrical material and equipment including:  junction boxes, control panels, electrical systems, as well as general electrical equipment such as transformers, switchgears, singular motor control centers, and electric motors (over 500 HP). This study guide assumes the reader has a firm understanding about AC/DC electricity.

This document assumes that suppliers/vendors (S/V) have been pre-qualified by a systematic quality review process of their facilities to determine if the facility has the ability to meet the requirements of the contractual agreements. That process generally leads to a list of pre-approved S/V's deemed acceptable to the supply chain management of the purchaser and capable of meeting the requirements of the contract prior to it being executed. S/V's on such a list will normally have an acceptable quality process already in place that meets the requirements of the contract. The purpose of source inspection in such cases is simply to verify that the S/V quality process is working as it should and to verify that certain vital steps in the inspection and test plan (ITP) have been satisfactorily accomplished prior to fabrication completion and/or shipping.

The primary purpose of this study guide is to assist candidates intending to take the API Source Inspector Electrical Equipment examination to become certified source inspectors. The study guide outlines the fundamentals of source inspection and may be useful to all personnel conducting such activities to perform their jobs in a competent and ethical manner. For more information on how to apply for Source Inspection Certification, please visit API website at www.api.org and follow the work process shown in chart below.


The Source Inspector Electrical Equipment examination contains 100 multiple-choice questions targeting core knowledge necessary to perform source inspection of electrical equipment. The focus of the exam is on source inspection issues and activities rather than design or engineering knowledge contained in the reference standards. The exam is closed book and administered via computer based testing (CBT). The bulk of the questions address electrical and mechanical inspection/surveillance which are typically known by persons who have electrical experience working as source inspectors or persons intending to work as source inspectors who have studied the material in this study guide and the associated reference materials.

# 2.0 Introduction

Like most business processes, the source inspection work process follows the Plan–Do–Check–Act circular process first popularized in the 1950's by Edward Deming. The "Planning" part of source inspection is covered in Sections 6 and 7 of this study guide and involves the source inspection management systems, source inspection project plan and the inspection and test plan (ITP). The "Doing" part is covered in Sections 8 and 9 and involves implementing the ITP, participating in scheduled source inspection work process events, filing nonconformance reports and source inspection report writing. The "Checking" part, covered in Section 8.7, involves looking back at all the source inspection activities that occurred in the Planning and Doing segments to see what went well and what should be improved based on the results of that look-back. And finally the "Act" part (sometimes called the "Adjust" part) covered in Section 8.8 involves implementing all the needed improvements in the "Planning and Doing" process before they are implemented on the next source inspection project.

# 3.0 References

The Source Inspector (SI) needs to be familiar with all industry codes and standards that are specified in the contractual agreements to the extent that requirements and expectations in those codes and standards are part of the contractual agreements and therefore part of the source inspector duties. Those industry codes and standards are typically published by recognized industry standards development organizations (SDO's).

The most recent editions of these codes, standards or other recommended practices are referenced in this study guide and are the documents from which the SIEE exam has been developed. The exam questions will come from this study guide and the standards referenced in this section only.

## 3.1 API Codes and Standards

There are a wide variety of Codes and Standards that may be included in the contractual agreements to specify and control the quality of products for the energy industry. A few of those that the SI should be familiar with and apply when specified are shown in the following subsections; but this list is not all-inclusive. Others that are specified in the contractual agreements may be equally important to the quality of the delivered product. The information contained in the following industry standards is generic to a wide variety of products and therefore should be general knowledge to the experienced SI.

### 3.1.1 API RP 540

This recommended practice provides information on electrical installations in petroleum facilities. Petroleum processing requires specialized equipment that continually processes, often at high rates and elevated temperatures and pressures, liquids, and gases that undergo both chemical and physical changes. Consequently, it is necessary that electrical installations and equipment in petroleum facilities be designed to prevent accidental ignition of flammable liquids and gases. To maintain safety and operating continuity, requirements for the electrical systems in petroleum facilities are more stringent than those for most other manufacturing facilities. This recommended practice addresses specific requirements for those electrical systems.

### 3.1.2 API STD 541

This standard covers the minimum requirements for special purpose form-wound squirrel cage induction motors 375 kW (500 hp) and larger for use in petroleum, chemical, and other industry applications. This standard can also be used for induction generators by substituting “generator” for “motor” where applicable.

A special purpose machine typically has one or more of the following characteristics:

- is in an application for which the equipment is designed for uninterrupted, continuous operation in critical service, and for which there is usually no installed spare equipment;
- is larger than 2250 kW (3000 hp) for speeds 1800 rpm and below;
- is rated 600 kW (800 hp) or greater for two pole (3000 rpm or 3600 rpm) machines of totally enclosed construction, or rated 930 kW (1250 hp) or greater for two pole machines of open or guarded construction (including machines with WP-I or WP-II type enclosures);
- drives a high-inertia load (in excess of the load $Wk^2$ listed in NEMA MG 1, Part 20);
- uses an adjustable speed drive (ASD) as a source of power;
- is an induction generator;
- is a vertical machine rated 375 kW (500 hp) or greater; or
- operates in abnormally hostile environments.

### 3.1.3 API RP 14F

This document recommends minimum requirements and guidelines for the design, installation, and maintenance of electrical systems for fixed and floating offshore petroleum facilities classified as Division 1 or Division 2. These facilities include drilling, producing and pipeline transportation facilities associated with oil and gas exploration and production. This recommended practice (RP) is not applicable to Mobile Offshore Drilling Units (MODUs) without production facilities. This document is intended to bring together in one place a brief description of basic electrical practices for offshore electrical systems.

The recommended practices contained herein recognize that electrical considerations exist for offshore petroleum facilities. These include:

- the inherent electrical shock possibility presented by the marine environment and steel decks.
- space limitations that require that equipment be installed in or near classified locations.
- the corrosive marine environment.
- motion and buoyancy concerns associated with floating facilities.

This RP applies to both permanent and temporary electrical installations. The guidelines presented herein should provide a high level of electrical safety when used in conjunction with well-defined area classifications. This RP emphasizes safe practices for classified locations on offshore petroleum facilities but does not include guidelines for classification of areas; for guidance on classification of areas refer to API RP 500 and RP 505, as applicable.

### 3.1.4 API RP 14FZ

API RP 14 FZ recommends minimum requirements and guidelines for the design, installation, and maintenance of electrical systems on fixed and floating petroleum facilities located offshore for facilities classified as Zone 0, Zone 1, or Zone 2. These facilities include drilling, producing and pipeline transportation facilities associated with oil and gas exploration and production. This recommended practice is not applicable to Mobile Offshore Drilling Units (MODUs) without production facilities. This document is intended to bring together in one place a brief description of basic desirable electrical practices for offshore electrical systems. The recommended practices contained herein recognize that special electrical considerations exist for offshore petroleum facilities.

These include:

- inherent electrical shock possibility presented by the marine environment and steel decks;
- space limitations that require that equipment be installed in or near hazardous (classified) locations;
- corrosive marine environment;
- motion and buoyancy concerns associated with floating facilities.

### 3.1.5

Refer to Table 1 for a listing of common codes and standards that are referenced in the examination.

**Table 1: Codes and Standards**

| Code | Description |
|---|---|
| **API RP 540** | Electrical Installations in Petroleum Processing Plants |
| **API STD 541** | Form-wound Squirrel Cage Induction Motors-375 kW (500 Horsepower) and Larger |
| **API RP 14F** | Design, Installation, and Maintenance of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class 1, Division 1 and Division 2 Locations |
| **API RP 14FZ** | Recommended Practice for Design and Installation of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class I, Zone 0, Zone 1 and Zone 2 Locations |
| **IEEE 841** | IEEE Standard for Petroleum and Chemical Industry--Premium-Efficiency, Severe-Duty, Totally Enclosed Fan-Cooled (TEFC) Squirrel Cage Induction Motors--Up to and Including 370 kW (500 hp) |
| **IEEE STD 141** | IEEE Recommended Practice for Electric Power Distribution for Industrial Plants |
| **ANSI/IEEE C57.12.00** | IEEE Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers |
| **ANSI/IEEE C57.12.36** | IEEE Standard Requirements for Liquid-Immersed Distribution Substation |
| **ANSI/IEEE C37.20.1** | IEEE Standard for Metal-Enclosed Low-Voltage (1000 Vac and below, 3200 Vdc and below) Power Circuit Breaker Switchgear |
| **ANSI/IEEE C37.20.2** | IEEE Standard for Metal-Clad Switchgear |
| **ANSI/IEEE C37.20.3** | IEEE Standard for Metal-Enclosed Interrupter Switchgear (1 kV - 38 kV) |
| **ANSI/IEEE C37.20.7** | IEEE Guide for Testing Metal-Enclosed Switchgear Rated Up to 38 kV for Internal Arcing Faults |
| **ANSI/IEEE C37.100** | IEEE Standard Definitions for Power Switchgear |
| **ANSI/NETA ATS** | Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems |
| **DOE-HDBK-1092-2013** | DOE Handbook Electrical Safety |
| **NFPA 70** | National Electrical Code |
| **NFPA 70 (E)** | Standard for Electrical Safety in the Workplace |
| **NEMA ICS 1** | Industrial Control and Systems: General Requirements |
| **NEMA ICS 2** | Industrial Control and Systems Controllers, Contactors and Overload Relays Rated 600 Volts |
| **NEMA ICS 3** | Industrial Control and Systems: Medium Voltage Controllers Rated 2001 to 7200 Volts AC |
| **NEMA 250** | Enclosures for Electrical Equipment (1000 Volts Maximum) |

# 4.0 Definitions, Abbreviations and Acronyms

See Table 2 for definitions, abbreviations and acronyms that can apply to systems and equipment to be inspected:

**Table 2: Common Definitions, Abbreviations and Acronyms**

| Term | Definition |
|---|---|
| **AC** | Alternating Current |
| **Alternating Current** | A current that reverses at regular recurring intervals of time and that has alternately positive and negative values |
| **Ammeter** | Measures the current flow in amperes in a circuit. An ammeter is connected in series in the circuit |
| **Ampere (A)** | The practical unit of electric current flow. If a one ohm resistance is connected to a one volt source, one ampere will flow |
| **Anode** | An electrode through which current enters any conductor of the nonmetallic class. Specifically, an electrolytic anode is an electrode at which negative ions are discharged, or positive ions are formed, or at which other oxidizing reactions occur |
| **ANSI** | American National Standards Institute |
| **API** | American Petroleum Institute |
| **Apparent Power** | Expressed as an absolute value in VA, apparent power is the product of rms voltage and rms current |
| **ASNT** | American Society of Nondestructive Testing |
| **ASTM** | ASTM International (formerly known as the American Society for Testing and Materials) |
| **BOK** | Body of Knowledge (in this case the BOK for the Source Inspector examination) |
| **Branch Circuit** | The circuit conductors between the final over current device protecting the circuit and the outlet(s) |
| **Buchholz Relay** | A circuit breaking safety device designed to detect dielectric failure in oil-filled equipment, such as transformers and reactors. Connected between the overhead oil tank (conservator) and the transformer or reactor, the Buchholtz relay may employ several measures to detect potential equipment failure. |
| **Calibration** | A comparison between measurements—one of known magnitude or correctness (the standard) compared to the measuring device under test in order to establish the accuracy of a measuring device. |
| **Capacitance** | Measure, in farads (F), or the opposition to voltage changes in an AC circuit, causing voltage to lag behind current; exhibited by condensers, two conductors separated by a nonconductor |
| **Capacitive Reactance** | The effect of capacitance in opposing the flow of alternating or pulsating current |
| **Capacitor** | Two electrodes or sets of electrodes in the form of plates, separated from each other by an insulating material called the dielectric |

| Term | Definition |
|---|---|
| **Cathode** | An electrode through which current leaves any conductor of the nonmetallic class. Specifically, an electrolytic cathode is an electrode at which positive ions are discharged, or negative ions are formed, or at which other reducing reactions occur. |
| **Certification** | Documented and signed testimony of qualification. Certification generally refers to a 3rd party certification by a nationally recognized laboratory or a self-certification where the design has been type tested in accordance with a recognized standard. |
| **Circuit** | A complete path over which an electric current can flow |
| **Circuit Breaker** | A device designed to open and close a circuit by non-automatic means and to open the circuit automatically on a predetermined over current |
| **Circuit (Series)** | A circuit supplying energy to a number of devices connected in series. The same current passes through each device in completing its path to the source of supply |
| **Clamp Meter** | Electronic instrument that externally measures the sum of the current flowing through the cable |
| **Close Circuit** | A circuit permitting a continuous current |
| **Coil** | An assemblage of successive convolutions of a conductor. A unit of a winding consisting of one or more insulated conductors connected in series and surrounded by common insulation, and arranged to link or produce magnetic flux. |
| **Conductance** | The measure of ease with which a substance conducts electricity, measured in mhos or Siemens (℧ or S). It is the opposite of resistance which is expressed in ohms (Ω). |
| **Conductor** | An electrical path which offers comparatively little resistance. A wire or combination of wires not insulated from one another, suitable for carrying a single electric current. Bus bars are also conductors. Conductors may be classed with respect to their conducting power as; (a) good; silver, copper, aluminum, zinc, brass, platinum, iron, nickel, tin, lead; (b) fair; charcoal and coke, carbon, acid solutions, sea water, saline solutions, metallic ores, living vegetable substances, moist earth; (c) partial; water, the body, flame, linen, cotton, mahogany, pine, rosewood, lignum vitae, teak, and marble. |
| **Coulomb (C)** | A unit of electrical charge; the quantity of electricity passing in one second through a circuit in which the rate of flow is one ampere |
| **Critical Equipment** | Equipment that has been risk assessed and determined that if it were to fail in service, it would have an unacceptable impact on process safety, environment, or business needs and therefore deserves a higher level of source inspection attention to make sure the equipment being delivered is exactly as specified. |
| **CT** | Current Transformer |
| **Cu** | The chemical symbol for copper |
| **Current** | The movement of electrons through a conductor; measured in amperes |

| Term | Definition |
|---|---|
| **Cycle** | A complete rotation of alternating current, passing through a complete set of changes or motions in opposite directions, from a rise to maximum, return to zero, rise to maximum in the other direction, and another return to zero. One complete positive and one complete negative loop of current or voltage. |
| **DC** | Direct Current |
| **DCS** | Distributed Control System |
| **Dead** | Free from any electric connection to a source of potential difference and from electric charge. The term is used only with reference to current carrying parts that are sometimes energized. |
| **Decibel** | (a) A measure of relative power levels<br>(b) A measure of the loudness of a bell, siren, horn, or other noise<br>(c) The strength of an audio signal |
| **De-energized** | Equipment is at earth potential |
| **Deflection** | The distance or angle by which one line departs from another |
| **Delta Connection** | A delta connection is connected between phases of a three-phase system with the polarity of one phase being connected to the non-polarity of another phase. It is named for it resemblance to the Greek letter delta ($\Delta$). |
| **Deviation** | A departure from requirements in the contractual agreements or its referenced PO, engineering design, specified codes, standards or procedures. |
| **Diagram** | A skeleton geometrical drawing, illustrating the principles of application of a mechanism. |
| **Diode** | A two electrode electron tube containing an anode and a cathode. Diodes are used as rectifiers and detectors. |
| **Direct Current** | A unidirectional current. It may be constant or periodically fluctuating, as rectified alternating current. |
| **Dissipation** | Loss of electric energy as heat |
| **Drop** | The voltage drop developed across an impedance due to current flowing through it. |
| **E** | Symbol for voltage |
| **Earth** | The ground, often considered a common reference point for circuits, considered 0V. |
| **Electrical Horsepower** | 746 watts |
| **Electrical Units** | In the practical system, electrical units comprise the volt, the ampere, the ohm, the watt, the watt-hour, the coulomb, the henry, the mho, the joule, and the farad. |
| **Electric Circuit** | The path (whether metallic or nonmetallic) of an electric current. |
| **Electrician** | A person who is versed and has demonstrated knowledge of the electrical applications, codes and standards. |

| Term | Definition |
|---|---|
| **Electricity** | Physical phenomena associated with the presence and flow of electric charge. |
| **Electrocution** | The destruction of life by means of electric current passing through the body. |
| **Electromagnet** | A magnet produced by passing an electric current through an insulated wire conductor coiled around a core of soft iron, as in the fields of a dynamo or motor. |
| **Electromotive Force (EMF)** | An energy-charge relation that results in electric pressure (voltage), which produces or tends to produce charge flow. |
| **Electron** | The smallest charge of negative electricity known.<br>It is equal to $1.6*10^{-19}$C. |
| **Employer** | The corporate, public or private entity which employs personnel for wages, salaries, fees or other considerations e.g. the employer of the source inspector. |
| **Energy Efficiency** | The efficiency of an electric machine measured in watt hours or kilowatt hours; ratio of power out to power in. |
| **Engineered Equipment** | Equipment that is custom designed and engineered by the client and/or EPC to perform a project-specific function. Engineered equipment will typically require more source inspection than non-engineered equipment. |
| **EPC** | Engineering/Procurement/Construction contract company |
| **Farad (F)** | Practical unit of electrostatic capacity in the electromagnetic system. A capacitor is said to have a capacity of one farad if it will absorb one coulomb of electricity when subjected to a pressure of one volt. |
| **Faraday Effect** | A wave of light polarized in a certain plane can be turned about by the influence of a magnet so that the vibrations occur in a different plane |
| **Fathom** | A measure of length equal to six feet, used chiefly in taking soundings, measuring cordage, etc. |
| **Fault** | Any accidental contact between electric wires or conductors |
| **Fiber Optics** | Piping light is the science that deals with the transmission of light through extremely thin fibers of glass, plastic, or other transparent material. |
| **Fluorescence** | That property by virtue of which certain materials become luminous under the influence of radiant energy. |
| **Force** | An elementary physical cause capable of modifying the motion of a mass |
| **Formula** | A prescribed form, principle, or rule expressed in mathematical terms, chemical symbols, etc. |
| **Frequency (Hz)** | The number of periods occurring in the unit of time periodic process, such as in the flow of electric charge. The number of complete cycles per second existing in any form of wave motion; such as the number of cycles per second of an alternating current. |

| Term | Definition |
|---|---|
| **Fuse** | A strip of wire or metal inserted in series with a circuit which, when subjected to a current over its rated capacity, will burn out. A sacrificial element for circuit protection. |
| **Generator** | A general name given to a machine for transforming mechanical energy into electrical energy. |
| **Ground** | A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth, or to some conducting body that serves in place of the earth. |
| **Ground Conductor (EGC)** | EGC connects the non-current carrying metal parts of electrical systems to the system grounded conductor or the grounding electrode conductor (or both). |
| **Grounded** | Connected to earth or to some conducting body that serves in place of the earth. |
| **Heat (electric)** | The heat produced in an impedance by the passage of an electric current through it. |
| **Henry (H)** | The inductance of a closed circuit in which an electromotive force of one volt is produced when the electric current in the circuit varies uniformly at a rate of one ampere per second. |
| **Hipot Test** | A test that determines the pass/fail acceptance criteria of an electrical insulation system by measuring current resulting from elevated voltage. |
| **Horsepower (hp)** | Unit used to express rate of work, or power. One horsepower =746 watts. Work done at the rate of 33,000 foot pounds per minute or 550 foot pounds per second. |
| **I** | Symbol for electric current |
| **IEC** | International Electrotechnical Commission |
| **IEEE** | Institute of Electrical and Electronics Engineers |
| **ICP** | API's Individual Certification Program under which this source inspector certification program is administered |
| **Impedance (Z)** | The total opposition which a circuit offers the flow of alternating current at a given frequency; combination of resistance and reactance, measured in ohms. |
| **Inspection** | The evaluation of a component or equipment for compliance with a specific product specification, code, drawing and/or standard specified in the contractual requirements, which may include the measuring, testing or gauging of one or more characteristics specified for the product to determine conformity. |
| **Inspection Agency** | An entity employed to provide competent, qualified and certified source inspection personnel for the purpose of performing source inspection. For example, and inspection agency can be an EPC company, an owner-user, or an inspection service company. |
| **Inspection Coordinator** | Individual responsible for the development of the source inspection strategy, coordination of the source inspection visits, and implementation of the source inspection. |

| Term | Definition |
|---|---|
| **Inspection Waiver** | Permission to proceed with production/shipment without having a purchaser source inspection representative present for a specific activity. |
| **Induction** | The process by which the voltage or current in one electrical conductor affects the voltage or current of another, otherwise unenergized electrical conductor via time-varying electric and/or magnetic fields. |
| **Input** | The intake or energy absorbed by a machine during its operation, as distinguished from the output of useful energy delivered by it. |
| **Instrument Ground Bus (IGB)** | Grounding system connected to a high-quality earth ground, independent from the AC Safety Ground, for all instrumentation signals. The IGB is tied to the AC Safety Ground at only one point, near a high-quality earth ground, per NEC. The IGB is isolated from all other grounds. |
| **Insulator** | A device for fastening and supporting a conductor. Glass, porcelain, or composite insulators employed almost universally for supporting over-head wires. |
| **Ion** | An electrically charged atom or radical |
| **ISA** | International Society of Automation |
| **ITP** | Inspection and Test Plan—A detailed plan (checklist) for the source inspection activities which will guide the source inspector in his/her quality assurance activities at the S/V site with reference to applicable technical information, acceptance criteria and reporting information. The supplier/vendor should also have their own ITP to guide their fabrication personnel and quality assurance personnel in the necessary quality steps and procedures. |
| **Jacobi's Law** | A law of electric motors which states that the maximum work of a motor is performed when its counter electromotive force is equal to one-half the electromotive force expended on the motor. |
| **Joint** | The tying together of two single wire conductors so that the union will be good, both mechanically and electrically. |
| **Joule** | A unit of Electric Work, defined as 1/3600 watt-hour, or 1 watt-second |
| **Joule's Law** | The law first stated by Joule, that the quantity of heat developed in a conductor by the passage of an electric current is proportional to the resistance of the conductor, to the square of the strength of the current, and to the duration of the flow. |
| **Junction Box (JB)** | A protective enclosure around connections between electric wires or cables *(ISA Comprehensive Dictionary)*. The junction box may be a Field Junction Box, usually referred to as JB, or it may be within a control building or instrument enclosure, where it is referred to as an Interface Box (IB). The IB is sometimes called a Marshalling Cabinet or Termination Cabinet. |
| **L** | The symbol for inductance measured in henries (H) |
| **Leakage** | The escape of electric current through defects in insulation or other causes |

| Term | Definition |
|---|---|
| **Levelness** | The position of a surface of a component or structure that is horizontal (within tolerances) with the base plate and at 90 degrees to the vertical plumb line. Nozzle and attachment levelness tolerances are not addressed in ASME *BPVC* Section VIII, Division 1; however, in the pressure vessel handbook, a ½˚ tolerance is permissible. For levelness checking of a nozzle on a vessel, a level gauge is used. If the bubble is in the middle of the designated lines, the nozzle is level. A level gauge would be used for verification and measurement that the angle of a hillside (tangential) nozzle is properly installed relative to the vessel centerline. |
| **Loss** | Power expended without accomplishing useful work |
| **Made Circuit** | A closed or completed circuit |
| **Megohmmeter** | A special type of ohmmeter used to measure the electrical resistance of insulation |
| **Meter** | An electric indicating instrument as a voltmeter, ammeter, etc. |
| **MSS** | Manufacturers Standardization Society |
| **NEC** | National Electrical Code, NFPA 70 |
| **Negative** | The opposite of positive. A potential less than that of another potential or of the earth. In electrical apparatus, the pole or direction toward which the current is supposed to flow. |
| **NEMA** | National Electrical Manufacturers Association |
| **NESC** | National Electrical Safety Code |
| **Network** | An electric circuit in which the parts are connected in some special manner and cannot be classed as in series, in parallel, or in series-parallel. |
| **Neutral** | A circuit conductor that may carry current in normal operation, and is connected to ground (earth) at the main electrical panel |
| **NETA** | International Electrical Testing Association |
| **NFPA 70** | National Fire Protection Association. NEC |
| **Nonconformance** | A departure/deviation from project contractual agreements such as the PO, engineering design, specified codes, standards or procedures. |
| **Nonconformance Report (NCR)** | A report filled out by the SI detailing an issue that has been discovered to be not in accordance with project contractual agreements such as the PO, engineering design, specified codes, standards or procedures. |
| **Non-engineered Equipment** | Equipment that is designed and fabricated by S/Vs, which includes off-the-shelf items such as valves, fittings, as well as some skid units, instruments, pumps and electrical gear. Such equipment is usually purchased by catalog model numbers, etc. Non-engineered equipment will typically require less source inspection than engineered equipment. Sometimes known as commodity equipment. |
| **Ohm (Ω)** | The unit of electrical impedance. Impedance is one ohm when a source of one volt will deliver a current of one ampere. |

| Term | Definition |
|---|---|
| **Open Circuit** | A circuit, the electrical continuity of which has been interrupted, as by opening a switch |
| **OSHA** | Occupational Safety and Health Administration |
| **Output** | The current, voltage, power, or driving force delivered by a circuit or device |
| **Peak** | The maximum instantaneous value of a varying voltage or current |
| **Period** | The time required for a complete cycle of alternating current or voltage; for 60 cycles per second, a period would be 1/60 second. |
| **Photoelectric** | Descriptive of the effect which light has on electric circuits, through a device controlled by light |
| **PLC** | Programmable logic controller |
| **Point-to-point test** | A test to determine the resistance between main grounding systems and all major electrical equipment frame, system neutral, and/or derived neutral points. |
| **Positive** | The term used to describe a terminal with fewer electrons than normal so that it attracts electrons. Electrons flow into the positive terminals of a voltage source. |
| **Power (P)** | The rate at which work is done; it is usually expressed as the number of foot pounds in one minute, that is, if 33,000 foot pounds is lifted in one minute, 1 horsepower of work has been done. |
| **Power Factor** | A measure of system efficiency, a power factor is the ratio of real power or active power flowing to the load to the apparent power expressed in the circuit. The calculated ratio is a unitless quantity between 0 and 1 according to the type of load on the circuit. A power factor closest to the ideal of 1 is considered the most efficient. |
| **Procedure** | A document detailing how a work process is to be performed; e.g. a welding procedure |
| **PT** | Potential transformer also known as Voltage Transformers, or VTs |
| **Quick-Break** | A switch or circuit breaker that has a high contact opening speed |
| **QA Quality Assurance** | A proactive quality process that aims to prevent defects and refers to a program of planned, systematic and preventative activities implemented in a quality system that is intended to provide a degree of confidence that a product will consistently meet specifications. It includes the systematic measurement, comparison with a standard, monitoring of processes and an associated feedback loop that is intended to avoid deviations from specification. |
| **QC Quality Control** | The specific steps in a QA process that aim to find potential defects in a product before it is released for delivery e.g. VT, PT, RT, UT, dimensional verification, etc. The QA process will specify the particular QC steps necessary during manufacture/fabrication of a product. |

| Term | Definition |
|---|---|
| **Qualification** | Demonstrated skill, demonstrated knowledge, documented training, and documented experience required for personnel to perform the duties of a specific job e.g. a certified source inspector. |
| **Quality Surveillance** | The process of monitoring or observing the inspection activities associated with materials, equipment and/or components for adherence to the specific procedure, product specification, code or standard specified in the contractual requirements. For the purposes of this guide, quality surveillance and source inspection mean the same thing (see definition for source inspection). |
| **Reactance (X)** | Opposition offered to the flow of AC by the inductance or capacitance of a part; measured in ohms. |
| **Reactive Power** | A calculated unit of power where the current is out of phase with voltage. The resulting product of Volt-Amperes (VAR) does not perform any real work. Reactive power is most often encountered as dissipated power from equipment with complex values of capacitive and inductive loads. |
| **Recovery Voltage** | The voltage impressed upon the fuse after a circuit is cleared. |
| **Real Power** | Also known as active power, it is the energy delivered to a load, expressed in Watts. |
| **Relay** | An electric device designed to respond to input conditions in a prescribed manner and, after specified conditions are met, to cause contact operation or similar abrupt change in associated electric control circuits. |
| **Resistance (R)** | The opposition offered by a substance or body to the passage through it of an electric current which converts electric energy into heat resistance is the reciprocal of conductance. |
| **Resistance Drop** | The voltage drop across a length of material resulting from a current, measured in ohms. |
| **Resistor** | An aggregation of one or more units possessing the property of electrical resistance. Resistors are used in electric circuits for the purpose of operation, protection, or control. |
| **S** | The chemical symbol for Sulfur which may appear on an MTR |
| **SDO** | Standards Development Organization e.g. API, ASME, ASTM, NACE, MSS, TEMA, etc. |
| **Semiconductor** | A name given to substances having only moderate power of transmitting electricity, and which may be said in that respect to, stand midway between conductors and insulators. |
| **Series Circuit** | A circuit supplying energy to a number of loads connected in series, that is, the same current passes through each load in completing its path to the source of supply. |
| **Series Parallel Circuit** | An electric current containing groups of parallel connected receptive devices, the groups being arranged in the circuit in series; a series multiple circuit. |

| Term | Definition |
|---|---|
| **Short Circuit** | A fault in an electric circuit or apparatus due usually to imperfect insulation, such that the current follows a by-path and inflicts damage or is wasted. |
| **SI** | Source Inspector or Source Inspection |
| **SME** | Subject Matter Expert |
| **Solenoid** | A spiral of conducting wire, wound cylindrically so that when an electric current passes through it, its turns are nearly equivalent to a succession of parallel circuits, and it acquires magnetic properties similar to those of a bar magnet. |
| **Source Inspection** | The process of providing quality surveillance of materials, fabrications and equipment being supplied by supplier/vendor (S/V) or manufacturer/fabricator (M/F) for use in the oil, petro-chemical and gas industry, including upstream, midstream and downstream segments. Source inspection largely consists of verifying that the S/Vs own quality assurance process is functioning as it should to produce quality products that meet the contractual agreements. |
| **Source Inspector** | Individual responsible for performing the actual source inspection activities at the S/V facilities in accordance with the applicable inspection and test plan (ITP). |
| **Spark** | A discharge of electricity across a gap between two electrodes. The discharge is accompanied by heat and incandescence. |
| **Specification** | A document that contains the requirements for the M&F of specific types of equipment and components |
| **Steady Current** | An electric current of constant amperage |
| **Supplier Observation Reports (SOR)** | Documents filled out by the SI indicating concerns or other factual descriptions of what was noticed during the course of product surveillance, but not necessarily issues that may be considered defects or requiring NCRs. |
| **Supplier/Vendor (S/V)** | The entity which is responsible for the actual manufacturing and fabrication (M&F) of the material, equipment or components and which is responsible for meeting the contractual requirements. |
| **Switch** | A device for making, breaking, or changing the connections in an electric current |
| **TEFC** | The TEFC enclosure (totally enclosed fan cooled as defined by NEMA) is a construction where free exchange of air is prevented between the inside and outside of the motor. |
| **Tesla Coil** | A form of induction coil designed by Nicola Tesla for obtaining high voltages and frequencies; it consists of a primary of a few turns of coarse wire and a secondary of fine wire, both immersed in oil insulation; a Tesla transformer. |
| **Three Phase Power** | Electric power that is a common method of alternating-current electric power generation, transmission, and distribution. Consists of three related AC voltage sources equal in magnitude and offset by 120 degrees. |

| Term | Definition |
|---|---|
| **Tolerance** | Engineering tolerances refer to the limit (or limits) of specified dimensions, physical properties or other measured values of a component. |
| **Training** | An organized program developed to impart the skills and knowledge necessary for qualification as a source inspector |
| **Transformer** | An apparatus used for changing the voltage and current of an alternating circuit. A transformer consists of primary winding, secondary winding, and an iron core. In principle, if a current is passed through a coil of wire encircling a bar of soft iron, magnetic flux is created. This magnetic flux induces a voltage on the secondary winding proportional to the turn ratio between the primary and secondary winding. |
| **Transistor** | An active semiconductor device with three or more terminals. Transistors turn on instantly. They don't require a warm-up time like a tube does. A transistor will last for years and very little voltage is needed. |
| **UBC** | Uniform Building Code |
| **UL** | Underwriters Laboratory |
| **VAC** | Volts alternating current |
| **VDC** | Volts direct current |
| **Volt (V)** | The practical unit of electric pressure. The pressure which will produce a current of one ampere against a resistance of one ohm. |
| **Voltage Drop** | The drop of potential in an electric circuit due to the resistance of the conductor and the current passing through it. |
| **V-O-M Meter** | Electronic instrument used for measuring electrical potential difference between two points in an electric circuit |
| **VT** | 1. Visual Testing (Examination)<br>2. Voltage Transformers |
| **Watt (W)** | The practical unit of electric power, being the amount of energy expended per second by an unvarying current of one ampere under the pressure of one volt or one joule per second. |
| **WP-II** | The WP-II enclosure (weather protected type II as defined by NEMA) is a common enclosure. Air from outside the motor is drawn into and passed through its interior for cooling |
| **Wye (or Y) Connection** | This method of transformer connection consists in connecting both the primary and secondary windings in a star grouping. |

**Table 3: Websites Useful to the Source Inspector**

| Abbreviation | Organization | Web Address |
|---|---|---|
| **ANSI** | American National Standards Institute | http://www.ansi.org |
| **API** | American Petroleum Institute | http://www.api.org |
| **ASM** | American Society for Metals | http://www.asminternational.org/portal/sit |

| | | |
|---|---|---|
| | | e/www/ |
| **ASNT** | American Society for Nondestructive Testing | http://www.asnt.org |
| **ASTM International** | Formerly known as American Society for Testing and Materials | http://www.astm.org |
| **IEC** | International Electro-technical Commission | http://www.iec.ch/ |
| **IEEE** | Institute of Electrical and Electronics Engineers | http://www.ieee.org |
| **ISA** | International Society of Automation | http://www.isa.org |
| **ISO** | International Organization for Standardization | http://www.iso.org/iso/home.html |
| **NEC** | National Electric Code (NFPA70) | http://www.nfpa.org |
| **NEMA** | National Electrical Manufacturers Association | http://www.nema.org |
| **SSPC** | The Society for Protective Coatings | http://www.sspc.org |

# 5.0 Training and Certification

The levels of training and experience are unique to each organization and beyond the scope of this document.

# 6.0 Source Inspection Management Program

Employers or inspection agencies tasked with the responsibility of performing source inspection coordination and/or source inspection activities should develop a management program in order to provide the individuals performing the specific source inspection functions the necessary information to accomplish their duties. These source inspection management programs are generic in nature in that they provide requirements and guidance of source inspection activities on all types of projects that will require source inspection. See Section 7 for the types of source inspection plans that are needed for each specific project.

Source inspection management programs should cover most of the generic activities identified in this study guide but also include company specific information like:

- Activities required
- Personnel responsible for performing source inspection
- Training and competencies required for source inspectors
- Milestone and frequency with which each activity will be accomplished
- Procedure for each activity
- Application of acceptance criteria and industry standards.

These management programs may reference many other company specific source inspection procedures, practices and policies with more details that will be needed for specific types of source inspection activities, for example:

- How to prepare an overall Source Inspection Plan for an entire project and an Inspection and Test Plan (ITP) for each equipment item.
- How to conduct an equipment risk assessment in order to determine the level of source inspection activities that will be required.
- Guidance on the criteria to use for selecting source inspectors to match their skills and training with different types of equipment with different risk levels.
- Guidance on scheduling and conducting significant source inspection events like the pre-inspection (fabrication kick-off) meeting, the S/V quality coordination meeting, final acceptance testing, etc.
- Guidance on SI safety and professional conduct at S/V shops.
- How to review testing procedures.
- How to review inspection/examination records of the S/V.
- Which inspections should be repeated by the source inspector to verify the results of S/V examinations and tests.
- How to handle change requests.
- How to handle deviations and non-conformances.
- How to write source inspection reports with specific forms to be filled out.
- What specific steps to take before approving product acceptance, etc.
- Interfacing with the jurisdictional authorized inspector.

# 7.0 Project Specific Source Inspection Planning Activities

From the Source Inspection Management Program documents, a Project Specific Inspection Plan should be developed by the inspection coordinator addressing the following activities.

## 7.1 Equipment Risk Assessment

Effective source inspection for each project begins with a risk-based assessment of the materials and/or equipment to be procured for the project. These risk based assessments are performed to identify the level of effort for source inspection activities during the M&F phase of a project at the S/V facility. Equipment identified as critical equipment will receive more intensive source inspection; while equipment identified as less critical will receive less intensive source inspection and thereby rely more on the S/V quality program.

Typically these risk based assessments occur early in the design stages of a project and identify the equipment risks into the following types of categories.

- Safety or environmental issues that could occur because of equipment failure to meet specification or failure while in service.

- Equipment complexity; the more complex the equipment, the higher level of source inspection may be required.
- Knowledge of S/V history and capabilities to deliver equipment meeting specifications on time i.e. newer S/V with relatively unknown history or capabilities may need closer scrutiny.
- Potential schedule impact from delivery delays or project construction impact from issues discovered after delivery i.e. long delivery items may require higher level of source inspection.
- Equipment design maturity level i.e. prototype, unusual or one-of-a-kind type equipment may require higher level of source inspection.
- Lessons learned from previous projects i.e. has the S/V had problems in the past meeting specifications on time?
- Potential economic impact on the project of S/V failure to deliver equipment meeting specifications on time.

The risked based assessment team typically consists of individuals from various company groups including: quality, engineering, procurement, construction, project management and source inspection. Input from those who will own and operate the equipment, i.e. the client, is also beneficial. This collaboration provides input from all parties that may be affected if material or equipment is delivered and installed with unacceptable levels of quality.

The risk assessment process takes into account the probability of failure (POF) of equipment to perform as specified, as well as the potential consequences of failure (COF) to perform in service e.g. safety, environmental and business impact. The ultimate risk associated for each equipment item is then a combination of the POF and COF assessments.

The risk assessment provides the information necessary for the inspection coordinator to specify a level of effort for source inspection of each S/V facilities commensurate with the agreed upon risk level. Typical levels of source inspection effort at the S/V facility commensurate with risk levels may include:

- No Source Inspection (lowest risk for equipment failure to meet specifications; rely solely on S/V quality).
- Final Source Inspection (final acceptance) only just prior to shipment (lower to medium risk material or equipment; rely primarily on S/V quality with minimum source inspection).
- Intermediate Source Inspection level (medium to medium high risk equipment; mixture of reliance on S/V quality with some source inspection activities at the more critical hold points). The number of shop visits may go up or down based on the performance level of the S/V.
- Advanced Source Inspection level (higher risk equipment; significant amount of source inspection e.g. weekly to provide higher level of quality assurance). The number of shop visits may go up or down based on the performance level of the S/V.

- Resident Source Inspection level (highest risk equipment; full time shop inspector(s) assigned, possibly even on all shifts).

## 7.2 Development of a Source Inspection Project Plan

A source inspection plan should be developed for projects that have materials or equipment which will be inspected for compliance to the contractual agreements, project specifications, drawings, codes and standards.

The project plan should consist of the project details, list of equipment to be inspected and the project specific details on how the inspection activities will be performed to meet the expected level of quality performance from the S/V and/or the equipment.

The plan should also be based upon the level of risk determined from the risk based assessment performed in the design stage of the project and the appropriate level of effort needed for the surveillance of the S/V that is commensurate with the risk level.

## 7.3 Development of Inspection and Test Plans

A detailed inspection and test plan (ITP) for each type of equipment to be inspected should be provided. This ITP should be specific to the type of equipment to be inspected, the associated risk level for each piece of equipment and should identify all the inspection activities necessary to be performed by the assigned source inspector. It should also include the appropriate acceptance criteria or reference theretofore.

The source inspector should follow the ITP and ensure that the fabrication and S/V quality activities performed meet the requirements specified in the contractual agreement, referenced project specifications, drawings, applicable codes and/or standards.

## 7.4 Selection of an Inspector

The source inspection coordinator should review the details of the project plan, location of the S/V and duration of the work and select the appropriate source inspector(s) for the assignment.

The source inspector(s) selected should have the necessary experience, training and qualifications to perform the inspection or surveillance activities referenced in the ITP.

## 7.5 Coordination of Inspection Events

Dates for source inspection scheduled work process events such as the pre-inspection meeting (fabrication kickoff), key inspection events (factory acceptance, performance testing and final inspection) and anticipated shipping date should be identified in advance to allow coordination with other project members involved in the activity.

## 7.6 Report Review

Source inspection reports are important deliverables from the SI to the project team or client. The amount and type should be specified in the ITP. Each inspection report should be reviewed for content, completeness and technical clarity prior to distribution.

# 8.0 Source Inspection Performance

## 8.1 Inspector Conduct and Safety

Individuals tasked with the responsibility of performing source inspection activities should conduct themselves professionally while visiting an S/V facility as a representative of their employer and/or purchaser. If any conflict should arise during the inspection activity, the source inspector should notify their supervisor for resolution as soon as possible. It is important that the SI not be confrontational or argumentative regardless of the importance of the issue at hand; but rather simply indicates in objective terms how the SI intends to proceed to resolve the issue.

Safety of the individual performing the source inspection activity is one of the most important aspects of their work. A safety program should be established which identifies specific safety hazards associated with the job. Source Inspectors should be adequately trained and knowledgeable in these safety programs in order to minimize the possibility of injury.

The safety program should include:

- Potential travel safety issues specific to the job.
- Required PPE in manufacturing facility.
- Potential shop safety issues and hazard recognition.
- How to handle the observation of unsafe acts in the shop.
- Electrical hazards present during equipment testing.

The SI should observe the safety procedures and policies of the S/V while on their premises or if more stringent, their own company safety requirements.

NFPA 70 (E) Standard for Electrical Safety in the Workplace defines what is considered the minimum personal safety practices the S/V must adhere to when working around or performing source inspection of electrical equipment.

## 8.2 Review of Project Documents

### 8.2.1 General

Typical project documents include, but are not limited to, contractual agreements (purchase orders and/or subcontracts), source ITP, project specifications, engineering or fabrication drawings, applicable codes, references or standards.

The source inspectors should familiarize themselves with all project documents and ensure that they have access to the edition/version of those documents specified in the contractual agreement at all times during their inspection visits. Prior to commencing the quality surveillance specified in the ITP, the source inspector should confirm that the S/V has the most current documents, drawings, etc. specified in the engineering design. Later editions of industry codes and standards do not apply if the engineering design has specified an earlier edition of a specific standard. Additionally, the source inspector should confirm that that all project documents have been reviewed/approved by the purchaser.

#### 8.2.2 Contractual Agreements

The contractual agreements including the purchase order, all specified engineering design documents, specified company standards, and specified industry standards form the basis for the requirements for source inspection of the purchased products.

#### 8.2.3 Engineering Design Documents

For engineered equipment, the SI needs to be familiar with the engineering design documents and drawings that are vital to quality of the purchased products.

#### 8.2.4 Company and Client Standards

The SI needs to be familiar with all company and client standards that are specified in the contractual agreements. These standards typically augment or supplement industry standards for issues not sufficiently well covered in industry standards. All mandatory requirements i.e. "shall/must" statements, included in the company specifications must be met or become an issue for an NCR,  and handled in accordance with standard purchaser management NCR systems requirements. Other issues contained in the specified standards such as those suggested or recommended i.e. "should" statements which are expectations of the S/V, but not necessarily requirements may become an issue to be reported in Supplier Observation Reports (SORs) and handled in accordance with standard purchaser management systems. Company and client standards may cover engineered and non-engineered equipment.

### 8.3 Performing the Source Inspection

Individuals assigned to perform the source inspection activity must follow the ITP as specified by the purchaser. Visual inspection, electrical inspection, dimensional inspections, observing functional testing, and all other examinations and tests must be performed in accordance with the source ITP, project specification and applicable codes and standards and meet the applicable acceptance criteria. See Section 9 for Examination Methods, Tools and Equipment.

One important step in the source inspection work process is to verify evidence that the Source/Vendor personnel conducting the fabrication and quality control steps during fabrication are properly trained, qualified and certified, as specified in the ITP or other contractual documents. This may include verification of such credentials as:

#### 8.3.1 Source Vendor Quality Personnel Qualifications as specified

During the course of manufacturing, the S/V may propose changes to the design that could impact cost, schedule and/or quality. In such cases, the source inspector should request that the S/V propose such changes in writing for review by the purchaser and/or owner-user of the equipment.

While the responsibility of establishing and monitoring the delivery is not generally in the purview of the SI and the responsibility of meeting the schedule remains with the S/V, the SI may be requested to report on fabrication status or slippage of milestone progress. The SI should notify the inspection coordinator if he/she believes that product quality may be compromised by schedule pressures.

## 8.4 Source Inspection Work Process Scheduled Planning Events

Typical source inspection scheduled work process events include the following:

### 8.4.1 Pre-purchase Meeting (Prior to Contract Placement)

The source inspector may or may not participate in a pre-purchase meeting. The purpose of such a meeting is to cover some specific design, fabrication, and/or QA/QC requirements expected of the S/V to make sure that their bid does not inadvertently overlook them and result in unanticipated occurrences during fabrication and source inspection activities.

### 8.4.2 Pre-inspection Meeting (Prior to Start of Fabrication)

The source inspector assigned to the S/V facility should participate in the pre-inspection meeting (PIM). The purpose of this meeting is to ensure that everyone at the S/V who will be involved in manufacturing, fabrication and monitoring the quality of the equipment fully understands specific requirements and details of the job, especially those requirements that may be non-routine or different relative to normal S/V quality surveillance. Advance preparation by the source inspector is important for the pre-inspection meeting to ensure the meeting covers all necessary issues and requirements as specified in the contractual agreements and source inspector's company policy/practices. Those requirements may include review of:

- PO and contractual agreements.
- Engineering, technical and material requirements and status.
- Fabrication schedules.
- Critical path and long-lead equipment/materials.
- Quality requirements e.g. ITP, NCR, inspection frequency, etc.
- Sub-suppliers and their quality requirements.
- Special requirements e.g. performance or functional testing requirements.
- Painting, preservation and tagging.
- Communication requirements e.g. inspection point notification, report distribution, proposed changes, hold points, schedule impacts, etc.
- Shipping and release plan.
- Final documentation requirements.
- Recording and reporting any observations, exceptions or deviations.

These source inspection work process events may also be observed or handled by others besides the source inspector including: project engineering, client representatives or third party inspection agency.

## 8.5 Report Writing

A key deliverable of source inspection is the progressive inspection reports detailing the documents reviewed, inspection activity performed, observed and/or witnessed during the source inspection visits. The report is normally on a standard format, and follows a consistent approach to reporting as specified by the purchaser.

The source inspector should reference the following minimum information in each report:

- Date of visit.
- Appropriate contract number and key information.
- Purpose of visit.
- Action items or areas of concerns.
- Results of inspection/surveillance.
- Reference drawings/data used (including drawing numbers) to perform inspection/surveillance.
- Revisions of referenced drawings/data.
- Reference to the applicable requirement in the ITP.
- Identification of nonconforming or deviating items/issues.

Photographs are common place in inspection reports as they assist in the description of the inspection results. The SI should request permission from the S/V prior to taking any photographs. Care should be exercised to ensure that an appropriate number of photos are attached as too many can be detrimental to report issuance due to file size. Photos should be dated and labeled with description of area of interest or product tag reference so that they can be easily understood by those reading the SI reports.

Reports should be submitted to the inspection coordinator for review of content and technical clarity before they are distributed to the purchaser unless otherwise instructed.

## 8.6 Nonconformance/Deviations

When deviations to the contractual agreement or its referenced specifications, drawings, codes or standards are identified, the source inspector should identify them as non-conformances. The source inspector should notify the inspection coordinator as soon as practical once a nonconformance has been identified.

Nonconformance reports should reference the following minimum information:

- Date of inspection.
- Contract number and information.
- Description of nonconforming item and issue.
- Photo of discrepancy if possible.
- Specification, drawings, codes or standards involved.
- Impact on the product.

- S/V recommended disposition of the nonconformance.

The source inspector should issue the nonconformance report to the inspection coordinator for review and distribution unless instructed otherwise.

In general, deviations from specifications must be approved by the responsible engineer/technical personnel.

Acceptable disposition of a nonconformance (as approved by the responsible engineer/SME) may include:

- Use as is.
- Rework/repair per original contractual documents or approved repair procedure.
- Scrap the equipment/component involved and start over.

Once the disposition of the nonconformance has been agreed by all appropriate parties and implemented, the source inspector is normally responsible for determining if the nonconforming item currently conforms to the original or revised requirements based on the agreed disposition. It is SI responsibility to verify that NCR disposition has been properly implemented.

### 8.7 Source Inspection Project Continuous Improvement

At the completion of the source inspection activities at an S/V, the source inspector, inspection coordinator, and all others involved in the "planning and doing" processes should review the entire planning and doing part of the "Plan–Do–Check–Act" continuous improvement (CI) cycle to determine which activities went well and where improvements/adjustments could/should be made. Determinations should be made if improvements are possible and necessary in the source inspection management systems; the source inspection project planning process: the creation and implementation of the ITP; and the implementation of the source inspection work process events. Any such improvements should be documented and made available to source inspection managers and coordinators to implement the improvements. This should include an evaluation of the performance of the S/V.

### 8.8 Source Inspector Continuous Improvement

The source inspector can/should also learn from the continuous improvement cycle how they can improve their performance on the job by answering such questions as:

- Are there some industry codes and standards that I should be more familiar with?
- Are there any safety and or personal conduct improvements I can make?
- Can I improve the way I write the various SI reports?
- Do I need to improve my review of project documents before showing up at the S/V site?
- Can I improve the way I conducted the pre-fabrication meeting?

- Can I improve the timeliness of closing out my part of the source inspection project?

This document recognizes two different systems of standards for the manufacturing and testing of electrical machines: the North American ANSI, IEEE, and NEMA standards and the international IEC and ISO standards. The North American standards are the base documents. When specified by the purchaser, the corresponding international standards are acceptable for use as alternatives; however, this shall not be construed that they are identical to the North American standards.

Requirements for examinations from the purchaser or references in the contract agreement that may be more stringent than industry codes/standards or the S/V normal procedures should be included in the ITP.

Some inspections and tests may require an independent testing organization or an equipment manufacturer's representative. It is outside the scope of this Guide to identify which tests require a third party or to designate responsibility for obtaining and coordinating these third parties. When necessary, these tests will be defined in the project scope and the ITP.

# 9.0 Examination Methods, Tools and Equipment

Requirements for examinations from the purchaser or references in the contract agreement that may be more stringent than industry codes/standards or the S/V normal procedures should be included in the ITP.

Some inspections and tests may require an independent testing organization or an equipment manufacturer's representative. It is outside the scope of this Guide to identify which tests require a third party or to designate responsibility for obtaining and coordinating these third parties. When necessary, these tests will be defined in the project scope and the ITP.

## 9.1 Review and Confirmation of Materials of Construction

Ensuring that the S/V is using the correct material during the fabrication or manufacturing of the equipment is a critical element of quality surveillance. Typical reviews should consist of the following:

Material Test Reports (MTRs) — the information necessary for the source inspector to know and understand about MTRs is covered in API 541 section 6.2.2. Any reports (e.g. MTRs) that have been modified or corrected, should be cause for immediate rejection as these could indicate the potential for the material or component being counterfeit material. All MTRs must be legible.

Confirming that the construction materials proposed are the actual materials used during construction is a typical source inspection activity. The source inspector should:

- confirm the correct material type and grade;
- confirm the origin of the material;
- check material size and/or thickness'

- verify traceability of the material to a certifying document;
- verify that the material complies with specific chemical, marking, color and/or mechanical properties as specified in the contractual documents.

The SI should be aware of the potential for counterfeit materials/documents slipping into the supply chain. Key issues to watch for include, but are not limited to:

- generic documentation which is not product specific;
- material or equipment containing minimal or no documentation;
- questionable or damaged markings or logos;
- items that have inconsistent appearance;
- documents that have been altered;
- items that lack material traceability or product certification;
- UL, ETL, IEEE or other markings that may have been counterfeited.

## 9.2 Dimensional Inspections

The SI should be proficient in understanding and performing dimensional inspections. Equipment such as tape measures, dial indicators, calipers, protractors, and levels are all typical tools that are used for dimensional inspection. When performing dimensional inspections, the source inspector should be familiar with the dimensional requirements and the allowable tolerances. Actual dimensions should be recorded in the inspection reference drawing. Dimensions which exceed the tolerances should be reported as a nonconformance or deviation.

## 9.3 Visual Inspections

Adequate lighting is essential when performing visual inspection. The SI must be familiar with the minimum lighting requirements defined by the applicable code, standard or specification. If there is inadequate lighting available during the visual inspection, the source inspector must address these concerns with the S/V and inspection coordinator to resolve. Portable lighting such as pen lights, high power flashlights, etc. must be available to the source inspector to perform adequate visual inspection to include:

- Physical & Mechanical condition.
- All Nameplate data.
- Verify all equipment grounding.
- Verify one line drawings match equipment

## 9.4 Typical Electrical Testing Techniques

### 9.4.1 Continuity/Point-to-Point

A continuity or point-to-point test is used to determine if an electrical path can be established between two points; that is if an electrical circuit can be made. Continuity refers to being part of a complete or connected whole. In electrical applications, when an electrical circuit is capable of conducting current, it demonstrates electrical continuity. It is also said to be “closed,” because the circuit is complete. In the case of a light switch, for example, the circuit is closed and capable of conducting electricity when the switch is flipped to "on." The user can break the continuity by flipping the switch to "off," opening the circuit and rendering it incapable of conducting electricity.

### 9.4.2 Insulation Resistance Testing

The insulation resistance (IR) test (also commonly known as a Megger) is a spot insulation test which uses an applied DC voltage (typically 250 Vdc, 500 Vdc or 1,000 Vdc for low voltage equipment <600 V and 2,500 Vdc and 5,000 Vdc for high voltage equipment) to measure insulation resistance in either kΩ, MΩ or GΩ. The measured resistance is intended to indicate the condition of the insulation or dielectric between two conductive parts, where the higher the resistance, the better the condition of the insulation. Ideally, the insulation resistance would be infinite, but as no insulators are perfect, leakage currents through the dielectric will ensure that a finite (though high) resistance value is measured.

Because IR testers are portable, the IR test is often used in the field as the final check of equipment insulation and also to confirm the reliability of the circuit and that there are no leakage currents from unintended faults in the wiring (e.g. a shorted connection would be obvious from the test results).

One of the advantages of the IR test is its non-destructive nature. DC voltages do not cause harmful and/or cumulative effects on insulation materials and provided the voltage is below the breakdown voltage of the insulation, does not deteriorate the insulation. IR test voltages are all well within the safe test voltage for most (if not all) insulation materials.

The presence (or lack) of moisture can also affect the IR test measurements, the higher the moisture content in the air, the lower the IR test reading. If possible, IR tests should not be carried out in very humid atmospheres (below the dew point). While there are no standard correction factors or guidance for humid conditions, it is good practice to record the relative humidity of each IR test so that they can be used for baseline comparisons in future tests. For example, having past data on the IR test values for dry and humid days will give you a foundation for evaluating future test values.

### 9.4.3 High Potential (Hipot)/Dielectric Withstand Test

Traditionally, Hipot is a term given to a class of electrical safety testing instruments used to verify electrical insulation in finished appliances, cables or other wired assemblies, printed circuit boards, electric motors, and transformers.

Under normal conditions, any electrical device will produce a minimal amount of leakage current due to the voltages and internal capacitance present within the product. Yet due to design flaws or other factors, the insulation in a product can break down, resulting in excessive leakage current flow. This failure condition can cause shock or death to anyone that comes into contact with the faulty product.

A Hipot test (also called a dielectric withstand test) verifies that the insulation of a product or component is sufficient to protect the operator from electrical shock under normal operating conditions. In a typical Hipot test, a deliberate over or high voltage potential is applied between the product current-carrying conductors and the metallic chassis. Any resulting current that flows through the insulation, known as leakage current, is detected by the Hipot test instrument. The theory behind the test is that if a deliberate over-application of test voltage does not cause the insulation to break down, the product will be safe to use under normal operating conditions—hence the name, Dielectric Withstand Test.

In addition to over-stressing the insulation, the test can also detect material and workmanship defects that may not be observed under normal operating conditions at first. For example, small gap spacing between current-carrying conductors and earth ground. When a product is operated under normal conditions, environmental factors such as humidity, dirt, vibration, shock and contaminants can close these small gaps and allow current to flow.

This condition can create a shock hazard if the defects are not corrected at the factory. No other test can uncover this type of defect as well as the Dielectric Withstand Test.

Three types of Hipot tests are commonly used. These three tests differ in the amount of voltage applied and the amount (or nature) of acceptable current flow:

#### 9.4.3.1 Dielectric Breakdown Test

The test voltage is increased until the dielectric fails, or breaks down, allowing too much current to flow. The dielectric is often destroyed by this test so this test is used on a random sample basis or for type testing. This test allows designers to estimate the breakdown voltage of a product's design.

#### 9.4.3.2 Dielectric Withstand Test

A standard test voltage is applied (below the established Breakdown Voltage) and the resulting leakage current is monitored. The leakage current must be below a preset limit or the test is considered to have failed. This test is non-destructive and is usually required by safety agencies to be performed as a 100% production line test on all products before they leave the factory.

#### 9.4.3.3 Insulation Resistance Test

This test is used to provide a quantifiable resistance value for all of a product's insulation. The test voltage is applied in the same fashion as a standard Hipot test, but is specified to be Direct Current (DC). The voltage and measured current value are used to calculate the resistance of the insulation.

#### 9.4.3.4 Differences between an Insulation Resistance (IR) and Hipot Test

"Megger" is a generic term for a test that is performed with a megohmmeter. Hipot is a generic term for a test using high potential used to identify a potential fault of insulators. Megger and Hipot tests are standard in the electrical industry for determining the integrity for electrical conductors and components. Although both tests share similarities in how they are performed there are distinct differences between Megger and Hipot tests.

A Hipot tester also performs a dielectric breakdown test. In this test, voltage is increased on a conductor or component until the insulation fails. This test is performed primarily for sample or demonstration purposes at the point of manufacture, as it often destroys the component being tested. A Megger cannot perform the dielectric withstand or breakdown test.

Megger and Hipot insulation resistance tests differ in applied voltage and in test duration. A Megger test for low voltage equipment applies a charge between 600 to 2,000 volts over the span of a minute. Hipot testers apply a much higher voltage in the range of 15,000 volts and above, to a maximum of 300 volts per mil of insulation. Hipot tests are performed over 15 minutes with readings taken every minute.

## 9.5 Functional Testing

Performance and functional testing is generally applicable to electrical equipment such as motors, generators, motor control centers, switchgears etc. to determine that the equipment will perform as specified in service. In situations where the SI is involved in functional testing, a specific procedure with acceptance criteria will be involved and often an engineer or other SME will also witness the test. Unless otherwise specified in the contractual documents this should be established as a hold/witness point for the SI.

The S/V shall operate, or cause to be operated, each system, device, or equipment item, both intermittently and continuously, for a period as indicated in the Specification Section(s) for such item and/or in accordance with the S/V written recommendations, the Contract Documents, and the Commissioning Plan.

During these tests the SI should take specific care in assuring that there is strict adherence to the approved applicable test procedures as well as verifying that all testing equipment is properly calibrated and in good general working order. All activities undertaken should have detail records to support the testing protocols.

## 9.6 Surface Preparation/Coatings Inspections

Performance of coating systems typically depends on the how well the substrate or surface is prepared for coating applications. Typically on electrical equipment, visual inspection of the final coated surfaces is recommended or required. Inspections typically consist of a visual surface comparison.

Coating systems are usually specified in the contractual and engineering documents and likely will involve baked on coating applications. The method of inspection of these coating systems is by the use of a dry film thickness gauge (DFT) per SSPC-PA 2, which the SI should be familiar with.

In addition to purchase order requirements and company standards, coating manufacturer’s recommendations will provide the details for correct coatings application to be followed.

Prior to releasing the electrical equipment for shipment, the source inspector should inspect the coated or lined surfaces for the following items: raised areas, pinholes, soft spots, disbondment, delaminations, blisters, holidays, bubbling, fisheyes, runs and sags, uniformity, mechanical damage, and proper color or shade.

Any areas found in need of coating repairs should be properly identified and documented (NCR) by the source inspector as well as any testing and re-inspection performed after repairs have been made.

# 10.0 Final Acceptance

Prior to final acceptance of electrical equipment, the source inspector should determine the following:

- All work specified in the contractual agreements is completed by the S/V.
- All Non-Conforming Reports (NCRs) have been closed out and resolved by the S/V QC representative and owner's QA representative.
- All punch list items have been completed.
- All Inspection related activities have been completed and documented.
- All S/V work has been deemed to meet the requirements in accordance with the requirements of codes, standards and project specifications.

  NOTE: The role of the inspector is not acceptance of the work, but to verify that the work meets the requirements of the purchaser. Final acceptance of the equipment rests with the Purchaser

Shipping Preparations may also be specified in the contractual and engineering documents. It is the responsibility of the SI to confirm that all bracing, strapping, mounting, covering, packaging, marking, and protection from the weather, etc. is effectively completed before the equipment is released for shipment.

## 10.1 Reviewing Final S/V Data

It is typical for the SI to perform a final review of the contractually required S/V data upon the completion of the manufacturing/fabrication and prior to shipment of the materials or equipment. This review is to determine that all documents are complete, with the as built item with all supporting documents as identified in the contractual agreement. Such documentation may include but is not limited to:

- Final fabrication drawings.
- MTRs.
- Functional test documentation.
- Product specific QC checks.
- NCR close outs.
- Certification documents.
- Code compliance documentation.

# 11.0 Manufacturing and Fabrication (M&F) Processes

The manufacturer/fabricator is responsible for the quality of all their M&F products, which includes not only good workmanship, but also compliance with all codes, standards and project specifications contained in the contractual agreements. The source inspector is responsible as defined in the inspection and test plan (ITP) for performing the source quality surveillance activities at the S/V facilities in accordance with the applicable ITP.

# 12.0 Electrical Skid Mounted Equipment

## 12.1 General

This study guide assumes the SI has experience and familiarity with basic electricity and electronics. The specifications in this guide reference the minimum installation requirements for electrical pre-engineered, custom engineered pre-assembled and pre-wired skid mounted packaged units.

## 12.2 Packaged, Pre-Engineered and Custom Skids

### 12.2.1 Packaged Skids Design

Package Unit Equipment items that include electric power and auxiliary devices normally requiring engineering, assembly, wiring and piping. Packaged Units can be defined as having the following requirements:

- is generally shop-built, structurally integrated, and transportable as a unit;
- is capable of operation once integrated with the main process piping and utilities;
- employs a control system of sufficient complexity to require an engineered design;
- can be stand-alone but is typically designed and built to enable or support a primary process;
- a basic regulatory control system and a shutdown alarm system that monitors and protects its own performance and safety.

### 12.2.2 Pre-Engineered Process Packaged Skids

A pre-assembled, pre-wired skid mounted equipment, which is a standard field tested, mass produced product (e.g., pump systems, instrument air packaged plants, small utility boilers, air conditioning systems, etc.).

### 12.2.3 Engineered Process Packaged Skids

A package that is particularly made to purchaser standards and specifications (e.g., custody metering skids, surge relief skids, process boilers, etc.).

### 12.2.4 Process Packaged Skids

Typical packaged process skids in the oil and gas industry incorporates only the process equipment. This is due to the requirement to classify the immediate area surrounding the process equipment. Depending on the probability of a flammable release, the duration of a release and the level of ventilation available, a process skid may be classified Class I, Division 1 or 2 using the division method of area classification, or Class I, Zone 1 or Zone 2 under the Zone method of area classification. Once the process module is classified, the electrical and instrumentation equipment must be certified for the hazardous location. Because hazardous certified electrical equipment is more costly, the majority of the electrical and control equipment is located off-skid in an unclassified location with only the end device sensors located on the process skid. The result may be a large number of conduits and wiring interconnections.

## 12.3 Electrical Equipment for Hazardous (Classified) Locations

### 12.3.1 General

The National Electrical Code (NEC), NFPA 70 Article 500, defines hazardous classified locations. Articles 500 through 504 cover the requirements for electrical and electronic equipment and wiring for all voltages in Class I, Divisions 1 and 2; Class II, Divisions 1 and 2; and Class III, Divisions 1 and 2 locations where fire or explosion hazards may exist due to flammable gases, flammable liquid–produced vapors, combustible liquid–produced vapors, combustible dusts, or ignitable fibers / flyings.

The National Electrical Code (NEC), NFPA 70 Article 505, defines electrical and electronic equipment and wiring for all voltages in Zone 0, Zone 1, and Zone 2 hazardous (classified) locations where fire or explosion hazards may exist due to flammable gases or vapors or flammable liquids.

### 12.3.2 Class 1, Division 1 Boundary. NFPA 70 Article 501.15

The conduit seal shall be required in each conduit run leaving a Division 1 location. The sealing fitting shall be permitted to be installed on either side of the boundary within 10 feet (3.05 m) of the boundary, and it shall be designed and installed to minimize the amount of gas or vapor within the portion of the conduit installed in the Division 1 location that can be communicated beyond the seal. The conduit run between the conduit seal and the point at which the conduit leaves the Division 1 location shall contain no union, coupling, box, or other fitting except for a listed explosion proof reducer installed at the conduit seal.

Figure 1 shows an example of seal installation required for process-connections to and from classification boundaries to contain an explosion in the enclosure to which it is attached. NFPA 70 Article 505.16 / API 14F 6.8 Class 1 Division locations / API 14FZ 6.8 Class 1 Zone locations.

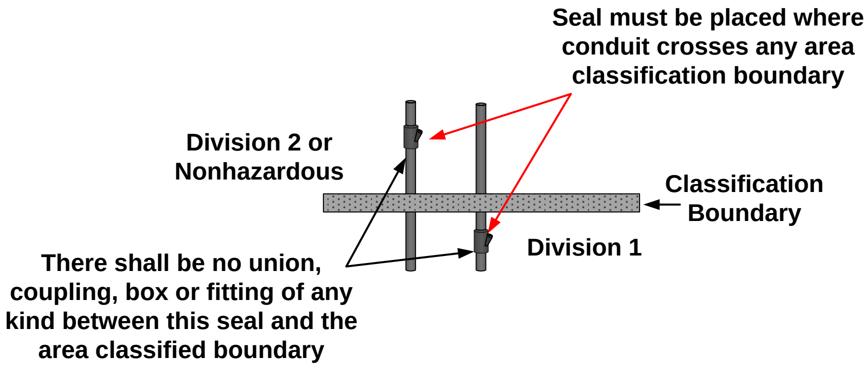



**Figure 1: Seal Installation**

### 12.3.3 Enclosure, electrical

The case or housing of electrical apparatus provided to prevent personnel from accidentally contacting energized parts and to protect the equipment from physical damage. Certain enclosures also serve to prevent electrical equipment from being a source of ignition of flammable mixtures outside the enclosure. NFPA 70 Article 100 Definitions

### 12.3.4 Class I, Division 1 locations

Switches, circuit breakers, motor controllers, and fuses, including pushbuttons, relays, and similar devices, shall be provided with enclosures, and the enclosure in each case, together with the enclosed apparatus, shall be identified as a complete assembly for use in Class I locations 501.115 (A).

### 12.3.5 General –purpose enclosures are allowed if any of the following apply

- The interruption of current occurs within a chamber hermetically sealed against the entrance of gases and vapors.
- The current make-and-break contacts are oil-immersed and of the general-purpose type having a 2 inch (50 mm) minimum immersion for power contacts and a 1 inch (25 mm) minimum immersion for control contacts.
- The interruption of current occurs within a factory sealed explosion proof chamber.
- The device is a solid state, switching control without contacts, where the surface temperature does not exceed 80 percent of the auto ignition temperature in degrees Celsius of the gas or vapor involved.

### 12.3.6 Enclosure, NEMA type

NEMA is an American system of safety ratings for protective enclosures that safeguard people from coming into contact with live or moving parts of an electrical apparatuses.

- The protection provided by the enclosure against ingress of solids and/or liquids
- The protection provided by the enclosure against the deleterious effects of corrosion.
- The protection provided by the enclosure against damage to the formation of external ice. This enclosure type is in addition to (and not an alternative to) the types of protection necessary to ensure protection against ignition in hazardous (classified) locations, see Hazardous Areas:

### 12.3.7 Explosion-Proof Equipment

Equipment enclosed in a case capable of withstanding an explosion of a specified gas or vapor within it and of preventing the ignition of a specified gas or vapor surrounding the enclosure by sparks, flashes, or explosion of the gas or vapor within, and that operates at such an external temperature that a surrounding flammable atmosphere will not be ignited thereby.

#### 12.3.7.1 NFPA 70 Article 100 Definitions

- **Explosion Proof Component:** An explosion proof component that is capable of keeping an internal explosion of a specific flammable air-vapor mixture within the component enclosure without releasing burning or hot gases to the external environment which may be potentially explosive.
- **Flameproof:** A type of protection of electrical apparatus in which an enclosure will withstand an internal explosion of a flammable mixture which has penetrated into the interior, without suffering damage and without causing ignition, through any joints or structural openings in the enclosure, of an external explosive atmosphere consisting of one or more of the gases or vapors for which it is designed. This type of protection is referred to as "d." NFPA 70 Article 505.2 Definitions.
- **Enclosures and Sealed Fitting:** There are many enclosures, devices, and fixtures suitable for all classified areas. A Class 1 device which could contain an explosion of a specified gas would also have to prevent dust from entering the enclosure to be suitable for Class 2. The close tolerance of the flame path which cools the burning gases is also close enough to exclude explosive dust so that a gasket would not be needed. Where cables with a gas/vapor tight continuous sheath capable of transmitting gases or vapors through the cable core are installed within conduit, the annulus space between the conduit and the cable(s) shall be sealed with sealing compound, and the cable core shall be sealed after removing the jacket and any other coverings so that the sealing compound will surround each individual conductor and the outer jacket. An exception for multi-conductor cables, shielded cables, and twisted pair cables with a gas/vapor tight continuous sheath capable of transmitting gases or vapors through the cable core, is that such cables are permitted to be considered as a single conductor by sealing the cable in the conduit within 18 inches (457 mm) of the enclosure, but it is also necessary to seal the cable end within the enclosure by an approved means to minimize the entrance of gases or vapors and to prevent the propagation of flame into the cable core. NFPA 70 Article 501.15. See Figure 2.

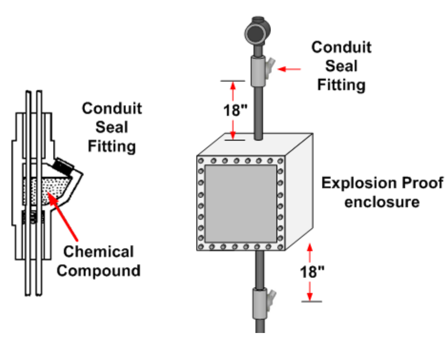



**Figure 2: Conduit Seals**

- **Steel Conduit, Fitting, and Accessories:** National Electrical Code (NFPA Standard 70) covers the installation of steel rigid metal conduits (RMC), steel intermediate metal conduits (IMC), and steel electrical metallic tubing (EMT) and conduits with a supplementary PVC coating as well as the proper installation of hazardous location equipment calls for the use of seals. Special fittings are required to keep hot gases from travelling through the conduit system igniting other areas if an internal explosion occurs in a Class 1 device.

  They are also needed in certain situations to keep flammable dusts from entering dust-ignition-proof enclosures through the conduit. In the event that arcs and sparks cause ignition of flammable gases and vapour, the equipment contains the explosion and vents only cool gases into the surrounding hazardous area. Sealing fittings are designed to be filled with a chemical compound after the wires have been pulled. As the compound hardens, it seals passageways for dusts and gases.

- **Flexible Electrical Conduit:** The National Electrical Manufacturers Association, NEMA FB 2.20-2014, has detailed guidelines for use with flexible electrical conduit and cable. This standard also provides practical information on proper industry-recommended practices for installation of fittings for flexible electrical conduit and cable. Guidelines provide inspectors with industry practices and the installation of fittings for instrument and AC cables.

### 12.4 Purged and Pressurized in a (Classified) Location

The process of purging, supplying an enclosure with a protective gas at a sufficient flow and positive pressure to reduce the concentration of any flammable gas or vapor initially present to an acceptable level; and pressurization, supplying an enclosure with a protective gas with or without continuous flow at sufficient pressure to prevent the entrance of a flammable gas or vapor, a combustible dust, or an ignitable fiber. The requirements for a pressurized building are defined in Chapter 7 of NFPA 496 Standard for Purged and Pressurized Enclosures for Electrical Equipment are as follows:

- The purge system may be integral to the building HVAC system.
- The positive pressure air system must provide 25pa (0.1 inch WC) of pressure with all openings closed. The system must also be capable of providing an outward air velocity of 60 ft/min (0.305 m/sec) through all openings capable of being opened. In many situations this requirement is often difficult to achieve without the use of an air lock entry system.
- The air used to create the pressurized zone must be sourced from an unclassified location and contain no more than trace amounts of flammable gas.
- The purge system air ducts must be constructed of non-combustible materials and protected against mechanical damage and corrosion.

The operation of the purge system must be monitored by a pressure or flow switch. In the event of an interruption to the purge system, a procedure is required to test the atmosphere of the unclassified area prior to energizing any equipment not approved for a hazardous location. For this reason, any equipment that is essential to the operation of the purged system must be certified for use in a classified location.

Depending on if the unclassified room or building is located in a Class I, Division 1 (Zone 1) or Class I Division 2 (Zone 2) location, additional requirements will apply. Within a Division 2 location, a type ‘Z’ purge is required. A type ‘Z’ purge requires that the purge system be monitored in a constantly attended location.

For an unclassified area, in the event of a purge system failure, an alarm must annunciate. There is no requirement to immediately shutdown any unclassified equipment located within the purged building. If the unclassified area is located within a Class I, Division 1 location, a failure of the purge system will require the de-energizing all equipment not approved for a Class I, Division 1 location.

### 12.4.1 Enclosure, purged and pressurized

An enclosure supplied with clean air or an inert gas at sufficient flow and positive pressure to reduce to an acceptably safe level any flammable gas or vapor concentration initially present, and to maintain this safe level by positive pressure with or without continuous flow

## 12.5 Cable Support Systems

### 12.5.1 General

A unit or assembly of units or sections and associated fittings forming a structural system used to securely fasten or support cables and raceways (NFPA 70 392).

Cable support systems made of metal or other noncombustible material forming a rigid structural system used to support electrical cable. Commercially made cable trays are generally preferred for multiple cable runs. For small installations, standard pipe or conduit, or specially designed brackets or supports may be utilized.

### 12.5.2 Cable Tray

In the electrical wiring of skids and buildings, a cable tray system is used to support insulated instruments, electric cables and conduits used for power distribution and communication. A support consisting of a base with integrated side members or a base connected to side members.

### 12.5.3 Materials

Recommended materials for cable trays include copper-free aluminum, stainless steel, and fiberglass. Cable tray supports made of hot-dipped galvanized steel or painted pipe or structural steel are recommended.

### 12.5.4 Design

Cable tray systems should be designed in accordance with Article 392 “Cable Trays” of the *NEC*. Trays should be selected, using manufacturer’s data, to adequately support anticipated cable loads and to sustain wind loads. It is recommended that the rung spacing of open-type trays not exceed 12 in. Trays should be supported in accordance with the manufacturer's recommendations. If cable supports are used, cables should be individually secured to the supports at intervals to prevent excessive sag or strain on the cables. Bundling of cables on supports is not recommended. All electrically conductive cable support systems should be grounded.

## 12.6 Equipment Grounding

The grounding requirements of a power system will vary from those of electrical equipment, lightning protection or for the function of electronic equipment.

- **Ground:** A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth or to another conducting body that serves in place of the earth.
- **Earth:** The conductive mass of the earth, whose electric potential at any point is conventionally taken as equal to zero. (The term "ground" is used instead of "earth.")
- **Bonding:** The permanent joining of metallic parts to form an electrically conductive path that will ensure electrical continuity and the capacity to conduct any current likely to be imposed.
- **Bonding Conductor or Jumper:** A reliable conductor to ensure the required electrical conductivity between metal parts required to be electrically connected.
- **Bonding Jumper, Equipment:** The connection between two or more portions of the equipment grounding conductor.
- **Lightning protection:** The ground system must efficiently couple lightning surges into the ground by maximizing capacitive coupling to the soil. The resistance of the ground itself to lightning currents must also be minimized.
- **Grounding Connections:** Grounding connections are used to tie the elements of the grounding system together. Exothermically welded connections provide a molecular bond that will never loosen or corrode. Mechanical connectors, such as crimp, bolted, and wedge type, rely on physical point to point surface contact to maintain the integrity of the electrical connection. IEEE Standard 837 provides detailed information on the application and testing of permanent grounding connections.
- **Equipment Grounding Conductor:** The Equipment Grounding Conductors (EGC) are the most important conductors in the electrical system. The grounding conductor is the electrical safety conductor. Below are NEC 392 approved methods and options.
    - Use the cable tray as the EGC.
    - Use a single conductor cable as the common EGC for all the circuits in the cable tray.
    - Use individual EGC conductors in each multi-conductor cable in the cable tray.
    - Parallel the separate EGC with the cable tray.

## 12.7 AC Control Wiring

Typical electrical wiring for Packaged Equipment is detailed in the purchaser's Data Sheet. An AC control circuit that begins and ends within the panel is typically single conductor, stranded copper with 600-volt insulation. Wiring for AC and DC power distribution branch circuits are color coded for identification of individual wires. See Figure 3 for IEC wiring color codes for AC branch circuits.

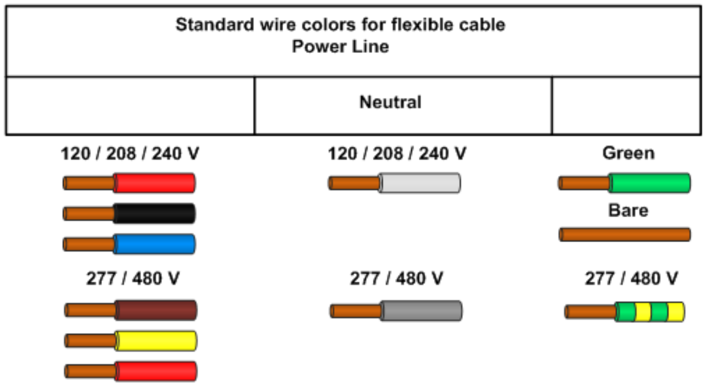



**Figure 3: Standard Wire Colors for Flexible Cable Power Lines**

The US National Electrical Code (NFPA 70) only mandates white (or grey) for the neutral power conductor and bare copper, green, or green with yellow stripe for the protective ground. Any other colors except these may be used for the power conductors. The table above depicts Black, red, and blue are used for 208 VAC three-phase; brown, orange and yellow are used for 480 VAC. Conductors larger than #6 AWG are only available in black and are color taped at the ends.

### 12.7.1 Cable Construction

The cable industry has many ways to construct a cable and there is no generally applicable industry standard. However, all industry AC and DC cables have common characteristics when referring to thermoplastic and thermosetting insulated cable.

- Low voltage power and control cables pertain to electrical cables that typically have a voltage grade of 1 kV or below.
- Medium / High voltage cables pertain to cables used for electric power transmission at medium and high voltage (usually from 1 to 33 kV are medium voltage cables and those over 50 kV are high voltage cables).

### 12.7.2 Conductor

Stranded copper (Cu) or aluminum (Al) conductors may be used. Copper is denser and heavier, but more conductive than aluminum. Electrically equivalent aluminum conductors have a cross-sectional area that is approximately 1.6 times larger than copper, but half its weight.

### 12.7.3 Annealing

Annealing is the process of gradually heating and cooling the conductor material to make it more malleable and less brittle.

### 12.7.4 Coating

Surface coating (such as, tin, nickel, silver, lead alloy) of copper conductors is common to prevent the insulation from attaching or adhering to the copper conductor and prevents deterioration of copper at high temperatures.

### 12.7.5 Conductor Screen

A conductor screen is a semi-conducting tape used to maintain a uniform electric field and minimize electrostatic stresses for MV/HV power cables.

### 12.7.6 Plastics

Plastics are one of the more commonly used types of insulating materials for electrical conductors. It has good insulating, flexibility, and moisture-resistant qualities. Although there are many types of plastic insulating materials, thermoplastic is one of the most common. With the use of thermoplastic, the conductor temperature can be higher than with some other types of insulating materials without damage to the insulating quality of the material. Plastic insulation is normally used for low- or medium-range voltage.

The designators used with thermoplastics are much like those used with rubber insulators. The following letters are used when dealing with NEC type designators for thermoplastics:

- T – Thermoplastic
- H - Heat-resistant
- W - Moisture-resistant
- N - Outer nylon jacket
- S – Sun-resistant
- M - Oil-resistant

### 12.7.7 Aluminum-Sheathed Cables

These power cables are used for exposed and concealed wiring, in wet and dry locations, and where exposed to the weather. They may be installed in ventilated, unventilated and ladder-type cable-troughs, and ventilated flexible cableways. Aluminum-Sheathed Power Cables may be single-, two-, three- or four-conductor, the conductor(s) being annealed, bare, compressed-round stranded copper. The insulated core is enclosed in a liquid- and vapor-tight solid corrugated aluminum sheath, covered by a PVC jacket. See Figure 4.

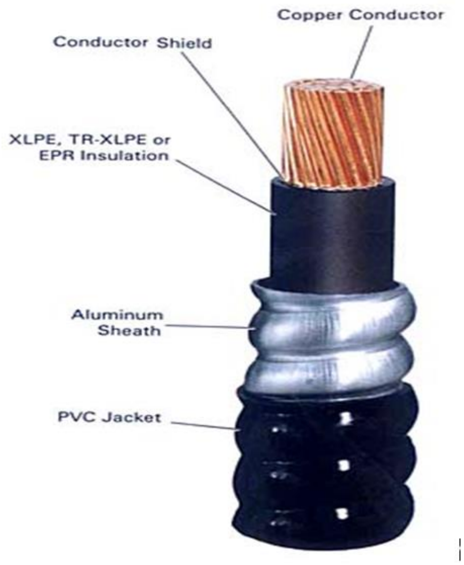



**Figure 4: Aluminum Sheathed Cable Composition Example**

Figure 5 displays additional examples of sheathed cable.

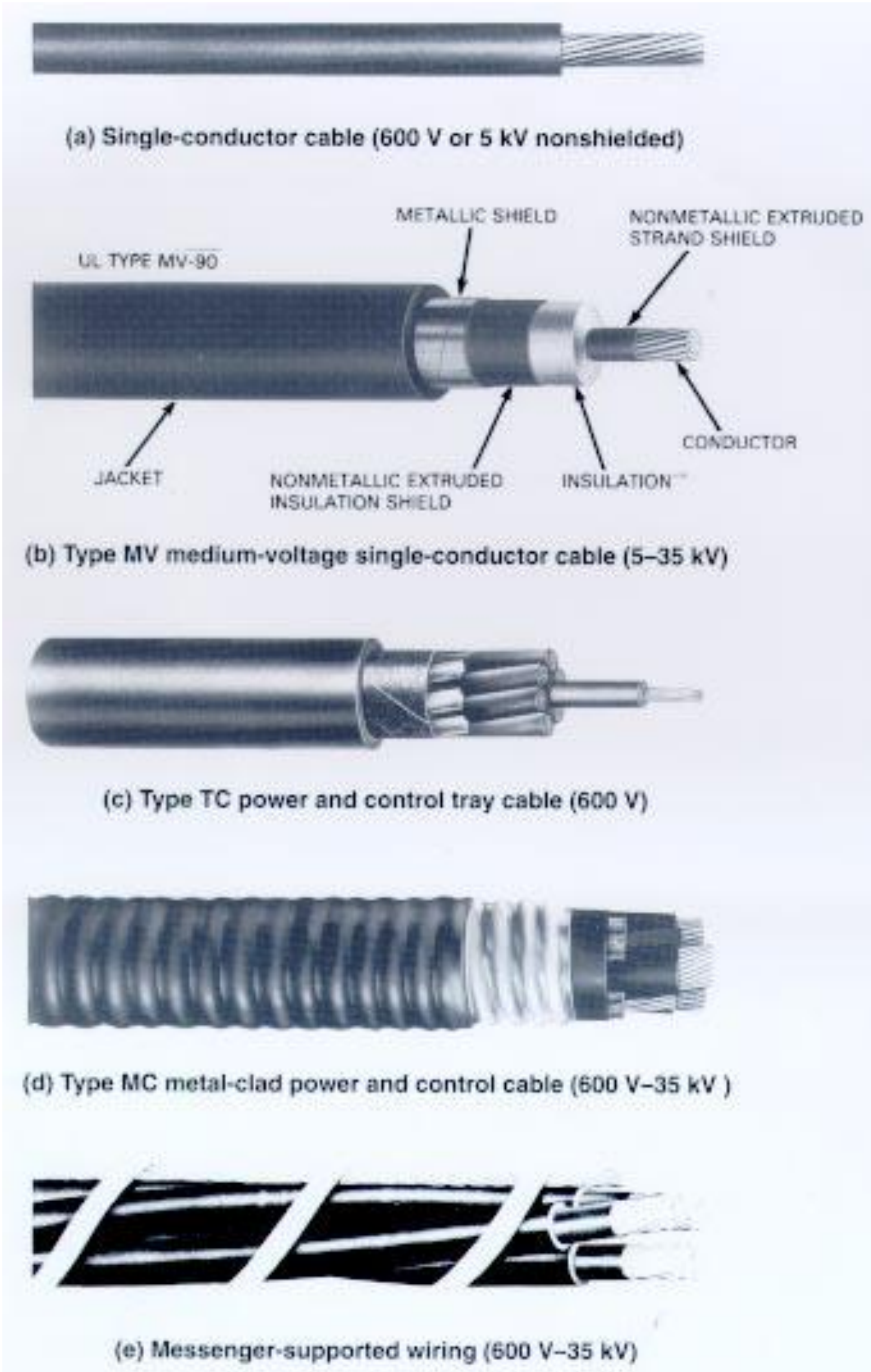



**Figure 5: Sheathed Cable Variations**

## 12.8 Industry Codes and Standards

Location classification requirements for electrical equipment

### 12.8.1 American Petroleum Institute (API)

- **API RP 540:** Electrical Installations in Petroleum Processing Plants
- **API RP 14F:** Design, Installation, and Maintenance of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class 1, Division 1 and Division 2 Locations
- **API 14FZ:** Recommended Practice for Design and Installation of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class I, Zone 0, Zone 1 and Zone 2 Locations

### 12.8.2 National Fire Protection Association (NFPA)

- **NFPA 70:** National Electrical Code (NEC)
- **NFPA 496:** Standard for Purged and Pressurized Enclosures for Electrical Equipment
- **NEMA ICS 2:** Industrial Control and Systems Controllers, Contactors and Overload Relays Rated 600 Volts

## 12.9 Materials of Construction

Packaged unit skids are typically designed to be contained within a frame that allows the system to be easily transported. Skid frames allow equipment to be layered. Tanks, piping, and process equipment fit into a smaller footprint built within the frames. Skids are designed for accessibility, usually including a center walk way, and major pieces of equipment placed around the edge of the frame.

### 12.9.1 Electrical

Inspection testing of electrical systems for unitized unenclosed equipment packages may include the following:

- Electrical enclosures
- Motors, motor controllers
- Heaters
- Relays
- Controls and control panels
- Control stations
- Pilot devices
- Indicating lights
- Transformers
- Wires

- Conduits

### 12.9.2 Instrumentation

Inspection testing of components supplied by the packaged unit vendors will include:

- Field instruments
- Pre-wired field interfaces
- Plant control system interfaces

## 12.10 Inspection and Testing

The electrical tests are performed to ensure correct operation of the packaged equipment. All testing is performed in accordance with industry standards and specific requirements of the purchase order. For example, PIP ELSP01 section 4.18 Inspection and Testing for Packaged Electrical Equipment.

Unless otherwise specified on the purchaser’s Data Sheet, the purchaser or their representative reserves the right to witness all packaged unit testing.

The testing to be performed shall consist of, but not be limited to, the following:

- All circuits and equipment shall be tested for grounds, short-circuits, and proper functioning.
- Insulation resistance and continuity tests shall be performed on all feeders, motor leads, and control wiring.
- A test shall be performed between conductors and ground.
- Interlocking, control, and instrumentation wiring for each item or system shall be tested to ascertain that the system will function as indicated on the wiring or schematic diagrams, description of operation, etc.
- Manual operation of control devices, such as limit switches, shall be used to simulate actual operating conditions in the testing of the system.
- For supplier-furnished motor starters, the ampere rating of all fuses including control fuses, circuit breakers, and thermal overload elements for motors shall be checked, adjusted, and corrected if necessary.
- Motors shall be checked for proper operation.
- Any misalignment shall be corrected before shipment.

Test results shall be documented and provided to the purchaser upon request.

## 12.11 Final Inspection and Shipping Preparations

Packaged Equipment final inspection typically consists of the following items:

- Resolution of all FAT issues.
- All final manufacturing/drawing issues closed.
- Manufacturer’s QC checkout signed off.

- Assembly/Packaging/Shipping
- Visual inspection of packaging requirements.

# 13.0 Liquid-Immersed Transformers

## 13.1 Basic Transformer Knowledge

A transformer is an electrical device used to convert AC power at a certain voltage level to AC power at a different voltage level, but at the same frequency. Transformers transforms electrical energy from one circuit to another without any direct electrical connection. This is possible because of mutual induction between two windings.

In theory, when an alternating electric voltage flows through a coil, it generates a magnetic field or “flux.” The strength of the magnetism or “magnetic flux density” is directly related to the magnitude of the voltage. The larger the voltage, the stronger the magnetic flux.

When a magnetic field fluctuates around a wire winding, it generates a voltage in the winding. If there is a second winding in close proximity, the magnetic flux generated by one winding generates a voltage in the second winding. The voltage in the first winding is usually called the primary voltage and the voltage in the second winding is the secondary voltage.

Figure 6 illustrates primary and secondary winding passing electric current through empty space from one winding to another.

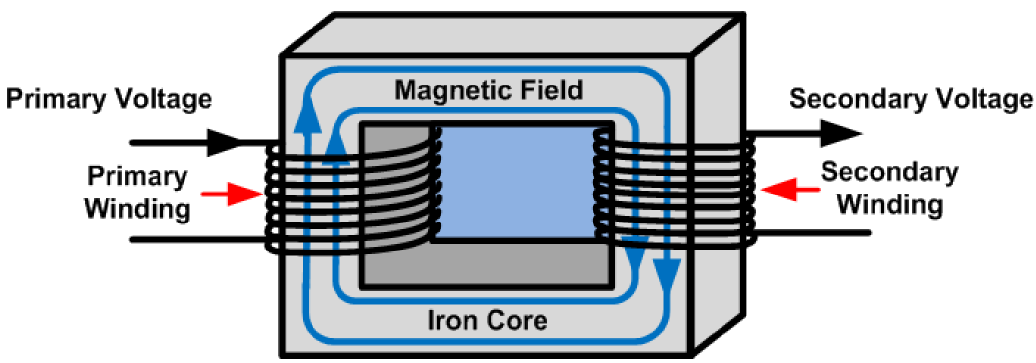



**Figure 6: Transformer Primary and Secondary Windings**

Figure 6 also shows electromagnetic induction because the voltage in the primary winding causes or "induces" a voltage in the secondary winding. Electrical energy transfers more efficiently from one winding to the other by wrapping them around a soft iron bar called a core. Notice that the two coil windings are not electrically connected but are only linked magnetically. A single-phase transformer can operate to either increase or decrease the voltage applied to the primary winding. When a transformer is used to increase the voltage on its secondary winding with respect to the primary, it is called a “Step-up transformer.” When it is used to decrease the voltage on the secondary winding with respect to the primary it is called a “Step-down transformer.”

The difference in voltage between the primary and the secondary windings is calculated with the ratio of coil turns in the primary winding ($N_P$) compared to the number of coil turns on the secondary winding ($N_S$). As the transformer is basically a linear device, a ratio exists between the number of turns of the primary coil divided by the number of turns of the secondary coil. This ratio, called the ratio of transformation, more commonly known as a transformer's "turn ratio", (TR). This turn ratio value dictates the operation of the transformer and the corresponding voltage available on the secondary winding.

The voltage at the secondary winding is directly related to the primary voltage by the turn ratio, or the number of turns in the primary winding divided by the number turns in the secondary winding. For instance, if the primary winding consists of 100 turns and a secondary winding consists of 25 turns, the turn ratio is then: 4:1. See Figure 7: Winding Ratio.

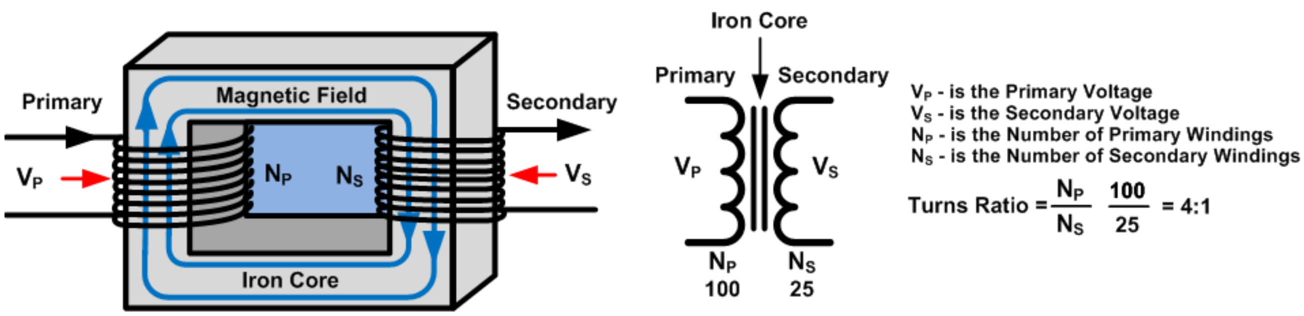



**Figure 7: Winding Ratio**

The turn ratio, which has no units, compares the two windings in order and is written with a colon, such as 4:1 (4-to-1). In the example, there are 4 volts on the primary winding there will be 1 volt on the secondary winding, 4 volts-to-1 volt. If the ratio between the numbers of turns changes the resulting voltages must also change by the same ratio.

The ratio of the primary to the secondary, the ratio of the input to the output, and the turn ratio of any given transformer will be the same as its voltage ratio. In other words for a transformer: "turn ratio = voltage ratio". The actual number of turns of wire on any winding is generally not important, just the turns ratio and this relationship as displayed in Figure 8:

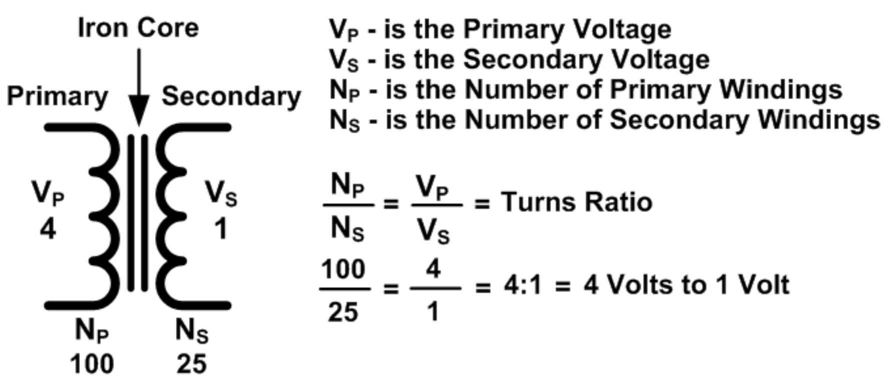



**Figure 8: Ratio Formula**

The ratio result simply means there are 4 primary windings for every one secondary winding. Utilizing the 4:1 ratio and applying 480V to the primary winding resulting in secondary voltage of 120V displayed in Figure 9.

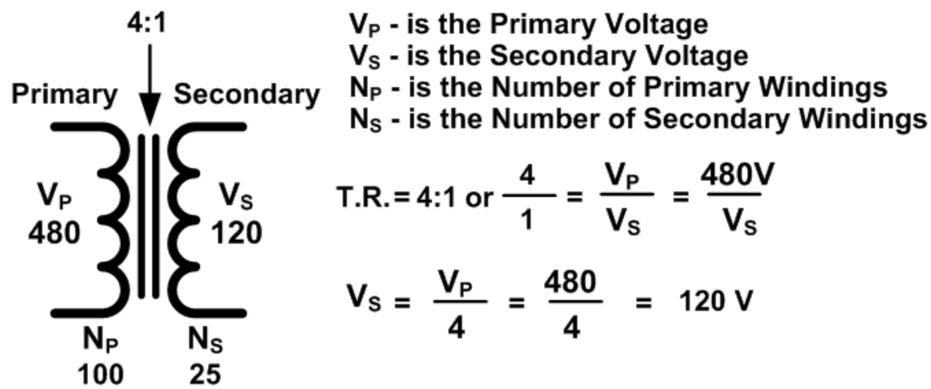



**Figure 9: Calculated Voltage Illustration**

## 13.2 Basic Construction

Transformers are ground mounted electric power distribution transformer in a locked steel cabinet mounted on a concrete pad. A single transformer may serve one large industrial building or residential homes. Since all energized connection points are securely enclosed in a grounded metal housing, a pad mount transformer can be installed in an indoor substation or on a bottom floor of a commercial building.

Typically, pad mount transformers are used with underground electric power distribution lines at service drops, to step down the primary voltage on the main utility line to a lower secondary voltage supplied to a specific load.

Pad mount transformers vary throughout the industry. The basic construction of a transformer begins with the core. The core provides the path to channel the magnetic flux density utilizing thin strips of high-grade steel called laminations, which are electrically separated by a thin coating of insulating material. Iindividual laminations are stamped or punched out from larger steel sheets and formed into strips of thin steel resembling the letters E, L, U, and I as shown in Figure 10.

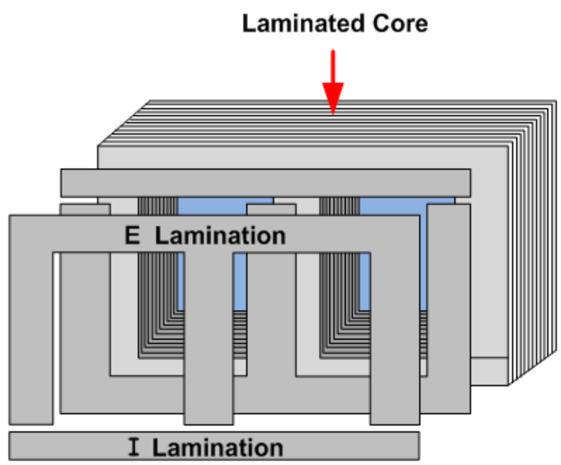


**Figure 10: Transformer Core Laminations**

The strips can be stacked or wound, with the windings either built integrally around the core or built separately and assembled around the core sections. Core steel can be hot or cold-rolled, grain-oriented or non-grain oriented, and even laser-scribed. The core cross section can be circular or rectangular. Circular cores are commonly referred to as cruciform construction. Rectangular cores are used for smaller ratings and as auxiliary transformers used within a power transformer. Rectangular cores use a single width of strip steel, while circular cores use a combination of different strip widths to approximate a circular cross-section. The type of steel and arrangement depends on the transformer rating as related to cost factors such as labor and performance.

While the steel and coating may be capable of withstanding higher temperatures, it will come in contact with insulating materials with limited temperature capabilities. In larger units, cooling ducts are used inside the core for additional convective surface area, and sections of laminations may be split to reduce localized losses.

The core is held together and insulated from mechanical structures and is grounded to a single point in order to dissipate electrostatic buildup. The core ground is usually accessible inside the tank or outside the tank wall.

There are two basic types of core construction used in power transformers: core form and shell form. In core-form construction; there is a single path for the magnetic circuit. Single-phase applications windings are typically divided on both core legs. Below displays a diagram of a single-phase core type, with the arrows showing the magnetic path. See Figure 11 and Figure 12 for more information.

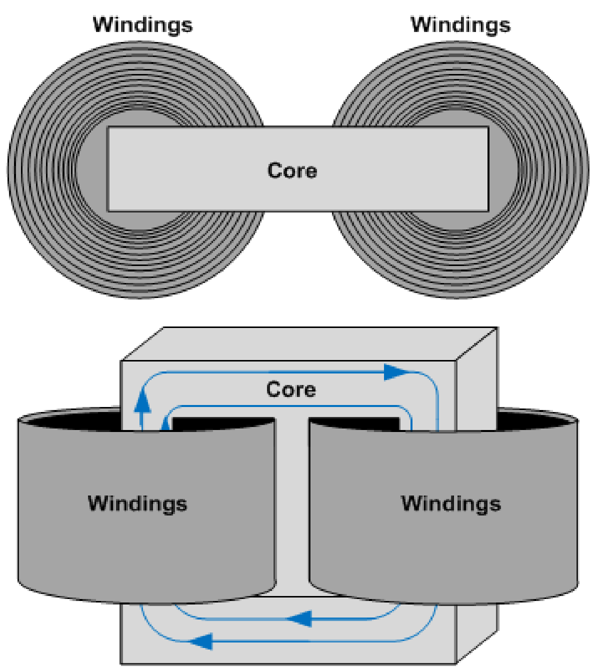



**Figure 11: Single-phase core-form construction**

In three-phase applications, the windings of a particular phase are typically on the same core leg. Windings are constructed separate of the core and placed on their respective core legs during core assembly utilizing an E assembly typically used by a three-phase core-form transformer.

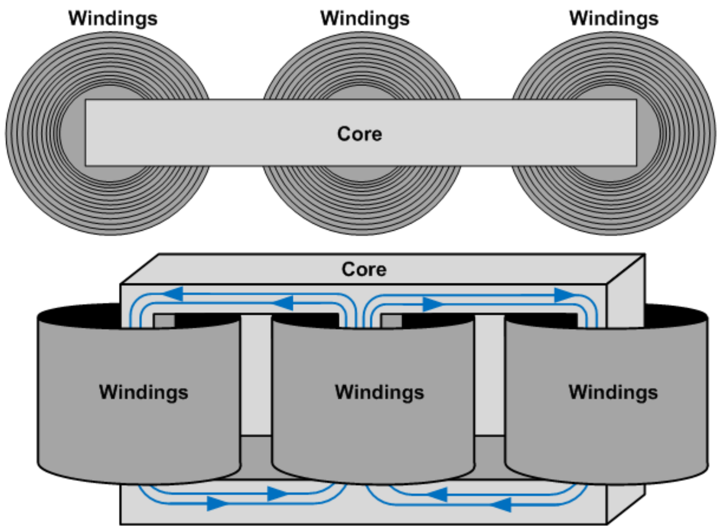



**Figure 12: Three-phase core-form construction**

Shell-form construction cores provide multiple paths for the magnetic circuit. Single-phase shell-form cores have two magnetic paths. The core is typically stacked directly around the windings, although some applications are such that the core and windings are assembled similar to core form. Due to short-circuit and transient-voltage performance, shell forms tend to be used more frequently in the largest transformers, where conditions can be more severe. Variations of three-phase shell-form construction include five- and seven-legged cores, depending on size and application.

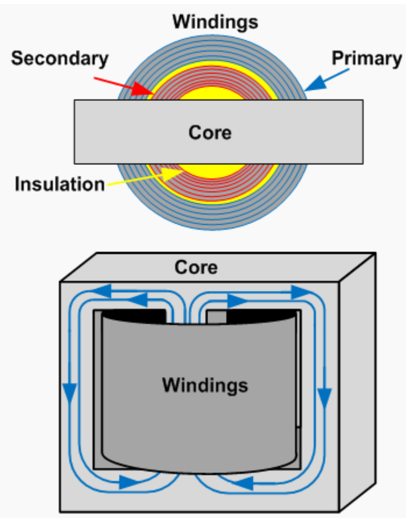



**Figure 13: Single-phase Shell-form Construction**

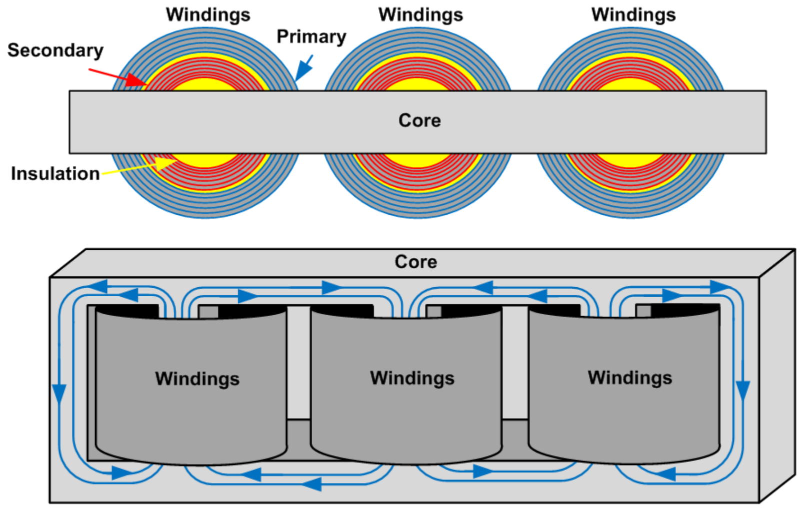



**Figure 14: Three-phase Shell-form construction**

## 13.3 Design and Construction

This portion of the study guide defines some of basic requirements for three-phase liquid-immersed distribution, power and regulating transformers.

IEEE C57.12.36 covers certain electrical, dimensional, and mechanical characteristics of 50 Hz and 60 Hz, two winding, liquid-immersed distribution substation transformers. Such transformers may be remotely or integrally associated with either primary and secondary switchgear or substations, or both, for step-down or step-up purposes rated as follows:

- 112.5 kVA through 10,000 kVA three-phase
- 250 kVA through 6667 kVA single-phase
- High voltage 69,000 V and below and low voltage 34,500 V and below

### 13.3.1 Rating Data

Per IEEE C57.12.00 section 5.1, Transformers shall be identified according to the cooling method employed. For liquid-immersed transformers, this identification is expressed by a four-letter code, described as follows. These designations are consistent with IEC 60076-2: 1993 [B12].

First letter: Internal cooling medium in contact with the windings:

| | |
|---|---|
| O | Mineral oil or synthetic insulating liquid with fire point 300°C |
| K | Insulating liquid with fire point > 300°C |
| L | Insulating liquid with no measurable fire point |

Second letter: Circulation mechanism for internal cooling medium:

N Natural convection flow through cooling equipment and in windings

F Forced circulation through cooling equipment (i.e., coolant pumps), natural convection flow in windings (also called non-directed flow)

D Forced circulation through cooling equipment, directed from the cooling equipment into at least the main windings

Third letter: External cooling medium:

A Air

W Water

Fourth letter: Circulation mechanism for external cooling medium:

N Natural convection

F Forced circulation [fans (air cooling), pumps (water cooling)]

#### 13.3.2 Rated Kilo Volt-Amperes

The rated kilovolt amperes of a transformer shall be the output that can be delivered for the time specified at rated secondary voltage and rated frequency without exceeding the specified temperature-rise limitations under prescribed conditions of test, and within the limitations of established standards.

#### 13.3.3 BIL: Basic impulse level

##### 13.3.3.1 Insulation Levels

Transformers shall be designed to provide coordinated low-frequency and impulse insulation levels on line terminals, and low-frequency insulation levels on neutral terminals. The primary identity of a set of coordinated levels shall be its basic impulse level (BIL). The system voltage and the type of transformer may also influence insulation levels and test procedures. In this regard, power transformers are separated into two different classes as follows:

- Class 1 power transformers shall include power transformers with high-voltage windings of 69 kV and below.
- Class 2 power transformers shall include power transformers with high-voltage windings from 115 kV through 765 kV.

#### 13.3.4 Bushings

Transformers shall be equipped with bushings with an insulation level not less than that of the winding terminal to which they are connected, unless otherwise specified.

### 13.4 Industry Codes and Standards

The SI should be familiar with the following codes and or standards prior to performing source inspection activities for:

- **ANSI/IEEE C57.12.00:** General Requirements for Liquid Immersed Distribution, Power and Regulating Transformers.
- **ANSI/IEEE C57.12.26:** Standard for Transformers Pad-Mounted, Compartmental-Type, Self-Cooled, Three-Phase Distribution Transformers for Use with Separable Insulated High-Voltage Connectors, High-Voltage, 34,500 Grd Y/19,920 Volts and below; 2,500 kVA and Smaller.
- **ANSI/IEEE C57.12.28:** Pad-mounted Equipment-Enclosure Integrity.
- **ANSI/IEEE C57.12.36:** Standard Requirements for Liquid-Immersed Distribution Substation Transformers
- **ANSI/IEEE C57.12.90**: Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers and Guide for Short-Circuit Testing of Distribution and Power Transformers.
- **NEMA TR1:** Transformers, Regulators and Reactors
- **ASTM D3487**: Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus.
- **IEC 60296**: Specification for New Insulating Oils for Transformers and Switchgear.

These codes are not inclusive of all transformer equipment.

## 13.5 Test and Inspections

Following are typical inspection points that would be on the S/V inspection checklist:

Visual and Mechanical:

- Compare equipment nameplate data with drawings and specifications
- Inspect physical and mechanical condition
- Inspect anchorage, alignment, and grounding
- Verify the presence of PCB content labeling
- Verify the bushings are clean
- Verify that alarm, control, and trip settings on temperature and level indicators are as specified
- Verify operation of alarm, control, and trip circuits from temperature and level indicators, pressure relief device, gas accumulator, and fault pressure relay, if applicable
- Verify that cooling fans and pumps operate correctly and have appropriate over-current protection
- Inspect bolted electrical connections for high resistance using a low-resistance ohmmeter
- Verify tightness of accessible bolted electrical connections by calibrated torque-wrench in accordance with manufacturer's published data, UL

requirements, or component-specific instructions that may be noted directly on the component

- Verify correct liquid level in tanks and bushings if applicable
- Verify that positive pressure is maintained on gas-blanketed transformers
- Perform inspections and mechanical tests as recommended by the manufacturer
- Bill of Material – Drawing Review
- One-line Wiring Diagram Review
- Test equipment within calibration date verification
- Insulation capacitance and power factor
- Voltage, ratio, and phase relationship, winding resistance
- Winding/core ground.
- Insulation
- Load loss, no-load loss
- Impedance, zero-seq. impedance
- Applied voltage
- Induced voltage
- Impulse test
- Power dielectric tests
- Control cabinet functional tests, gauges, etc.
- Special tests: sound level, temperature, SFRA, etc.

### 13.6 Final Inspection and Shipping Preparations

Transformer final inspection typically consists of the following items:

- Resolution of all FAT issues.
- All final manufacturing/drawing issues closed.
- Manufacture's QC checkout signed off.
- Assembly/Packaging/Shipping.
- Visual inspection of packaging requirements.

## 14.0 Switchgear (Low & Medium Voltage)

### 14.1 Basic Switchgear Knowledge

Switchgear is a general term that describes switching and interrupting devices, either alone or in combination with other associated control, metering, protective, and regulating equipment, which are assembled in one or more sections.

A power switchgear assembly consists of a complete assembly of one or more of the above noted devices and main bus conductors, interconnecting wiring, accessories, supporting structures, and enclosure. Power switchgear is applied throughout the electric power system of an industrial plant, but is principally used for incoming line service and to control and protect load centers, motors, transformers, motor control centers, panel boards, and other secondary distribution equipment.

The main task of low and medium-voltage switchgears is to provide power distribution. Both primary and secondary distribution production centers are used in the world today. Primary electric power systems are a network of electrical components that supply, transmit and use electric power. An example of a primary electric power system is the network that supplies a region's homes with power. These power systems are known as grids.

Secondary power systems are found in industry and large commercial buildings. The majorities of these systems rely upon three-phase AC power and is the standard for large-scale power transmission and distribution across the modern world.

Electrical designs for larger commercial systems are rated for load flow, short-circuit fault levels, and voltage drop for steady state loads and during the starting of large motors. Industry standards are followed by manufacturers to assure proper equipment and conductor sizing of protective devices have minimal disruption caused when a fault is cleared.

This study guide primarily focuses on secondary low and medium voltage commercial installations that contain switchgears. Switchgears generally have an orderly system of sub-panels, separate from the high voltage primary utility power distribution centers. Separate secondary distribution allows for better system protection and more efficient electrical installations. Figure 15 depicts a basic power flow path from the primary utility power down to a 3 phase induction motor.

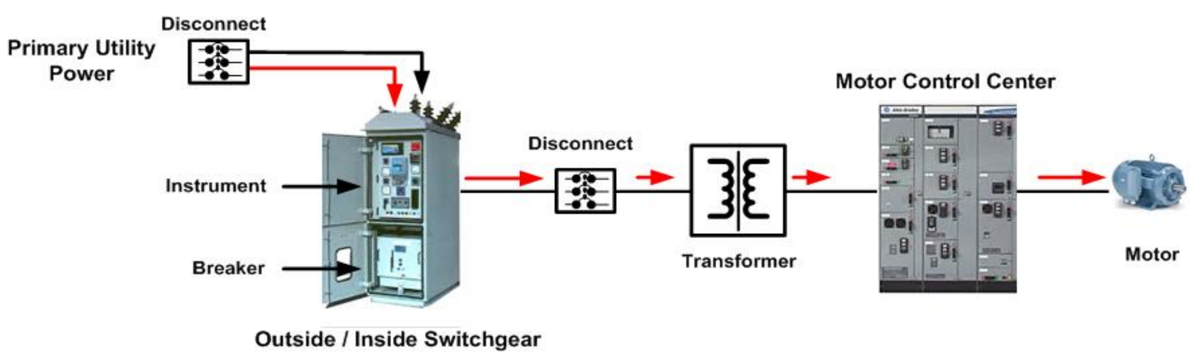



**Figure 15: Basic Power Flow Path from Source to Induction Motor**

MC switchgears are compartmentalized structures with electrical mechanical operated circuit breakers. Individual compartments isolate all components such as instrumentation, main bus, and both incoming and outgoing connections with grounded metal barriers.

Metal enclosed switchgears also contain associated control, instruments, metering indicators, relaying, protective, and regulating devices, as necessary and defined by the purchaser. Certain service conditions, ratings, temperature limitations and classification of insulating materials are also defined to withstand voltage requirements.

Metal-enclosed switchgear equipment is arranged with primary and secondary compartments in the front of the equipment. Generally, primary compartments may contain either a draw-out circuit breaker or interior auxiliary equipment, such as voltage or control power transformers, located behind a front panel. The front panel door can be used for relays, instruments, and similar devices. Primary compartment front panels may be opened to provide access to the circuit breaker or interior auxiliary equipment while the secondary compartment front panel provides access to secondary control equipment. Manufactures offer many different compartment configurations based on the purchasers application.

## 14.2 Design and Construction

Refer to IEEE C37.20.1 for metal-enclosed low-voltage power circuit breaker switchgear—which contains either stationary or draw-out, manually or electrically operated low-voltage ac or dc power circuit breakers in individual metal compartments, in three-pole, four-pole, two-pole, or single-pole construction.

## 14.3 Ratings

The ratings of a switchgear assembly are designations of operating limits under normal (usual) service conditions. Where the switchgear assembly comprises a combination of primary and secondary circuits, each may be given ratings. Low-voltage switchgear shall have the following ratings:

- rated maximum voltage;
- rated power frequency;
- rated insulation level;
- rated continuous current;
- rated short-time withstand current;
- rated short-circuit withstand current.

## 14.4 Interlocks

Mechanical interlocks are provided in LV switchgears to prevent moving the circuit breaker to or from the connected position when the circuit breaker is in the closed position. To prevent closing the circuit breaker unless the primary disconnecting devices are in full contact or are separated by a safe distance. Circuit breakers equipped with stored energy mechanisms are designed to prevent the release of the stored energy unless the mechanism has been fully charged. Operators and service personnel shall be protected from the effects of accidental discharge of the stored energy by any of the following means:

- Interlocks provided in the housing to prevent the complete withdrawal of the circuit breaker from the housing when stored energy mechanism is charged.
- A suitable device provided to prevent the complete withdrawal of the circuit breaker until the closing function is blocked.

- A mechanism is provided to automatically discharge the stored energy during the process of withdrawing the circuit breaker from the housing.
- Mechanisms as described above are not required provided the stored energy mechanism and contact assembly are located within the circuit breaker element and not accessible except by removable of barriers, guards, or covers.

## 14.5 LV Switchgear Grounding

Circuit connections to a ground bus or continuity bus for LV DC switchgear are made so that it is not necessary to open-circuit the ground bus to remove any connection made to the ground bus. Connections to ground or to a continuity bus are provided for all removable elements so that the frame and mechanism are grounded until the primary circuit is disconnected and the removable element is moved a safe distance. When mounted on metal switchgear structures, cases of instruments, instrument transformers, meters, relays, and similar devices shall be considered as being adequately grounded (or bonded to the continuity bus, if applicable) when secured to these structures by metal mounting hardware with adequate provision for penetrating the paint film. When devices are door-mounted, the door shall be bonded to the main structure. The bonding impedance shall be not greater than 0.100 Ω between the metal door and the grounding bus (or continuity bus, if applicable) when measured with a dc current of at least 30 A.

## 14.6 LV AC Switchgear Grounding

The ground bus shall be included in the switchgear and run entire length of the assembly. The ground bus electrically connects together the structures in a switchgear assembly in or on which primary equipment or devices are mounted. At all points of connection between a ground bus and the assembly, any nonconductive coatings, such as paint, shall be removed or penetrated to provide good electrical contact.

The ground bus for each group of vertical sections shall have facilities for connection to a station ground (ground grid) by suitable conductors.

## 14.7 Wiring

Flame-resistant, 600 V insulated stranded copper wire shall be used for internal wiring between components of switchgear assemblies, and to terminals for connection to external controls, metering or instrumentation. All wire used to connect instruments, meters, relays or other components directly to the main power circuit of ac or dc switchgear, shall have an insulation rating equal to or greater than the maximum voltage of the assembly and subject to the High Potential (Hipot)/Dielectric Withstand Test as discussed in 9.4.3 of this study guide.

## 14.8 Housing Frames and Enclosure Compartment

The frame assembly is braced with reinforcing gussets, as required, to assure rectangular rigidity. Metal enclosures are steel with all exposed parts painted and fabricated from the gauge required by NEMA and IEEE Standards. Adequately spaced holes are provided for connecting adjacent compartment structures to ensure proper alignment and to allow for future additions. The equipment sections are configured to provide an arc resistance enclosure with the ability to have all cable terminations located near the front of the equipment with suitable clearances and bending radius for the cable type and termination types specified.

The cable compartment and current transmitters are accessible from the front of the compartment. Doors, covers, and infrared windows require UL and CUL/CSA rating if arc resistant equipment is supplied. Arc plenum ducting connections provides the exit of gases resulting from an internal arc.

UL, IEEE, and NEMA standards require individual bus compartments with circuit breakers, buses, & cable terminations to be properly isolated with steel partitions or barriers of approved and tested materials.

### 14.9 Switchgear Section Compartments

Typical individual switchgear sections comprise of individual compartments. An individual compartment may contain a Voltage Transformer (VT); Circuit Breaker, Control Power Transformer (CPT) or Low Voltage (LV) control instrumentation. Each compartment has individual circuit breakers (active or spare) for troubleshooting and isolation of LV switchgear components.

### 14.10 Switchgear Compartment Doors

Doors permit convenient removal and interchanging of the circuit breakers between cubicles. The doors are capable of a swinging 180 degrees. Purchasers sometimes require doors equipped with infrared windows for circuit breaker compartment. Infrared windows require blast proof certifications. Each door has suitable handles for opening and heavy duty hinges are required for arc resistant rating.

### 14.11 Bus Compartment

The bus bar compartment is fully insulated and totally encloses the buses within the bus compartment of the switchgear. Bus bars and interconnections are typically silver plated copper buses, rated and tested for the amperage required by the purchaser and shown on the drawings. The current rating of the circuit bus is never less than the main incoming circuit breaker. Rated frequency is specified by the purchaser. Buses are mounted on spaced insulators and braced to withstand the available short circuit currents.

### 14.12 Circuit Breakers

Switchgear circuit breakers are electro-mechanically operated switches designed to protect an electrical circuit from damage caused by overload or short circuit. The basic function of a complete switchgear and circuit breaker assembly is to detect a fault condition and interrupt current flow.

The circuit breaker mainly consists of fixed contacts and moving contacts. In normal "on" condition of circuit breaker, these two contacts are physically connected to each other due to applied mechanical pressure on the moving contacts. There is stored potential energy in the operating mechanism of circuit breaker which is realized if a switching signal is given to the breaker. The potential energy can be stored in the circuit breaker by different ways, metal spring, compressed air, or by hydraulic pressure. Whatever the source of potential energy, it must be released during operation.

All circuit breakers have operating coils (tripping coils and close coil). These coils are energized by a switching pulse which displaces the plunger inside them. This operating coil plunger is typically attached to the operating mechanism of circuit breaker. As a result, the mechanically stored potential energy in the breaker mechanism is released in the form of kinetic energy, which makes the contact move.

MV circuit breakers are typically designed in accordance with IEEE C37.04, NEMA C37.06.1 and NEMA SG-4. Breakers that have the same ratings are interchangeable with other breakers in the switchgear line-up; however, safeguards are in place to prevent the substitution of a lower rated breaker when a higher rating is required (i.e. A 2000 amp breaker can be substituted for a 1200 amp breaker but a 1200 amp breaker cannot be substituted for a 2000 am breaker).

## 14.13 Electric Tie Breakers

Redundant source switchgear systems with bus tie breakers between the sources are used and designed for reliable electrical systems. Tie breakers are normally open so that if one source fails, the tie can be closed and the other source utilized for the entire load. Other uses of the main-tie-main arrangement include redundant service to each load from two different sources and also splitting loads between the two sources so that the main electrical distribution equipment can be serviced without disruption of service to the critical load.

Tie breakers are typically in designed in accordance with IEEE C37.04, NEMA C37.06.1 and NEMA SG-4. Breakers that have the same ratings are inter-changeable with other breakers in the switchgear line-up; however, safeguards are in place to prevent the substitution of a lower rated breaker when a higher rating is required.

## 14.14 Current Transformers

A current transformer (CT) is used for measurement of alternating electric currents. Current transformers, together with voltage (or potential) transformers (VT or PT), are known as instrument transformers. When current in a circuit is too high to apply directly to measuring instruments, a current transformer produces a reduced current accurately proportional to the current in the circuit, which can be connected to measuring and recording instruments. A current transformer isolates the measuring instruments from the medium voltage in the switchgear circuit. The (CT) is commonly used in metering and protective relay circuitry that trips the Circuit breakers in the event of overload or short circuit.

CT ratios are defined by the purchaser and shown on the drawings. Accuracies shall be coordinated with the associated relays and meters by the switchgear manufacturer to assure proper operation at the selected pick up and operating current ratings. Current transformers are mounted over the circuit breaker connections to the main (line) bus and are able to be replaced from the front of the equipment without major disassembly of the circuit breaker compartment.

## 14.15 Voltage Transformers

Voltage transformers (VT) are typically used to provide various transmission and utilization voltage levels. VTs should be designed and constructed in accordance with ANSI C57 standards as a minimum. In addition to VTs, small control transformers are frequently utilized in control circuits. Instrument transformers, both VTs and CTs are frequently utilized for instrumentation circuits.

A VT is a general purpose step down transformer. The primary of this transformer is connected across the phase and ground. VT has a lower turns winding at its secondary. The system voltage is applied across the terminals of primary winding of the transformer, and then proportional secondary voltage appears across the secondary terminals of the VT.

A switchgear VT is typically encapsulated in a draw-out cabinet which is protected by primary current-limiting fuses.

The VT ratios and accuracies are coordinated with associated relays and meters by the switchgear manufacturer.

## 14.16 Control Power Transformers

A Control Power Transformer (CPT) is used in switchgear to step down medium circuit voltage to a lower voltage which is then used to operate the control or switching components of the main circuit. These devices are commonly used in Switchgears that have large Motor breakers with starter circuits. The main circuit voltage is not suitable for use in the control circuit and a separate control circuit feed would not be practical.

Switchgear CPT is encapsulated, draw-out, and disconnect type that is protected by primary current-limiting fuses.

The (CPT) ratings of the transformer are indicated on the drawing.

## 14.17 Metering

Main incoming voltage metering is typically monitored by an analog or digital instrument meter for each switchgear assembly. This metering displays a voltage indication of all three phases, not necessarily all at once, of each main circuit bus of the switchgear. ANSI/NEMA C39.1 mandates that these meters not require control power to function. Meters are located on the door of a low voltage compartment.

## 14.18 Test and Inspections

The switchgear must meet all applicable engineering and workmanship standards and specifications listed in the purchasing document. All components are verified against engineering documentation to be present and correctly installed. The SI should confirm that prior to factory acceptance testing (FAT), the S/V (FAT) procedure and checklist has been submitted and agreed to by the purchaser. This procedure and checklist becomes the basis for the final acceptance testing. Typically the SI would observe the testing and confirm that the tests were performed per the procedure and the results of the test are correctly stated in the checklist.

Following are typical Inspection points that would be on the S/V Inspection checklist:

- Warning labels and nameplates must be present and in their specified positions to advise personnel of possible hazards.
- Ensure correct engraving of unit and master nameplates.
- Isolation barriers must be in place within the cabinet. These barriers protect personnel from touching live medium voltage components in an area that otherwise does not have power supplied to it.
- Operations of isolation switch handle (if supplied) and door interlocks must be verified. The interlocking prevents the opening of any medium voltage door on a medium voltage cabinet when the isolation switch handle has been moved to the full on position.
- One-line Wiring Diagram Review.
- Test equipment within calibration date verification.
- Continuity check – all circuits.
- Mechanical operation of all control circuits.
- Power dielectric tests.
- Control wiring insulation test.
- Primary bus insulation test.
- Hi-Pot dielectric withstand test shall be performed on all bus work and medium voltage cables from phase-to-phase & phase-to-ground (except solid-state components, low voltage controls, & instrument transformers).
- The voltage level used for this test depends on the product's nominal AC voltage. Component devices shall be functionally operated in circuits as shown on electrical diagrams or as called for by specific test instructions.
- Instruments, meters, protective devices, and associated controls shall be functionally tested by applying the specified control signals, current, and/or voltages.
- Switchgear shall conform to the arrangements and details of the drawings and space designed for installation.
- Interlocking shall be provided as shown on the drawings and as required for the safety of Indicating instruments in accordance with ANSI C39.1.
- Relays and relay systems in accordance with IEEE C37.90.
- Instrument transformers in accordance with IEEE C57.13.
- The switchgear line-up shall be a complete, grounded, continuous-duty, metal clad, dead-front, dead-rear, self-supporting, front connected switch-gear assembly.
- Relays: Comply with IEEE C37.90, integrated digital type; with test blocks and plugs.

## 14.19 Final Inspection and Shipping Preparations

Switchgear final inspection typically consists of the following items:

- Resolution of all FAT issues.
- All final manufacturing/drawing issues closed.
- Manufacturer's QC checkout signed off.
- Assembly/Packaging/Shipping
- Visual inspection of packaging requirements.

# 15.0 Motor Control Centers (Low to Medium Voltage)

## 15.1 Basic Motor Control Center Knowledge

A motor control center (MCC) is an assembly of one or more enclosed sections having a common power bus and containing motor control units. Wherever motors are used, they must be controlled. There are many types of power distribution equipment, which are used with different load types; motor control centers primarily control the distribution of power to electric motors. This section only deals with the Medium to Low voltage MCC equipment. The most common type of AC motor control starter unit is full-voltage and non-reversing. This is often accomplished using a motor starter made up of a contactor and an overload relay.

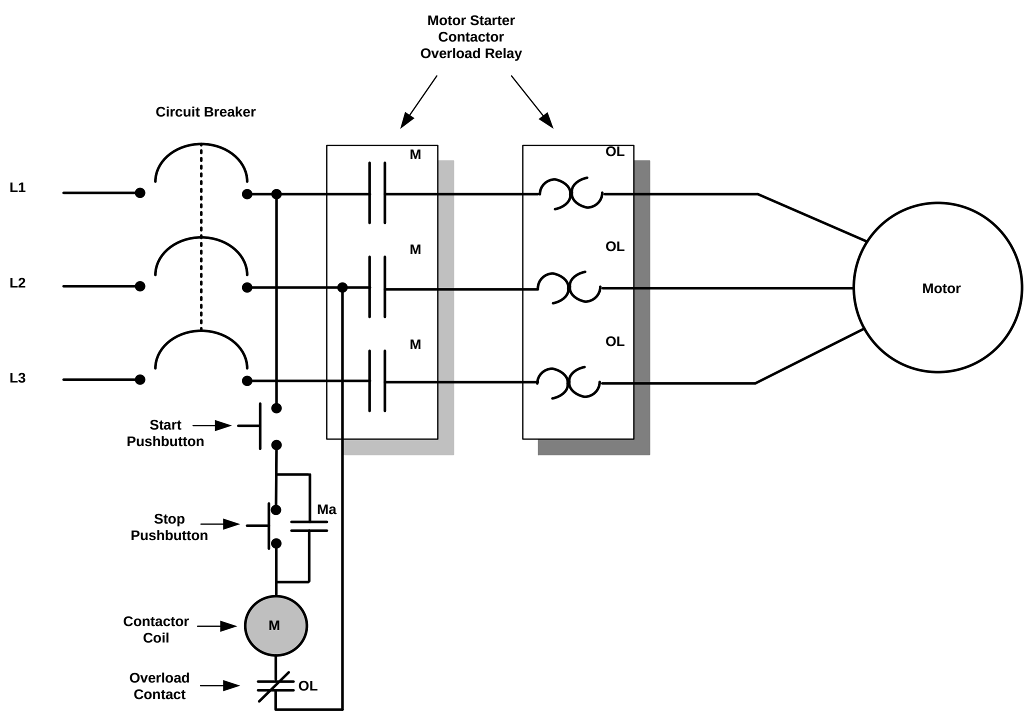



**Figure 16: Typical MCC**

The contactor's contacts are closed to start the motor and opened to stop the motor. This is done electromechanically and requires a local start and stop pushbutton. Other remote control devices are wired to control the contactor. The depiction below is an example of a Motor Control Center that controls AC Motors.

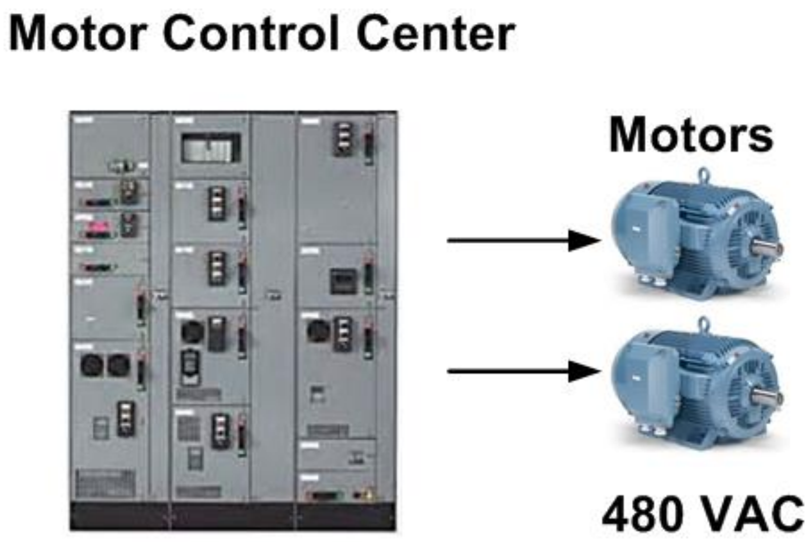



**Figure 17: Typical MCC Cubicle**

## 15.2 Design and Construction Standards

The SI should be familiar with the following codes and or standards prior to performing source inspection activities for Motor control centers:

- **ANSI/IEEE C37.20.7** - Guide for Testing Metal-Enclosed Switchgear Rated Up to 38 kV for Internal Arcing Faults.
- **NEMA ICS 3** - Industrial Control and Systems: Medium-Voltage Controllers 2001 to 7200 Volts AC.
- **UL 347**: Medium-Voltage AC Contactors, Controller, and Control Centers.

These codes are not inclusive of all MCC equipment.

## 15.3 Materials of Construction

Typically, Motor Control Centers are constructed in a standardized vertical enclosure with all the required relays, instruments, and controls. The MCC must have provisions to enable the center to be bolted together to form a rigid, free-standing assembly, and designed to permit bus extension for future controller additions to the left and/or the right. Typical medium voltage controllers are designed in two basic styles: 1-High: One medium voltage controller in one vertical section 2-High: Two medium voltage controllers in one vertical section. The structure is typically divided into three isolated compartments:

- Main power and ground bus compartment.
- Power cell compartment.
- Low voltage compartment.

- Metal or insulating barriers are provided between each vertical section between the low voltage compartment and the power cell and/or main power bus.
- Compartment, and between the power cell and main power bus compartment.

Each structure must have two non-removable base sill channels and removable lifting angles or brackets for ease of handling and installation.

### 15.4 Key items determine the MCC design:

- Enclosure type
- Bus material, Amp capability
- Main Feeder Cable Entry
- Control Cable
- Grounding Bus
- Main Isolating Switch
- Interlocking

### 15.5 Enclosures Types

- **Arc resistant Type 1:** Equipment with arc-resistant designs. Accessible front of the equipment only.
- **Arc resistant Type 2:** Equipment with arc-resistant designs. Accessible exterior (front, back, and sides) of the equipment only. Most common.
- **Arc resistant Type 1C:** Equipment with arc-resistant designs or features at the freely accessible front of the equipment only, plus the additional requirements of ANSI C37.20.7 Annex A, which are intended to reduce the collateral damage to adjacent compartments and equipment.

### 15.6 Circuit Breakers

Circuit breakers provide a method of energizing and de-energizing a circuit. One key advantage of a circuit breaker is that it allows a circuit to be reactivated quickly after a short circuit or overload is cleared by simply resetting the breaker.

### 15.7 Bus Material

- **Aluminum** bus material is commonly used in the industry. Aluminum is typically used to reduce costs and has different inspection requirements. Aluminum expands and contracts with different current loads. Thermal expansion causes gradual loosening of bolts and other fasteners. Thereby requiring special bus support fastening hardware used to connect the aluminum bus to the insulated bus supports. These fasteners must be properly tightened to the required torque specifications and inspected per the manufacturer's recommendations. In addition, due to its lower conductivity (relative to copper), aluminum bus must be larger to handle the same level of current.

- **Copper** bus material is commonly used in the industry also. Copper does not have the same thermal expansion of Aluminum and can be bolted to the bus supports with common hardware and has smaller dimensions based on current loads.

### 15.8 Amp Capacity

The amp capacity is the maximum amount of current that the main horizontal bus can accommodate without overheating. The minimum amp capacity of an MCC main horizontal bus is 600A. All busses will have nameplate indicating the Amp capacity.

The horizontal bus amp capacity specification is related to the vertical bus amp capacity. The minimum amp capacity of a vertical bus is 300A. The maximum amp capacity of an MCC horizontal bus is 3,200A and the maximum amp capacity of a vertical bus is 1,200A. If a group of loads requires more than 3,200A, two separately fed MCC line-ups are used.

### 15.9 Main Feeder Cable Entry Compartment

Purchasing specifications determine how the Main feeder cables will enter the MCC. Utility power cables that feed an MCC are typically large, feeder cable enter from overhead or underground and Inspection verification will eliminate difficult wire bends and/or costly field changes required to properly terminate an awkward cable feed.

Manufacturers can provide both types of feeds depending on the purchasing specification.

### 15.10 Ground Bus

A continuous bare copper ground bus must be provided along the entire length of the controller lineup. Each lineup shall be provided with a ground terminal or bus for connection to the station ground. The standard ground bus is bare copper.

### 15.11 Main Isolating Switch

The Main Isolating Switch is used to safely isolate contactor compartment from the main bus. It is manually operated from the front with door closed to avoid inadvertent operation.

### 15.12 Test and Inspections

The MCC must meet all applicable engineering and workmanship standards and specifications listed in the purchasing document. All components are verified against engineering documentation to be present and correctly installed. The SI should confirm that prior to factory acceptance testing (FAT), the S/V (FAT) procedure and checklist have been submitted and agreed to by the purchaser. This procedure and checklist becomes the basis for the final acceptance testing. Typically the SI would observe the testing and confirm that the tests were performed per the procedure and the results of the test are correctly stated in the checklist.

Following are typical Inspection points that would be on the S/V Inspection checklist:

- Warning labels and nameplates must be present and in their specified positions to advise personnel of possible hazards.
- Ensure correct engraving of unit and master nameplates.
- Isolation barriers must be in place within the cabinet. These barriers protect personnel from touching live medium voltage components in an area that otherwise does not have power supplied to it.
- Operations of isolation switch handle (if supplied) and door interlocks must be verified. The interlocking prevents the opening of any medium voltage door on a medium voltage cabinet when the isolation switch handle has been moved to the full on position.
- One-line Wiring Diagram Review.
- Test equipment within calibration date verification.
- Continuity check – all circuits.
- Mechanical operation of all control circuits.
- Power dielectric tests.
- Control wiring insulation test.
- Primary bus insulation test.
- Hi-Pot dielectric withstand test shall be performed on all bus work and medium voltage cables from phase-to-phase and phase-to-ground (except solid state components, low voltage controls, and instrument transformers). The voltage level used for this test depends on the product's nominal AC voltage.
- Component devices shall be functionally operated in circuits as shown on electrical diagrams or as called for by specific test instructions.
- Instruments, meters, protective devices, and associated controls shall be functionally tested by applying the specified control signals, current, and/or voltages.

### 15.13 Final Inspection and Shipping Preparations

Motor Control final inspection typically consists of the following items:

- Resolution of all FAT issues.
- All final manufacturing/drawing issues closed.
- Manufacturer’s QC checkout signed off.
- Assembly/Packaging/Shipping.
- Visual inspection of packaging requirements.

# 16.0 Electrical Induction Motors

## 16.1 General Induction Motor Knowledge

AC (Alternating Current) motors are used worldwide in many applications to transform electrical energy into mechanical energy. There are many types of AC motors; this study guide focuses on three phase AC induction motors. The most common type of motor used in industrial applications may be part of a pump or fan or connected to some other form of mechanical equipment such as a compressor, winder, conveyor, or mixer.

AC induction motors use a three-phase system. The currents in each conductor reach their peak instantaneous values sequentially, not simultaneously; in each cycle of the power frequency, first one, then the second, then the third current reaches its maximum value. The waveforms of the three supply conductors are offset from one another in time (delayed in phase) by one-third of their period (or 120 degrees). When the three phases are connected to windings around the interior of a motor stator, they produce a revolving magnetic field; such motors are self-starting.

AC induction motor consists of two assemblies - a stator and a rotor. The interaction of currents flowing in the rotor bars and the stators' rotating magnetic field generates a torque. In an actual operation, the rotor speed always lags the magnetic field's speed, allowing the rotor bars to cut magnetic lines of force and produce useful torque.

AC motors manufactured in the United States are generally rated in horsepower, but motors manufactured in many other countries are generally rated in kilowatts (kW). Conversion between these units can be calculated using Power in kW = 0.746 x power in HP. Example: A motor rated for 500 HP is equivalent to a motor rated for 375 kW. 0.746 x 500 HP = 375 kW. Kilowatts can be converted to horsepower with the following Formula: power in HP = 1.34 x power in kW.

The difference between the synchronous speed of the magnetic field and the shaft rotating speed is slip. The slip increases with an increasing load, thus providing a greater torque as more magnetic field lines are cut by the rotor bars.

## 16.2 Design and Construction Standards

The SI should be familiar with the following codes and or standards prior to performing source inspection activities for AC Induction Motors.

- **API STD 541:** Form-wound Squirrel Cage Induction Motors-375 kW (500 Horsepower) and Larger
- **NEMA MG1:** Motors and Generators
- **IEEE 112:** Test Procedure for Polyphase Induction Motors and Generators
- **IEEE 841:** This standard applies to premium efficiency totally enclosed fan-cooled (TEFC), horizontal and vertical, single-speed, squirrel cage poly-phase induction motors, up to and including 370 kW (500 hp), and 4000 volts in National Electrical Manufacturers Association (NEMA) frame sizes 143T and larger, for petroleum, chemical, and other severe duty applications (commonly referred to as premium efficiency severe duty motors).

These codes are not inclusive of all motors.

## 16.3 Materials of Construction

AC Motors are designed for continuous operation as well as for long periods of inactivity in an atmosphere that is made corrosive by traces of chemicals normally present in a petroleum processing facility. This environment may also include high humidity, storms, salt-laden air, insects, plant life, fungus, and rodents. Machines shall be suitable for operation, periods of idleness, storage, and handling at the ambient temperatures.

Three-phase AC induction motors have three main parts, stator winding, rotor, and enclosure. The stator and rotor do the work, and the enclosure protects the stator and rotor.

### 16.3.1 Stator Core

The stator is the stationary part of the motor’s electromagnetic circuit. The stator core is made up of many thin metal sheets, called laminations. Laminations are used to reduce energy loses that would result if a solid core were used.

### 16.3.2 Stator Windings

Stator laminations are stacked together forming a hollow cylinder. Coils of insulated wire are inserted into slots of the stator core. When the assembled motor is in operation, the stator windings are connected directly to the power source. Each grouping of coils, together with the steel core it surrounds, becomes an electromagnet when current is applied. Electromagnetism is the basic principle behind motor operation.

### 16.3.3 Rotor

The rotor is the rotating part of the motor’s electromagnetic circuit. The most common type of rotor used in a three-phase induction motor is a squirrel cage rotor. The squirrel cage rotor is so called because its construction is reminiscent of the rotating exercise wheels found in some pet cages. A squirrel cage rotor core is made by stacking thin steel laminations to form a cylinder. Rather than using coils of wire as conductors, conductor bars are die cast or driven into the slots evenly spaced around the cylinder.

### 16.3.4 Enclosure

The enclosure consists of a frame (or yoke) and two end brackets (or bearing housings). The stator is mounted inside the frame. The rotor fits inside the stator with a slight air gap separating it from the stator. There is no direct physical connection between the rotor and the stator. The enclosure protects the internal parts of the motor from water and other environmental elements. The degree of protection depends upon the type of enclosure.

### 16.3.5 Typical Motor Enclosures

Operational environment requires proper protection from surroundings. Listed are different types of Motor enclosures.

- Open drip proof (ODP)

- Totally enclosed-fan cooled (TEFC)
- Explosion proof (either TEFC or TENV)
- Totally enclosed-air over (TEAO)
- Totally enclosed-non ventilated (TENV)

### 16.3.6 Bearings

Bearings, mounted on the shaft, support the rotor and allow it to turn. Some motors use a fan, also mounted on the rotor shaft, to cool the motor when the shaft is rotating. When specified, machines with hydrodynamic bearings shall have provisions for the mounting of four radial vibration probes in each bearing housing. Where hydrodynamic thrust bearings are provided, they shall have provisions for two axial position probes at the thrust end.

### 16.3.7 Enclosure Area Classifications

The Motor and all of its auxiliary devices shall be suitable for and in accordance with the area classification system. Auxiliary devices will be listed or certified where required in accordance with the area classification system specified in NFPA 70, Article 500, Article 501, Article 502, and Article 505 (Class, Group, Division or Zone, and Temperature Code) or IEC 60079-10 (Zone, Class, Group, and Temperature Code) and specified local codes. Listed below are Hazardous Area classifications:

- Class I – Flammable gases and vapors;
- Class II – Combustible dust;
- Class III – Easily ignitable fibers;
- Class I Groups – A, B, C and D;
- Class II Groups – E, F and G;
- Division 1 – Hazard is normally present;
- Division 2 – Hazard is not normally present but could be during abnormal situations.

### 16.3.8 Ground Connectors

Visible ground pads shall be provided at opposite corners of the machine frame. A ground connection point shall be provided by drilling and tapping the frame for a 12.0 mm (1/2 in. NC) thread bolt, commonly known as a NEMA 2-Hole Pad.

### 16.3.9 Vibration Detectors

Hydrodynamic bearing machines intended to operate at synchronous speeds greater than or equal to 1,200 rpm, or when specified for other speeds, shall be equipped with non-contacting vibration probes and a phase reference probe, or shall have provisions for the installation of these probes. Non-contacting vibration probes and phase-reference probes shall be installed in accordance with API 670.

#### 16.3.10 Embedded Detector

Embedded detectors, such as resistance temperature detectors (RTD) or thermocouples, are commonly used on large machines to monitor the winding temperature during operation and are available for use during machine testing. They are usually installed between coil sides within a stator slot. An RTD gives a reading that is the average of the temperature of the two abutting coil sides over the length of the sensing element. A thermocouple measures the temperature of the spot where the thermocouple junction is located between the two coil sides.

### 16.4 Test and Inspections

There are electrical/Insulation tests that are done on motor parts such as Stator and Winding before motor assembly and tests that are done on an assembled motor during motor Routine or Complete tests. Stator tests described in API 541 4.3.4 test the Stator core, Stator Winding and Visual Inspection before VPI. All these tests are optional and shall be specified on motor data sheet if required.

### 16.5 Motor Testing

#### 16.5.1 Complete Motor Test

This test is an optional test that is requested on motor data sheet. See API 541 6.3.5.1 for detailed description of Complete Motor Test. The main purpose of the Complete Motor Test is to determine accurate motor efficiency, power factor and torque values under different loads. If motor has antifriction (ball/roller) bearings, oil conditions shall be checked after the test. Oil shall be clean and shall not change color when compared with same unused oil. If motor has hydrodynamic bearing, they have to be removed after the test and inspected for excessive or uneven wear, foreign material inclusions, hot spots and other signs of unsatisfactory performance.

#### 16.5.2 Routine Test

Per API 541 6.3.2, each machine shall be given a routine test to demonstrate that it is free from mechanical and electrical defects. These tests shall be conducted in accordance with the applicable portions of NEMA MG 1, IEEE 112, or IEC 60034-2.

#### 16.5.3 Cold Winding Resistance IEEE 112

With the machine at ambient temperature, measure the terminal-to-terminal winding resistance with the machine connected in the configuration to be used in the efficiency testing. Measure and record all combinations, i.e., T1-T2, T2-T3, and T3-T1, to assure that the specific precise value needed in further analyses will be available. Also measure and record the ambient temperature.

#### 16.5.4 Locked Rotor Test IEEE 112

The locked rotor test is done by mechanically holding the motor shaft from turning, and applying a reduced Voltage on the stator. The restraining on the shaft should be coupled to a scale or load cell in order to measure the torque. The Voltage supplied to the stator is reduced to prevent damage to the motor. Effectively a stall condition is applied.

It should be recognized that the testing of induction machines under locked-rotor conditions with poly-phase power involves high mechanical stresses and high rates of heating. Therefore, it is necessary that the mechanical means of securing the machine and locking the rotor are of adequate strength to prevent possible injury to personnel or damage to equipment. The direction of rotation is established prior to the test.

The machine is at approximately ambient temperature before the test is started. The current and torque readings shall be taken as quickly as possible, and, to obtain representative values, the machine temperature should not exceed rated temperature rise plus 40°C. The readings for any point shall be taken within 5 seconds after voltage is applied.

### 16.5.5 Temperature Rise Test IEEE 112

Temperature tests are made to determine the temperature rise of certain parts of the machine above the ambient temperature when running under a specified loading condition. The machine shall be shielded from air currents coming from pulleys, belts, and other machines. A very slight current of air may cause great discrepancies in the temperature test results. Conditions that result in rapid change of ambient air temperature shall not be considered satisfactory for temperature tests. Sufficient floor space shall be provided between machines to allow free circulation of air.

### 16.5.6 Load Test IEEE 112

Most of the efficiency test methods require that a load test be performed either to directly determine the efficiency as in Efficiency Test Method A or to determine the stray-load loss as in Efficiency Test Methods B, B1, and C. The machine is coupled to a load machine and is subjected to loads at four load points approximately equally spaced between not less than 25% and up to and including 100% load, and two load points suitably chosen above 100% load but not exceeding 150% load.

A spread in load test points is necessary to determine the efficiency accurately over the entire load range of the machine and more than six load points may be used if desired. Readings of electrical power, current, voltage, frequency, speed or slip, torque, stator winding temperature or stator winding resistance, and ambient temperature shall be obtained at each cubicle at the highest load value and move in descending order to the lowest.

### 16.5.7 Breakdown Torque Methods IEEE 112

Any one of the methods listed in 7.3.2.1 through 7.3.2.4 may be used to obtain data for a speed-torque curve. The selection of the method will depend upon the size and the speed-torque characteristics of the machine and the testing facility. In all four methods, sufficient test points should be recorded to ensure that reliable curves, including irregularities, can be drawn in the regions of interest from the test data. It is important that the frequency of the power supply be maintained constant throughout the test. For wound-rotor motors, the slip rings shall be short-circuited for this test.

Method 1 and Method 4 require the maintenance of constant speed for each reading. Therefore, they cannot be used in regions where the torque of the machine increases with speed more rapidly than that of the loading device. From the results of the following tests, adjusted to the rated voltage, curves of torque and current should be plotted vs. speed.

### 16.5.8 No Load Test IEEE 112

This test is performed by running the machine as a motor at rated voltage and frequency with no connected load. Perform this test when separation of no-load losses is to be accomplished, and read temperature, voltage, current, and power input at rated frequency and at voltages ranging from 125% of rated voltage down to the point where further voltage reduction increases the current.

### 16.5.9 High-Potential Test IEEE 112

High-potential tests are tests that consist of the application of a voltage higher than the rated voltage for a specified time for the purpose of determining the adequacy against breakdown of insulating materials and spacings under normal conditions.

### 16.5.10 Insulation Resistance Test IEEE 112

For maintenance purposes, insulation resistance tests are of value. All accessories, such as surge capacitors, surge arresters, current transformers, etc., that have leads located at the machine terminals shall be disconnected during this test, with the leads connected together and to the frame or core.

## 16.6 Visual and Mechanical Inspection

- Compare equipment nameplate data with drawings and specifications.
- Inspect physical and mechanical condition.
- Inspect anchorage, alignment, and grounding.
- Inspect air baffles, filter media, cooling fans, slip rings, brushes, and brush rigging.
- Inspect bolted electrical connections for high resistance using a low-resistance ohmmeter.
- Verify tightness of accessible bolted electrical connections by calibrated torque-wrench method in accordance with manufacturer’s published data.

- Verify that resistance temperature detector (RTD) circuits conform to drawings.

## 16.7 Final Inspection and Shipping Preparations

Motor final inspection typically consists of the following items:

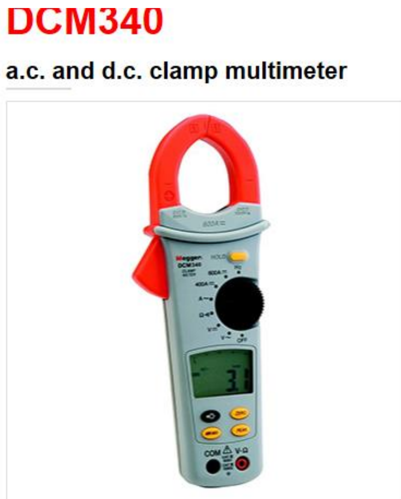
- Resolution of all FAT issues.
- All final manufacturing/drawing issues closed.
- Manufacturer’s QC checkout signed off.
- Assembly/Packaging/Shipping.
- Visual inspection of packaging requirements.

# 17.0 Electrical Inspection Tools and Test Equipment

The following common tools are typical to perform electrical inspection and system acceptance tests. See Table 4.

**Table 4: Electrical Inspection Tools and Test Equipment**

| **Equipment** | **Pictorial Example** | Description |
|---|---|---|
| **Flash Lights (Krypton)** |   | Supplemental light source for visual inspection. |
| **Tape Measures** |   | Dimensional inspection |
| **Digital Caliper** |  | Instrument used to measure distance between opposite sides of an object. Typically used for close tolerance dimensions on machined parts. |
| **OD Micrometer** |  | Instrument used to measure outside diameters/dimensions. Typically used for close tolerance dimensions on machined parts. |
| **Inspection Mirrors** |  | Tool designed to support visual inspection in limited and/or obscured areas. |
| **Laser Thermal Gun** |  | Tool for measuring surface temperature. |

| Equipment | Pictorial Example | Description |
|---|---|---|
| **Clamp on Amp Meter** |  | Tool designed to measure electric current in amperage and voltage. |
| **Camera** |  | Tool for photgraphic record keeping. |
| **Magnifying Glass** |  | Tool for enhanced visual inspection. |
| **Vibration Meter** |  | Tool designed to measure mechanical oscillations. |
| **Bore scope** |  | Designed for remote visual inspection. |

| Equipment | Pictorial Example | Description |
|---|---|---|
| **Inside Micrometer Set** |  | Used for measuring inside diameters. |
| **Depth Micrometer** |  | Used for measuring depth. |
| **Precision Gage Blocks** |  | Used for callibration of precision measurement equipment. |
| **Power Multi-Meter** |  | Used for measurement of ac primary and secondary currents, voltage power, reactive power, phase angle and frequency. |

| Equipment | Pictorial Example | Description |
|---|---|---|
| **Insulation resistance test set** |  | Used for insulation resistance measurement. |
| **Torque wrench** |  | Used to ensure hardware tightness meets engineering design. |
| **Low resistance ohm meter** |  | Used for accurate measurements of low resistance values of circuit breaker contacts, bus-bar joints and other high-current links. |