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# Safety Guidelines for the Application, Installation and Maintenance of Solid State Control

NEMA

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION • 2101 L STREET, N.W., WASHINGTON, D.C. 20037

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# NEMA ICS 1.1

# SAFETY GUIDELINES FOR THE APPLICATION, INSTALLATION, AND MAINTENANCE OF SOLID STATE CONTROL

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## Foreword

This Standards Publication has been written to assist the user of solid state components in industrial control applications to a better understanding of the unique characteristics of solid state devices or packaged assemblies incorporating solid state components. The thrust of this document is personnel safety. The product standard for components for solid state logic systems is contained in Part ICS 2-230. Standards for industrial systems are in Publication ICS 3.

In the preparation of this Standards Publication, input of users and other interested parties has been sought and evaluated.

Comments will be welcomed. They should be addressed to:

Manager, Engineering Department
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Washington, D.C. 20037

This publication is taken in its entirety from Part ICS 1-150, NEMA Standards Publication No. ICS 1-1983.

## Scope

This Standards Publication is intended to provide general guidelines for the application, installation, and maintenance of solid state control in the form of individual devices or packaged assemblies incorporating solid state components. The emphasis of the guidelines is personnel safety. Applicable NEMA standards and product related instructions should be carefully followed.



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# SAFETY GUIDELINES FOR THE APPLICATION, INSTALLATION AND MAINTENANCE OF SOLID STATE CONTROL

## Section 1
## DEFINITIONS

(This section is classified as NEMA Standard 11-15-1984.)

*Electrical Noise*—Unwanted electrical energy which has the possibility of producing undesirable effects in the control, its circuits and system.

*Electrical Noise Immunity*—The extent to which the control is protected from a stated electrical noise.

*Off-State Current*—The current that flows in a solid state device in the off-state condition.

*Off-State Condition*—The conditions of a solid state device where no control signal is applied.

*On-State Condition*—The condition of a solid state device when conducting.

*Surge Current*—A current exceeding the steady state current for a short time duration, normally described by its peak amplitude and time duration.

*Transient Overvoltage*—The peak voltage in excess of steady state voltage for a short time during the transient conditions (e.g., resulting from the operations of a switching device).

## Section 2
## GENERAL

(Sections 2 through 5 are classified as Authorized Engineering Information 11-15-1984.)

Solid State and electro-mechanical controls can perform similar control functions, but there are certain unique characteristics of solid state controls which must be understood.

In the application, installation and maintenance of solid state control, special consideration should be given to the characteristics described in 2.1 through 2.7.

### 2.1 AMBIENT TEMPERATURE

Care should be taken not to exceed the ambient temperature range specified by the manufacturer.

### 2.2 ELECTRICAL NOISE

Performance of solid state controls can be affected by electrical noise. In general, complete systems are designed with a degree of noise immunity. Noise immunity can be determined through tests such as described in 3.4.2. Manufacturer recommended installation practices for reducing the effect of noise should be followed.

### 2.3 OFF-STATE CURRENT

Solid state controls generally exhibit a small amount of current flow when in the off-state condition. Precautions must be exercised to ensure proper circuit performance and personnel safety. The value of this current is available from the manufacturer.

### 2.4 POLARITY

Incorrect polarity of applied voltages may damage solid state controls. The correct polarity of solid state controls should be observed.

### 2.5 RATE OF RISE—VOLTAGE OR CURRENT (DV/DT or DI/DT)

Solid state controls can be affected by rapid changes of voltage or current if the rate of rise (DV/DT and/or DI/DT) is greater than the maximum permissible value specified by the manufacturer.

### 2.6 SURGE CURRENT

Current of a value greater than that specified by the manufacturer can affect the solid state control. Current limiting means may required.

### 2.7 TRANSIENT OVERVOLTAGE

Solid state controls may be affected by transient overvoltages which are in excess of those specified by the manufacturer. Voltage limiting means should be considered and may be required.

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# Section 3
# APPLICATION GUIDELINES

## 3.1 GENERAL APPLICATION PRECAUTIONS

### 3.1.1 Circuit Considerations

The consequences of some malfunctions such as those caused by shorted output devices, alteration, loss of memory, or failure of isolation within components or logic devices, require that the user be concerned with the safety of personnel and the protection of the electronics.

It is recommended that circuits which the user considers to be critical to personnel safety, such as "end of travel" circuits and "emergency stop" circuits, should directly control their appropriate functions through an electromechanical device independent of the solid state logic. Such circuits should initiate the stop function through de-energization rather than energization of the control device. This provides a means of circuit control that is independent of system failure.

### 3.1.2 Power Up/Power Down Considerations

Consideration should be given to system design so that unsafe operation does not occur under these conditions since solid state outputs may operate erratically for a short period of time after applying or removing power.

### 3.1.3 Redundancy and Monitoring

When solid state devices are being used to control operations, which the user determines to be critical, it is strongly recommended that redundancy and some form of checking be included in the system. Monitoring circuits should check that actual machine or process operation is identical to controller commands; and in the event of failure in the machine, process, or the monitoring system, the monitoring circuits should initiate a safe shutdown sequence.

### 3.1.4 Overcurrent Protection

To protect triacs and transistors from shorted loads, a closely matched short circuit protective device (SCPD) is often incorporated. These SCPD's should be replaced only with devices recommended by the manufacturer.

### 3.1.5 Overvoltage Protection

To protect triacs, SCR's and transistors from overvoltages, it may be advisable to consider incorporating peak voltage clamping devices such as varistors, zener diodes, or snubber networks in circuits incorporating these devices.

## 3.2 CIRCUIT ISOLATION REQUIREMENTS

### 3.2.1 Separating Voltages

Solid state logic uses low level voltage (e.g., less than 32 volts dc) circuits. In contrast, the inputs and outputs are often high level (e.g., 120 volts ac) voltages. Proper design of the interface protects against an unwanted interaction between the low level and high level circuits; such an interaction can result in a failure of the low voltage circuitry. This is potentially dangerous. An input and output circuitry incorporating effective isolation techniques (which may include limiting impedance or Class 2 supplied circuitry) should be selected.

### 3.2.2 Isolation Techniques

The most important function of isolation components is to separate high level circuits from low level circuits in order to protect against the transfer of a fault from one level to the other.

Isolation transformers, pulse transformers, reed relays, or optical couplers are typical means to transmit low level logic signals to power devices in the high level circuit. Isolation impedance means also are used to transmit logic signals to power devices.

## 3.3 SPECIAL APPLICATION CONSIDERATIONS

### 3.3.1 Converting Ladder Diagrams

Converting a ladder diagram originally designed for electromechanical systems to one using solid state control must account for the differences between electromechanical and solid state devices. Simply replacing each contact in the ladder diagram with a corresponding solid state "contact" will not always produce the desired logic functions or fault detection and response. For example, in electromechanical systems, a relay having a mechanically linked normally open (NO) and normally closed (NC) contact can be wired to check itself. Solid state components do not have a mutually exclusive NO-NC arrangement. However, external circuitry can be employed to sample the input and "contact" state and compare to determine if the system is functioning properly.

### 3.3.2 Polarity and Phase Sequence

Input power and control signals should be applied with polarity and phase sequence as specified by the manufacturer. Solid state devices can be damaged by the application of reverse polarity or incorrect phase sequence.

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### 3.4 Planning Electrical Noise Rejection

The low energy levels of solid state controls may cause them to be vulnerable to electrical noise. This should be considered in the planning stages.

#### 3.4.1 Assessing Electrical Environment

Sources of noise are those pieces of equipment that have large, fast changing voltages or currents when they are energized or de-energized, such as motor starters, welding equipment, SCR type, adjustable speed devices and other inductive devices. These devices, as well as the more common control relays and their associated wiring, all have the capability of inducing serious current and voltage transients on their respective power lines. It is these transients which nearby solid state controls must withstand and for which noise immunity should be provided.

An examination of the proposed installation site of the solid state control should identify equipment that could contaminate power lines. All power lines that will be tapped by the proposed solid state control should be examined for the presence, severity, and frequency of noise occurrences. If found, system plans should provide for the control of such noise.

#### 3.4.2 Selecting Devices to Provide Noise Immunity

Installation planning is not complete without examination of the noise immunity characteristics of the system devices under consideration. Results of tests to determine relative immunity to electrical noise may be requested from the manufacturer. Two such standardized tests are the ANSI (C37.90a-1974) *Surge Withstand Capability Test* and the NEMA (ICS 1-1983) noise test referred to as *The Showering Arc Test.* These are applied where direct connection of solid state control to other electromechanical control circuits is intended. Circuits involving analog regulating systems or high speed logic are generally more sensitive to electrical noise; therefore, isolation and separation of these circuits is more critical.

Further information on electrical noise and evaluation of the severity of noise may be found in ANSI/IEEE Publication No. 518-1982.

Where severe power line transients are anticipated or noted, appropriate filters such as commercially available line filter, isolation transformers, or voltage limiting varistors, should be considered.

All inductive components associated with the system should be examined for the need for noise suppression.

#### 3.4.3 Design of Wiring for Maximum Protection

Once the installation site and power conductors have been examined, the system wiring plans that will provide noise suppression should be considered.

Conducted noise enters solid state control at the points where the control is connected to input lines, output lines, and power supply wires.

Input circuits are the circuits most vulnerable to noise. Noise may be introduced capacitatively through wire to wire proximity, or magnetically from nearby lines carrying large currents. In most installations, signal lines and power lines should be separate. Further, signal lines should be appropriately routed and shielded according to the manufacturer's recommendations.

When planning system layout, care must be given to appropriate grounding practice. Because design differences may call for different grounding, the control manufacturer's recommendations should be followed.

### 3.5 COUNTERING THE EFFECTS OF OFF-STATE CURRENT

#### 3.5.1 Off-State Current

Solid state components, such as triacs, transistors, and thyristors, inherently have in the off-state a small current flow called "off-state current".

Off-state current may also be contributed by devices used to protect these components, such as RC snubbers.

#### 3.5.2 Off-State Current Precautions

Off-state currents in a device in the off-state may present a hazard of electrical shock and the device should be disconnected from the power source before working on the circuit or load.

Precautions should be taken to prevent the off-state current of an output device which is in the off-state from energizing an input device.

### 3.6 AVOIDING ADVERSE ENVIRONMENTAL CONDITIONS

#### 3.6.1 Temperature

Solid state devices should only be operated within the temperature ranges specified by the manufacturer. Because such devices generate heat, care should be taken to see that the ambient temperature at the device does not exceed the temperature range specified by the manufacturer.

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The main source of heat in a solid state system is the energy dissipated in the power devices. Since the life of the equipment can be increased by reducing operating temperature, it is important to observe the manufacturer's "maximum/minimum ambient temperature" guidelines, where ambient refers to the temperature of the air providing the cooling. The solid state equipment must be allowed to stabilize to within the manufacturer's recommended operating temperature range before energizing control functions.

When evaluating a system design, other sources of heat in the enclosure which might raise the ambient temperature should not be overlooked. For example, power supplies, transformers, radiated heat, sunlight, furnaces, incandescent lamps. and so forth should be evaluated.

In instances where a system will have to exist in a very hot ambient environment, special cooling methods may have to be employed. Techniques that are employed include cooling fans (with adequate filtering), vortex coolers, heat exchanges, and air conditioned rooms.

Over-temperature sensors are recommended for systems where special cooling is employed. Use of air conditioning should include means for prevention of condensing moisture.

### 3.6.2 Contaminants

Moisture, corrosive gases and liquids, and conductive dust can all have adverse effects on a system that is not adequately protected against atmospheric contaminants.

If these contaminants are allowed to collect on printed circuit boards, bridging between the conductors may result in malfunction of the circuit. This could lead to noisy, erratic control operation or, at worst, a permanent malfunction. A thick coating of dust could also prevent adequate cooling on the board or heat sink, causing malfunction. A dust coating on heat sinks reduces their thermal efficiency.

Preventive measures include a specially conditioned room or a properly specified enclosure for the system.

### 3.6.3 Shock and Vibration

Excessive shock or vibration may cause damage to solid state equipment. Special mounting provisions may be required to minimize damage.

## 3.7 The Need for Education—Knowledge Leads to Safety

Planning for an effective solid state circuit requires enough knowledge to make basic decisions that will render the system safe as well as effective.

Everyone who works with a solid state control should be educated in its capabilities and limitations. This includes in-plant installers, operators, service personnel, and system designers.

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# Section 4
# INSTALLATION GUIDELINES

## 4.1 INSTALLATION AND WIRING PRACTICE

**4.1.1** Proper installation and field wiring practices are of prime importance to the application of solid state controls. Proper wiring practice will minimize the influence of electrical noise, which may cause malfunction of equipment.

Users and installers should familiarize themselves with and follow installation and wiring instructions in addition to requirements of all applicable codes, laws, and standards. The manufacturer of the device or component in question should be consulted whenever conditions arise that are not covered by the manufacturer's instructions.

**4.1.2** Electrical noise is a very important consideration in any installation of solid state control. While wiring practices may vary from situation to situation, the following are basic to minimizing electrical noise:

1. Sufficient physical separation should be maintained between electrical noise sources and sensitive equipment to assure that the noise will not cause malfunctioning or unintended actuation of the control.
2. Physical separation should be maintained between sensitive signal wires and electrical power and control conductors. This separation can be accomplished by conduits, wiring trays, or as otherwise recommended by the manufacturer.
3. Twisted-pair wiring should be used in critical signal circuits and noise producing circuits to minimize magnetic interference.
4. Shielded wire should be used to reduce the magnitude of the noise coupled into the low level signal circuit by electrostatic or magnetic coupling.
5. Provisions of the 1984 *National Electrical Code** with respect to grounding should be followed. Additional grounding precautions may be required to minimize electrical noise. These precautions generally deal with ground loop currents arising from multiple ground paths. The manufacturer's recommendations should be followed.

## 4.2 ENCLOSURES (COOLING AND VENTILATING)

Suitable enclosures and control of the maximum operating temperature, both of which are environmental variables, may be needed to prevent malfunction of solid state control.

The manufacturer's recommendations should be followed for the selection of enclosures, ventilation, air filtering (if required), and ambient temperature. These recommendations may vary from installation to installation, even within the same facility.

## 4.3 SPECIAL HANDLING OF ELECTROSTATIC SENSITIVE DEVICES

Some devices may be damaged by electrostatic charges. These devices are identified and should be handled in the special manner specified by the manufacturer.

NOTE: Plastic wrapping materials used to ship these devices may be conductive and should not be used as insulating material.

## 4.4 COMPATIBILITY OF DEVICES WITH APPLIED VOLTAGES AND FREQUENCIES

Prior to energization, users and installers should verify that the applied voltage and frequency agree with the rated voltage and frequency specified by the manufacturer.

NOTE: Incorrect voltage or frequency may cause a malfunction of, or damage to, the control.

## 4.5 TESTING PRECAUTIONS

When testing solid state control, the procedures and recommendations set forth by the manufacturer should be followed.

When applicable, instrumentation and test equipment should be electrically equivalent to that recommended by the manufacturer for the test procedure. A low impedance voltage tester should not be used.

High voltage insulation tests and dielectric tests should never be used to test solid state devices. If high voltage insulation of field wiring is required, solid state devices should be disconnected. Ohmmeters should only be used when and as recommended by the equipment manufacturer.

Testing equipment should be grounded; if it is not, special precautions should be taken.

## 4.6 STARTUP PROCEDURES

Checks and tests prior to startup and startup procedures recommended by the manufacturer should be followed.

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# Section 5
# PREVENTIVE MAINTENANCE AND REPAIR GUIDELINES

## 5.1 GENERAL

A well-planned and executed maintenance program is essential to the satisfactory operation of solid state electrical equipment. The kind and frequency of the maintenance operation will vary with the kind and complexity of the equipment as well as with the nature of the operating conditions. Maintenance recommendations of the manufacturer or appropriate product standards should be followed.

Useful reference publications for setting up a maintenance program are NFPA 70B-1983, *Maintenance of Electrical Equipment,* and NFPA 70E-1983, *Electrical Safety Requirements for Employee Workplaces.*

## 5.2 PREVENTIVE MAINTENANCE

The following factors should be considered when formulating a maintenance program:

1. Maintenance must be performed by qualified personnel familiar with the construction, operation, and hazards involved with the control.

2. Maintenance should be performed with the control out of operation and disconnected from all sources of power. If maintenance must be performed while the control is energized, the safety related practices of NFPA 70E should be followed.

3. Care should be taken when servicing electrostatic sensitive components. The manufacturer's recommendations for these components should be followed.

4. Ventilation passages should be kept open. If the equipment depends upon auxiliary cooling, e.g., air, water, or oil, periodic inspection (with filter replacement when necessary) should be made of these systems.

5. The means employed for grounding or insulating the equipment from ground should be checked to assure its integrity (see 4.5).

6. Accumulations of dust and dirt on all parts, including on semiconductor heat sinks, should be removed according to the manufacturer's instructions, if provided; otherwise, the manufacturer should be consulted. Care must be taken to avoid damaging any delicate components and to avoid displacing dust, dirt, or debris in a way that permits it to enter or settle into parts of the control equipment.

7. Enclosures should be inspected for evidence of deterioration. Accumulated dust and dirt should be removed from the top of the enclosures before opening doors or removing covers.

8. Certain hazardous materials removed as part of maintenance or repair procedure (e.g., polychlorinated biphenyls (PCB) found in some liquid filled capacitors) must be disposed of as described in Federal regulations.

## 5.3 REPAIR

If equipment condition indicates repair or replacement, the manufacturer's instruction manual should be followed carefully. Diagnostic information within such a manual should be used to identify the probable source of the problem, and to formulate a repair plan. The level of field repair recommended by the manufacturer should be followed.

When solid state equipment is repaired, it is important that any replacement part be in accordance with the recommendations of the equipment manufacturer. Care should be taken to avoid the use of parts which are no longer compatible with other changes in the equipment. Also, replacement parts should be inspected for deterioration due to "shelf life" and for signs of rework or wear which may involve factors critical to safety.

After repair, proper start-up procedures should be followed. Special precautions should be taken to protect personnel from hazards during start-up.

## 5.4 SAFETY RECOMMENDATIONS FOR MAINTENANCE PERSONNEL

All maintenance work should be done by qualified personnel familiar with the construction, operation, and hazards involved with the equipment. The appropriate work practices of NFPA 70E should be followed.

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## Purpose of Standards

National Electrical Manufacturers Association Standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist the purchaser in selecting and obtaining the proper product for its particular need. Existence of a National Electrical Manufacturers Association Standard does not in any respect preclude any member or nonmember from manufacturing or selling products not conforming to the standard.

*(Bylaw—Art. V, Sec. 1)*

## Definition of a Standard

A standard of the National Electrical Manufacturers Association defines a product, process or procedure with reference to one or more of the following: nomenclature, composition, construction, dimensions, tolerances, safety, operating characteristics, performance, rating, testing, and the service for which they are designed.

*(Bylaw—Art. V, Sec. 2, Subsection A)*

## Dimensions

Where dimensions are given for interchangeability purposes, alternate dimensions satisfying the other provisions of the standards publication may be capable of otherwise equivalent performance.

*(NEMA Policy Memorandum 84-2, dated June 7, 1984)*

## Classes of Standards

National Electrical Manufacturers Association Standards are of two classes:

1. NEMA Standard, which relates to a product commercially standardized and subject to repetitive manufacture, which standard has been approved by at least 90 percent of the members of the Subdivision eligible to vote thereon;
2. Suggested Standard for Future Design, which may not have been regularly applied to a commercial product, but which suggests a sound engineering approach to future development, which standard has been approved by at least two-thirds of the members of the Subdivision eligible to vote thereon.

*(Bylaw—Art. V, Sec. 2, Subsection B)*

## Authorized Engineering Information

Authorized Engineering Information consists of explanatory data and other engineering information of an informative character not falling within the classification of NEMA Standard or Suggested Standard for Future Design.

*(Bylaw—Art. V, Sec. 6, 1st Sentence)*

## Official Standards Proposal

An Official Standards Proposal is an official draft of a proposed standard which is formally recommended to an outside organization(s) for consideration, comment and/or approval.

*(Bylaw—Art. V, Sec. 4, Subsection A)*

## Identification of Status

Standards in NEMA Standards Publications are identified in the foreword or following each standard as "NEMA Standard" or "Suggested Standard for Future Design." These indicate the status of the standard. These words are followed by a date which indicates when the standard was adopted in its present form by the Association.

The material identified as "Authorized Engineering Information" and "Official Standards Proposal" is designated similarly.

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