ELECTRIC MOTOR CONTROL

FOURTH EDITION

Walter N. Alerich

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PREFACE

The fourth edition of *Electric Motor Control* updates a text long-regarded as one of the standard references for the study of motor control theory and applications. The rapidly changing state of the technology requires technicians who are familiar with the latest equipment, components, circuitry and applications. *Electric Motor Control* provides this information in a clear, well-illustrated format.

INTRODUCTION

Electric motors provide one of the principal sources for power for driving machine tools and other industrial equipment. In most cases, the motor is included as an integral part of the design of the machine. Related to this is the design, construction, installation, and maintenance of equipment to control the motor.

The phrase *motor control* refers to the functions available from a motor controller as applied to a motor, such as speed control, reversal, acceleration, deceleration, starting, and stopping. This new edition emphasizes solid-state control of these functions.

Various texts, handbooks, and manufacturers' manuals describe different types of controllers. However, it is often difficult to find a single source for this information. *Electric Motor Control* serves as a source of technical and practical information for students, instructors, apprentices, journeyman electricians, technicians, engineers, electrical contractors, and others. A thorough study of this text will contribute to an understanding of the theory, operation, installation, and maintenance of motor controllers.

The goal in all areas of industry is increased production and decreased costs through automation. Design, maintenance, and operation of the control systems for automated equipment creates the need for a thorough knowledge of motor control basics.

Electric Motor Control is especially helpful to construction electricians and apprentices for installing and operating control systems, to plant maintenance personnel for maintaining the operation of production machines, and to drafters and designers of motor control systems. It is used extensively in apprentice training programs, journeyman training, vocational-technical schools, and two-year colleges. A working knowledge of direct- and alternating-current fundamentals and direct- and alternating-current motor theory and operation, or equivalent experience, is a prerequisite to the study of this text.

Once the electrician is on the job, this text, in conjunction with the *National Electrical Code®*, serves as a quick reference handbook for both new construction and maintenance.

The text is written in easy-to-understand language. Each unit covers a concise topic. Expected student learning is outlined in the objectives at the beginning of each unit. Learning is tested through the Study/Discussion/Test Questions at the end of each unit. The Appendix and Glossary provide further explanation of terms and servicing or troubleshooting aids.

MAJOR CONTENT CHANGES FOR THE FOURTH EDITION

- Color has been added to the text to highlight important concepts.
- The units on circuit layouts, connections, and symbols were moved forward in the text so that students will have the necessary preparation to read circuit schematic diagrams in the following units.
- Unit 7, Relays and Contactors, has added solid-state relays and surge protection for solid-state devices used with magnetic switches.
- Unit 8, Timing Relays, has added electronic timers.
- Unit 12, Limit Switches, has added solid-state proximity switches, including operation and applications.
- Unit 13, Phase Failure Relays, has added solid-state, large motor current monitor.
- Unit 15, Temperature Switches, has added solid-state temperature control systems.
- Unit 21, Sequence Control, has added solid-state logic elements and control functions (AND and OR functions).
- NEW Unit 28, AC Solid-State Reduced Voltage Controller, covers solid-state control, reduced voltage control systems, solid-state control used with existing magnetic devices, noise suppression, and applications of controllers.
- NEW Unit 36, Solid-State Adjustable Speed Controller for AC Wound Rotor Motors, covers power factor correction.
- Unit 40, Synchronous Automatic Motor Starter, has added brushless solid-state motor excitation.
- Unit 45, Compensating and Definite Time Control Starting, has added definite time control starting.
- NEW Unit 46, Solid-State Adjustable Speed Control, covers power conversion and control, starting the motor, DC adjustable speed control (single-phase AC), and DC adjustable speed control (three-phase).
- Unit 50, Dynamic Braking, has added regenerative braking.
- Unit 51, Electric Braking, has added electronic braking.
- NEW Unit 55, AC Adjustable Frequency Solid-State Devices, covers solid-state control of AC motors, functions of converters and inverters, and features of adjustable frequency drives.
- NEW Unit 58, Programmable and Motion Control, covers components of a programmable control and their functions, installation of controllers, motor control centers, and motion control with stepper motors.

ABOUT THE AUTHOR

Walter N. Alerich, B.V.E., M.A., has an extensive background in the electrical trades. As a journeyman wireman, he has had years of experience in the practical applications of motor control. As a teacher, supervisor, and administrator, Mr. Alerich spent many years in education and is aware of the need for effective instruction in this field. A former department head of the Electrical-Mechanical Department, Los Angeles Trade-Technical College, he has written extensively on the subject of electricity and motor controls. He currently serves as an international specialist and consultant in the field of electrical trades, developing curriculum and training programs, certifying crafts people, and designing training facilities.

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Square D Co.
Sterling Electric Inc.
U.S. Electrical Motors
Ward Leonard Electric Co., Inc.
Warner Electric Brake and Clutch Co.
Westinghouse Electric Corporation

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SECTION ONE

INTRODUCTION

UNIT 1 General Principles of Electric Motor Control

Objectives **After studying this unit, the student will be able to:**

- **State the purpose and general principles of electric motor control.**
- **State the difference between manual and remote control**
- **List the conditions of starting and stopping, speed control, and protection of electric motors**
- **Explain the difference between compensating and definite time delay action**

There are certain conditions that must be considered when selecting, designing, installing, or maintaining electric motor control equipment. The general principles are discussed to help understanding and to motivate students by simplifying the subject of electric motor control.

Motor control was a simple problem when motors were used to drive a common line shaft to which several machines were connected. It was simply necessary to start and stop the motor a few times a day. However, with individual drive, the motor is now almost an integral part of the machine and it is necessary to design the motor controller to fit the needs of the machine to which it is connected. Large installations and the problems of starting motors in these situations may be observed in figures 1-1 and 1-2.

Motor control is a broad term that means anything from a simple toggle switch to a complex system with components such as relays, timers, and switches. The common function of all controls, however, is to control the operation of an electric motor. As a result, when motor control equipment is selected and installed, many factors must be considered to insure that the control will function properly for the motor and the machine for which it is selected.

MOTOR CONTROL INSTALLATION CONSIDERATIONS

When choosing a specific device for a particular application, it is important to remember that the motor, machine, and motor controller are interrelated and need to be considered as a package. In general, five basic factors influence the selection and installation of a controller.

1. ELECTRICAL SERVICE
   Establish whether the service is direct (dc) or alternating current (ac). If ac, determine the frequency (hertz) and number of phases in addition to the voltage.
2. MOTOR
   The motor should be matched to the electrical service, and correctly sized for the machine load in horsepower rating (hp). Other considerations include motor speed and torque. To select proper protection for

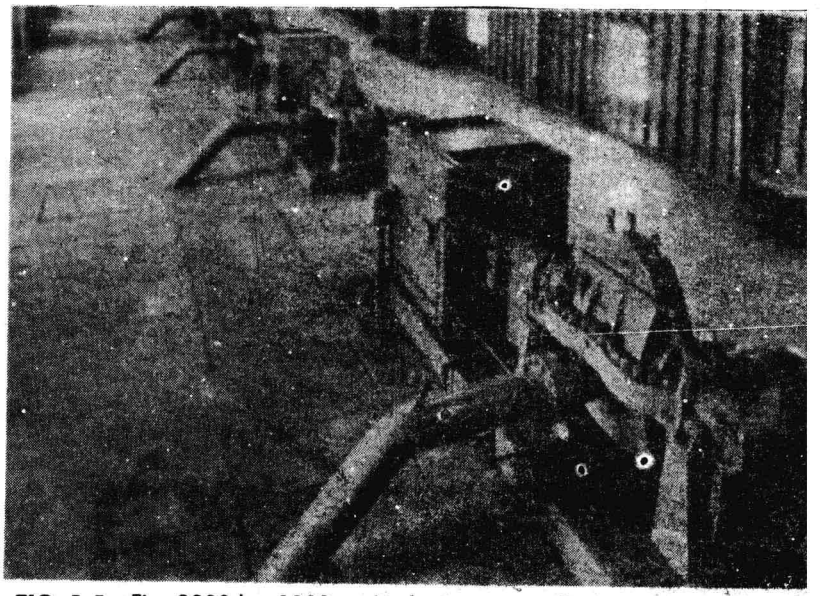

FIG. 1-1 Five 2000-hp, 1800-rpm induction motors driving water pumps for a Texas oil/water flood operation. Pumps are used to force water into the ground and "float" oil upward. *(Courtesy Electric Machinery Mfg. Co.)*

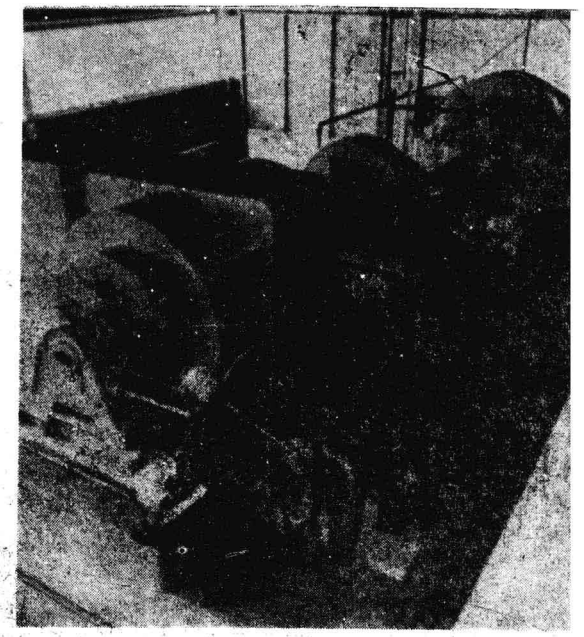

FIG. 1-2 Horizontal 4000-hp synchronous motor driving a large centrifugal air compressor *(Courtesy Electric Machinery Mfg. Co.)*

the motor, its full load current rating (FLC), service factor (SF), time rating (duty), and other pertinent data — as shown on the motor nameplate — must be used.

OPERATING CHARACTERISTICS OF CONTROLLER

The fundamental tasks of a motor controller are to start and stop the motor, and to protect the motor, machine, product and operator. The controller may also be called upon to provide supplementary functions such as reversing, jogging or inching, plugging, operating at several speeds or at reduced levels of current and motor torque. (See Appendix, glossary of terms).

ENVIRONMENT

Controller enclosures serve to provide safety protection for operating personnel by preventing accidental contact with live parts. In certain applications, the controller itself must be protected from a variety of environmental conditions which might include:

- Water, rain, snow or sleet
- Dirt or noncombustible dust
- Cutting oils, coolants or lubricants

Both personnel and property require protection in environments made hazardous by the presence of explosive gases or combustible dusts.

5. ELECTRICAL CODES AND STANDARDS Motor control equipment is designed to meet the provisions of the National Electrical Code (NEC). Also, local code requirements must be considered and met when installing motors and control devices. Presently, code sections applying to motors, motor circuits, and controllers and industrial control devices are found in Article 430 on motors and motor controllers, Article 440 on air conditioning and refrigeration equipment, and Article 500 on hazardous locations of the National Code.

   The 1970 Occupational Safety and Health Act (OSHA) as amended, requires that each employer furnish employment in an environment free from recognized hazards likely to cause serious harm.

   Standards established by the National Electrical Manufacturers Association (NEMA) assist users in the proper selection of control equipment. NEMA standards provide practical information concerning the construction, testing, performance, and manufacture of motor control devices such as starters, relays and contactors.

   One of the organizations which actually test for conformity to national codes and standards is Underwriters' Laboratories (UL). Equipment that is tested and approved by UL is listed in an annual publication, which is kept current by means of bimonthly supplements to reflect the latest additions and deletions. A UL listing does not mean that a product is approved by the NEC. It must be acceptable to the local authority having jurisdicition.

PURPOSE OF CONTROLLER

Some of the complicated and precise automatic applications of electrical control are illustrated in figures 1-3 and 1-8. Factors to be considered when selecting and installing motor control components for use with particular machines or systems are described in the following paragraphs.

Starting

The motor may be started by connecting it directly across the source of voltage. Slow and gradual starting may be required, not only to protect the machine, but also to insure that the line current inrush on starting is not too great for the power company's system. Some driven machines may be damaged if they are started with a sudden turning effort. The frequency of

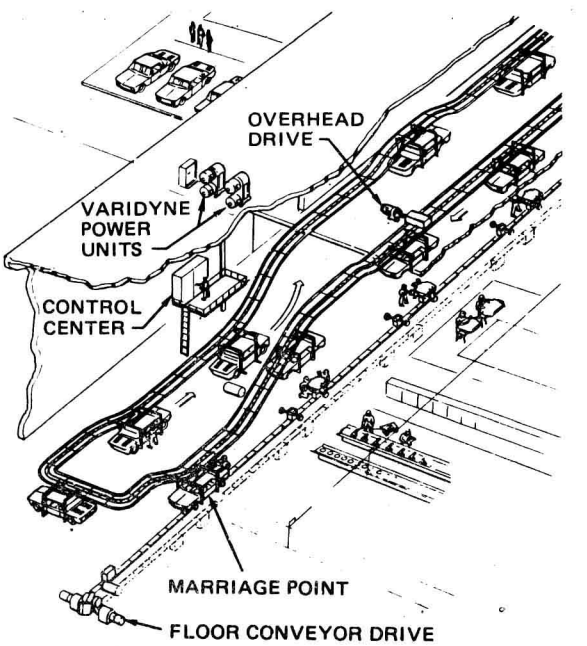

FIG. 1-3 Synchronizing two automobile assembly systems *(Courtesy U.S. Electrical Motors)*

starting a motor is another factor affecting the controller. A combination fused disconnect switch and motor starter is shown in figure 1-4.

Stopping

Most controllers allow motors to coast to a standstill. Some impose braking action when the machine must stop quickly. Quick stopping is a vital function of the controller for emergency stops. Controllers assist the stopping action by retarding centrifugal motion of machines and lowering operations of crane hoists.

Reversing

Controllers are required to change the direction of rotation of machines automatically or at the command of an operator at a control station. The reversing action of a controlier is a continual process in many industrial applications.

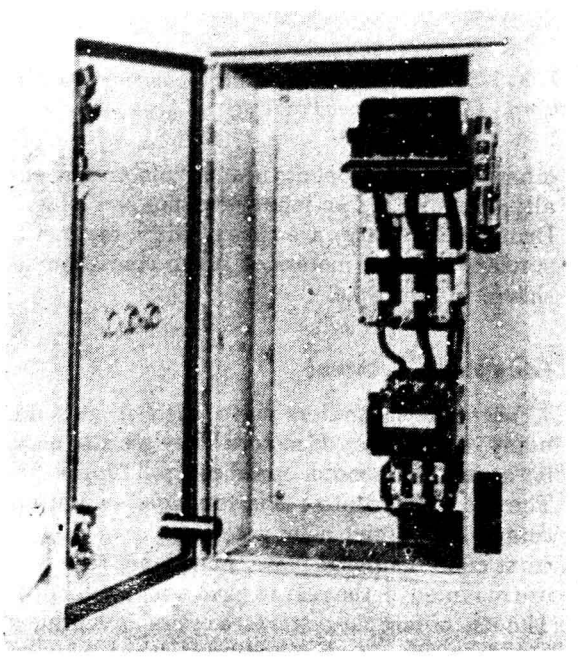

FIG. 1-4 Combination fused disconnect switch and motor starter *(Courtesy Square D Co.)*

Running

The maintaining of desired operational speeds and characteristics is a prime purpose and function of controllers. They protect motors, operators, machines, and materials while running. There are many different types of safety circuits and devices to protect people, equipment and industrial production and processes against possible injury that may occur while the machines are running.

Speed Control

Some controllers can maintain very precise speeds for industrial processes. Other controllers can change the speeds of motors either in steps or gradually through a continuous range of speeds.

Safety of Operator

Many mechanical safeguards have been replaced or aided by electrical means of protection. Electrical control pilot devices in controllers provide a direct means of protecting machine operators from unsafe conditions.

Protection from Damage

Part of the operation of an automatic machine is to protect the machine itself and the manufactured or processed materials it handles. For example, a certain machine control function may be the prevention of conveyor pileups. A machine control can reverse, stop, slow, or do whatever is necessary to protect the machine or processed materials.

Maintenance of Starting Requirements

Once properly installed and adjusted, motor starters will provide reliable operation of starting time, voltages, current, and torques for the benefit of the driven machine and the power system. The National Electrical Code,

supplemented by local codes, governs the selection of the proper sizes of conductors, starting fuses, circuit breakers, and disconnect switches for specific system requirements.

MANUAL CONTROL

A manual control is one whose operation is accomplished by mechanical means. The effort required to actuate the mechanism is almost always provided by a human operator. The motor may be controlled manually using any one of the following devices.

Toggle Switch

A toggle switch is a manually operated electric switch. Many small motors are started with toggle switches. This means the motor may be started directly without the use of magnetic switches or auxiliary equipment. Motors started with toggle switches are protected by the branch circuit fuse or circuit breaker. These motors generally drive fans, blowers, or other light loads.

Safety Switch

In some cases it is permissible to start a motor directly across the full line voltage if an externally-operated safety switch is used, figure 1-5. The motor receives starting and running protection from dual-element, time-delay fuses. The use of a safety switch requires manual operation. A safety switch, therefore, has the same limitations common to most manual starters.

Drum Controller

Drum controllers are rotary, manual switching devices which are often used to reverse motors and to control the speed of ac and dc motors. They are used particularly where frequent start, stop, or reverse operation is required. These controllers may be used without other control components in small motors, generally those with fractional horsepower ratings. Drum controllers are used with magnetic starters in large motors. A drum controller is shown in figure 1-6.

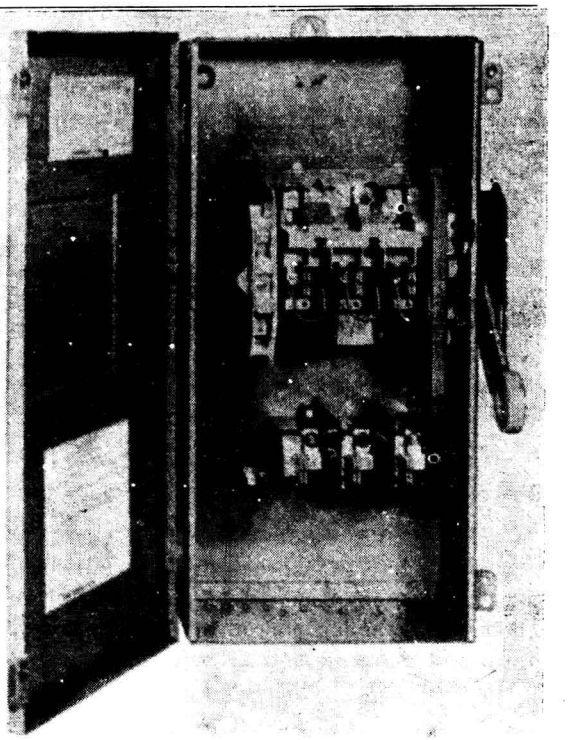

FIG. 1-5 Safety disconnect switch *(Courtesy EATON Corp., Cutler-Hammer Products)*

Faceplate Control

Faceplate controllers have been in use for many years to start dc motors. They are also used for ac induction motor speed control, figure 1-7. The faceplate control has multiple switching contacts mounted near a selector arm on the front of an insulated plate. Additional resistors are mounted on the rear to form a complete unit. The use of faceplate starters offers advantages and features not obtained with other manual controllers. They are also cheaper to purchase than automatic controls.

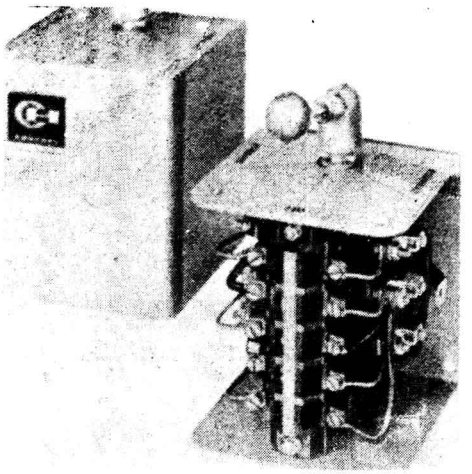

FIG. 1-6 Drum controller with cover (left) and with cover removed (right) *(Courtesy Cutler-Hammer Products)*

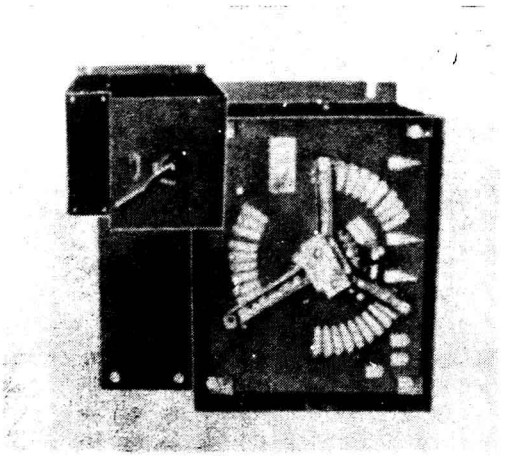

FIG. 1-7 One type of faceplate controller *(Courtesy EATON Corp., Cutler-Hammer Products)*

REMOTE AND AUTOMATIC CONTROL

The motor may be controlled by remote control using push buttons, figure 1-8 A and B. When push button remote control is used or when automatic devices do not have the electrical capacity to carry the motor starting and running currents, magnetic switches must be included. Magnetic switch control is one whose operation is accomplished by electromagnetic means. The effort required to actuate the electromagnet is supplied by electrical energy rather than by the human operator. If the motor is to be automatically controlled, the following two-wire pilot devices may be used.

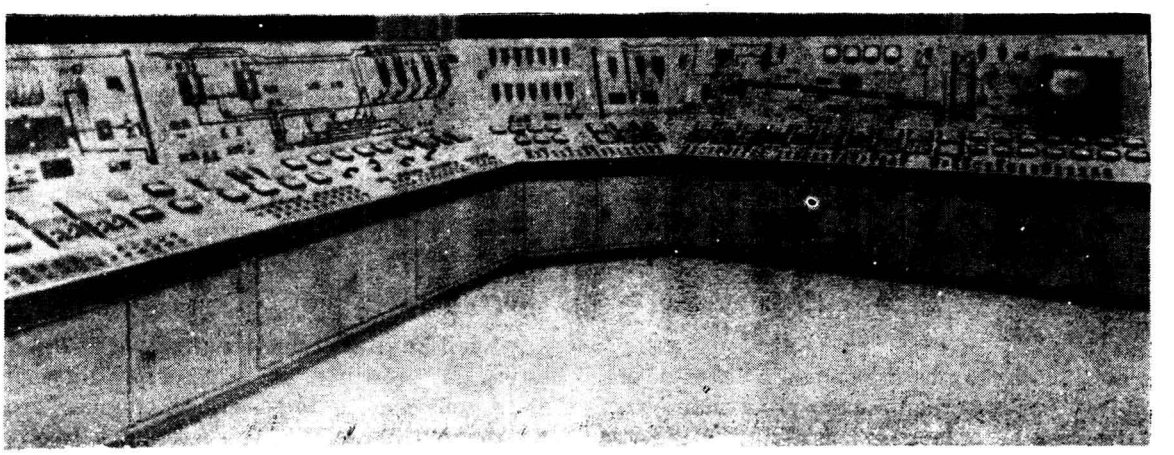

FIG. 1-8(A) Typical cement mill computer console carefully controlling and monitoring motors located remotely *(Courtesy Electric Machinery Mfg. Co.)*