NAC Executive Insights

Technical Fundamentals for Design and Construction of Electrical and Control Systems

Key Points: Design and Construction of Electrical Systems

- Electrical systems generate, transmit, distribute, and supply electric power to four main types of loads: large industrial equipment, electric motors, lighting, and receptacle or plug. The key technical fundamentals of these systems are Ohm's law as it relates to voltage and current; active and reactive electric power; three-phase power; and several types of electric motors.

- The main components of an electric grid are generators using fossil or renewable energy, transmission systems to move the electric energy at high voltages, distribution systems to connect the source and the load, and loads from four categories.

- Major elements of systems that supply electric energy to industrial plants, buildings, and infrastructure include: transformers, switchgear, feeder circuits (larger capacity), and branch circuits serving lighting and plug loads.

- Key activities to provide electric power systems include: 1) prepare schematic models or drawings and routing information for individual circuits; 2) obtain and install major electrical equipment; 3) design, fabricate, and install electrical raceway; 4) pull the electrical cable through the specified raceway and terminate it to designated points; and 5) complete testing and commissioning.

Key Points: Design and Construction of Control Systems

- Process control systems form the knowledge and information core of many facilities for refining, petrochemical, power, semiconductor, biotech, and several other types of process facilities. They are also a key element of control for heating ventilating and air conditioning (HVAC) systems.

- The technical fundamentals of feedback control focus on sensing, comparing actual with values desired or set points, and taking corrective actions when required.

- The major components of feedback control systems are: sensors for key parameters such as pressure, temperature, and flow; control systems to identify system operation outside of set values; and actuators to bring the actual value of the parameter within the acceptable range of values.

- Control systems are increasingly being credited as beneficial in monitoring the condition of construction resources, such as the production rate and health of earthmoving equipment and developing and accessing corrections.

Technical Fundamentals for Design and Construction of Electrical Systems

Purpose and Scope of Electrical Systems

Electrical systems supply energy to buildings, plants, and other loads. The electric current travels through transformers, switchgear, feeder circuits, and branch circuits to the eventual load served. The major types of loads served by electrical systems are motors and other types of equipment, lighting systems, and receptacle or "plug" loads. For commercial loads, the required capacity of the systems is generally estimated by watts per square foot for lighting and plug loads.

The scope of electric systems includes the equipment identified above and connectors or distribution trees that complete the systems and to the loads. These are typically electrical cable routed through conduit or cable tray or other specialized conductors for larger loads.

Ohm's Law (V = IR) relates the voltage applied to a circuit (V, analogous to pressure in a fluid system) to electrical current (I, analogous to water flow) times resistance (R, analogous to friction). Another important equation, P = V x I x cos theta, relates the power delivered to the voltage, the current, and the phase angle between the two.

Design Criteria, Materials, Constraints, and Work Processes

The major design criteria for electric power systems are the electrical load, the voltage at which it is delivered, and the current. These criteria determine the capacity and size of the electrical equipment, the total amperage of the circuit, and the rating of the insulation.

Spatial limitations create challenges for the design of electrical systems. The design of larger buildings and plants, for example, typically includes separate rooms for the main components of the electrical systems.

Main Components and Differences in Operations

Electrical systems include several types of components to perform different functions for their operation. Transformers use magnetic fields to raise or lower the output voltage, depending on the number of wire turns. High voltage transformers, such as 110 kV and much higher, are used in transmission systems to allow high voltage operation and increased efficiency. Lower voltage transformers are used with electrical distribution systems and switchgear to form load centers. Typical distribution currents are limited to 10 or 20 amps by the circuit breakers. The switchgear can be opened to isolate parts of the system similar to circuit breakers or can be closed to supply current to the load.

The purpose of an electrical raceway is to protect people working in the vicinity of the equipment and to protect the cable from physical damage. Electrical raceways are typically either cable tray or conduit. Cable trays are available in several standard sizes and are typically used with a support system; Unistrut™ is one of many product names. The different components in this system allow supporting all types of electrical components.

Electrical conduit is available in a range of types and sizes. Rigid and electric metallic tubing (EMT) are frequently used. Common practice is to limit conduit to four-inch diameter to allow the use of EMT and screwed connections. Rigid conduit requires threaded couplings. Unistrut™ is typically used to support all types of electrical systems.

Electrical cable conducts the electrical current from the source, typically switchgear or circuit breakers, to the load. The conductors are usually made of copper or aluminum. The insulation is rated by maximum voltage level to prevent failure of the material and possible fire damage. Electrical cable is available in several configurations, with four conductors for three phases and a ground the most common for intermediate voltage service.

Selected Resources and Operations to Build Electrical Systems

Setting large transformers, motors, or other large electrical equipment requires large capacity lifting equipment. Loads greater than 75 percent of the rated crane capacity are termed "critical lifts" by OSHA and therefore require specific plans for each lift. Positioning the equipment for safe lifting may require special roller devices or other methods of horizontal movement. The equipment is typically set over anchor bolts or is welded to plates embedded in the concrete. Setting and connecting the largest electrical equipment for industrial plants is a major construction challenge.

Cable tray and electrical conduit offer different advantages and disadvantages for cable pulling. Cable routed in tray is accessible at every turn, which allows locating branches at the most beneficial point. Tray, however, requires locating people at each change of direction, which increases cost. Cable routed in conduit allows pulling with smaller crews, but limits the number of cables and bends in each specific conduit run.

For electrical-intensive buildings or parts of plants, electrical conduit is often routed through concrete slabs and embedded in the concrete. This increases the scope of work required prior to concrete placement. Installation of exposed electrical conduit and cable tray follows the electrical equipment. Both offer the potential for shop fabrication and partial assembly to increase safety, quality, and productivity.

Best practice is to complete the entire installation of cable tray prior to cable pulling to allow maximum flexibility in planning the pull points. Specifications normally limit changes in direction in cable pulling to four to prevent cable damage. Pulling electrical through a raceway system requires special equipment and operations. If possible, pulling crews select pull points for positioning cable reels. Special equipment is usually located at the pull points to position and supply the electrical cable. Specifications will limit the number of bends in a conduit between pull points to avoid damaging the insulation during pulling operations. For pulling through cable trays, the crew often mounts pulleys at changes of direction to avoid excessive force on the cable.

Termination is the final step of completing installation of electrical systems. Depending on the cable size and insulation requirements, cable termination may require special tools, calibration, and quality control activities. The most common form of cable termination is the termed the "lug and screw." Electricians cut the cable to the correct length, strip about a half-inch of the insulation, thread the bare conductor through a lug, and crimp the lug and the conductor using a calibrated tool to form a single unit. The final step in the termination is to place the lug under the screw and tighten it to form a connection that can resist vibration and decrease the potential for loosening.

Commissioning electrical systems requires several types of testing. Continuity checks verify that the installation of the correct terminal lug has been made on the correct termination point. Insulation testing consists of applying high voltage to the conductor and checking the continuity of the protective covering or insulation.

The order of terminating the conductors for three-phase power determines the direction of rotation of a three-phase electric motor. Reverse rotation can damage the pump or other connected device. This requires removing a part of the coupling to allow free rotation of the motor and connecting the conductors to check the direction of rotation. If the direction is reversed, the crew will switch the leads and "bump" the motor again. Once correct rotation is verified, the crew can complete terminating the cables and align and connect the motor.

Related topics for electrical systems include: electrical design information for specific projects; National Electric Code; requirements for electrical raceway; electrical testing; technical characteristics of electrical cable; pre-cutting and special sequences for cable pulling; quality of electric power supply; and data and signals in control systems.

Technical Fundamentals for Design and Construction of Control Systems

Purpose and Scope of Control Systems

Control and instrumentation systems first collect information about the current status of the other types of systems they control. They then compare this "as is" information with the desired condition ("should be") and determine the corrective action required. To complete the cycle, the controller sends a signal to instruct the actuation part of the system, such as a valve or a thermostat, to take the necessary corrective action and monitor the results.

The key elements of control and instrumentation systems are the working fluid controlled, sensors, controllers, and actuators. Prior versions of these systems used pneumatic components for each of the operations. Current electronic versions concentrate the processing activities in microelectronic components.

Technical Fundamentals of Control Systems

Control systems for all types of applications are based on the technical fundamentals of feedback control systems. As described above, these systems maintain desired operational states in process and other systems. Although the concept and major activities are simple, the mathematics to simulate operation of control systems can become extremely complex. Parameters such as rate of change and overshoot provide additional flexibility of control system operation.

Design Criteria and Components of Control Systems

The main design and performance criteria for control systems are the response time to complete the corrective action after a disturbance and the accuracy of maintaining the set point for system operation. The electrical and electronic components to perform the operations that make up the control cycle are the main elements of the systems.

The main types of components for control systems are the working fluid, sensors, controllers, and actuators. Working fluids include water and other liquids and air and other gases. The most frequent control parameters are pressure, temperature, and flow rate. Control system designers may choose to implement the desired control function by changing the condition of the controlled variable to make the required change. For example, steam from boilers may heat process streams that deliver other streams at a specified temperature.

Resources and Operations to Install Control Systems

Installation of control systems may require installing control racks to centralize as many components as possible or distributing them for close proximity to the system being controlled. After locating and mounting the components of control systems, crews pull and terminate the cables. Information about the termination points at central locations or an individual device such as a control valve is a major resource.

After terminating all cables and verifying their continuity and correct location, commissioning begins. Commissioning the control systems involves running test functions for selected parts of the control loop. This continues until operation of the full system is verified.

Installing and commissioning control systems can bring about numerous challenges. Several steps can be taken, however, to lessen the risk of problems, such as:

- Review specification sheets for each device to verify the correct specifications and actual item shipped.
- Test and calibrate devices to verify correct operation.
- Provide a storage area with the required environmental controls.

Related Topics and Challenges for Control Systems

Major challenges can be found in several areas in designing and commissioning control systems. For example, writing and debugging software for control systems can be troublesome. Also, the coordination and integration of control systems with specialized software supplied with the main components requires patience and persistence to achieve the desired goals.

Variable frequency drive systems for electric motors illustrate the capability to develop specialized applications and the resulting benefits. The solid state components in these systems allow changing the standard drive frequency and resulting motor speed to allow operating the motor at the most efficient speed for the motor application, such as a fan in a HVAC system or a pump in a process system.

Additional Information Source for Electrical and Control Systems

For further information about design and construction of electrical and control systems, readers are encouraged to investigate the Instrumentation Society of America. Their website can be found at www.isa.org.

About the Author

Bob Tatum was elected to NAC membership in 2002. He served in the U.S. Army Corps of Engineers on infrastructure projects in Vietnam (1968-69). He worked as mechanical engineer, construction engineer, resident engineer, and area superintendent on power plant projects (1970-81). He joined the Stanford University construction faculty in 1983 and offered courses on construction engineering until retirement in 2015. His research focuses on integration and innovation in design and construction.