INST 230 (Motor Controls), section 1

Lab

Reversing three-phase motor starter circuit and PLC trainer construction: *Question 91*, **completed objectives due by the end of day 4, section 2**
PLC trainer details: *Question 92*

Feedback questions

Questions 81 through 90. "Feedback questions" serve as practice problems for upcoming exams and are completely optional. Your instructor will evaluate your answers and return detailed notes to you in response. Please submit them to your instructor **at the end of day 4**.

Exam

Day 4 of next section – only a simple calculator may be used! **Complete mastery of these objectives due by the next exam date**

Specific objectives for the "mastery" exam:

- Electricity Review: Calculate voltages and currents in a DC series-parallel resistor circuit given source and resistor values
- Sketch proper wire connections for a relay control circuit
- Determine status of a relay logic circuit given a schematic diagram and switch stimulus conditions
- Calculate either the full-load current or the horsepower of an electric motor (single-phase) given the line voltage and one of the other parameters
- Solve for a specified variable in an algebraic formula
- Determine the possibility of suggested faults in a simple circuit given measured values (voltage, current), a schematic diagram, and reported symptoms
- INST241 Review: Identify (American) wire colors for different thermocouple types
- INST251 Review: Determine the effect of a component fault or condition change in a single-loop controlled process
- INST260 Review: Convert between different numeration systems (decimal, binary, hexadecimal, octal)

Recommended daily schedule

Day 1

Theory session topic: Introduction to second-year program objectives, industry expectations

Questions 1 through 20; answer questions 1-4 in preparation for discussion (remainder for practice)

Take INST200 practice mastery exam

Note: Continuing students (i.e. those who have taken other INST200-level courses) may skip this introductory classroom session and focus on obtaining their PLC components in preparation for the INST231 course. All students need to attend the lab portion of Day 1, though!

Day 2

Theory session topic: AC power systems

Questions 21 through 40; answer questions 21-29 in preparation for discussion (remainder for practice)

Day 3

Theory session topic: AC electric motors and electrical workplace safety

Note: you will need access to the latest version of the NFPA 70E Standard for Electrical Safety in the Workplace in order to answer several of today's questions!

Questions 41 through 60; answer questions 41-48 in preparation for discussion (remainder for practice)

Day 4

Theory session topic: Relay circuits and motor controls

Questions 61 through 80; answer questions 61-69 in preparation for discussion (remainder for practice)

Feedback questions *(81 through 90)* are optional and may be submitted for review at the end of the day

How To . . .

Access the worksheets and textbook: go to the *Socratic Instrumentation* website located at `http://www.ibiblio.org/kuphaldt/socratic/sinst` to find worksheets for every 2nd-year course section organized by quarter, as well as both the latest "stable" and "development" versions of the *Lessons In Industrial Instrumentation* textbook. Download and save these documents to your computer.

Maximize your learning: complete all homework *before* class starts, ready to be assessed as described in the "Inverted Session Formats" pages. Use every minute of class and lab time productively. Follow all the tips outlined in "Question 0" as well as your instructor's advice. Make every reasonable effort to solve problems on your own before seeking help.

Identify upcoming assignments and deadlines: read the first page of each course worksheet.

Relate course days to calendar dates: reference the calendar spreadsheet file (`calendar.xlsx`), found on the BTC campus `Y:` network drive. A printed copy is posted in the Instrumentation classroom.

Locate industry documents assigned for reading: use the Instrumentation Reference provided by your instructor (on CD-ROM and on the BTC campus `Y:` network drive). There you will find a file named `00_index_OPEN_THIS_FILE.html` readable with any internet browser. Click on the "Quick-Start Links" to access assigned reading documents, organized per course, in the order they are assigned.

Study for the exams: Mastery exams assess specific skills critically important to your success, listed near the top of the front page of each course worksheet for your review. Familiarize yourself with this list and pay close attention when those topics appear in homework and practice problems. Proportional exams feature problems you haven't seen before that are solvable using general principles learned throughout the current and previous courses, for which the only adequate preparation is independent problem-solving practice every day. Answer the "feedback questions" (practice exams) in each course section to hone your problem-solving skills, as these are similar in scope and complexity to proportional exams. Answer these feedback independently (i.e. no help from classmates) in order to most accurately assess your readiness.

Calculate course grades: download the "Course Grading Spreadsheet" (`grades_template.xlsx`) from the Socratic Instrumentation website, or from the BTC campus `Y:` network drive. Enter your quiz scores, test scores, lab scores, and attendance data into this Excel spreadsheet and it will calculate your course grade. You may compare your calculated grades against your instructors' records at any time.

Identify courses to register for: read the "Sequence" page found in each worksheet.

Receive extra instructor help: ask during lab time, or during class time, or by appointment.

Identify job openings: regularly monitor job-search websites. Set up informational interviews at workplaces you are interested in. Participate in jobshadows and internships. Apply to jobs long before graduation, as some employers take *months* to respond! Check your BTC email account daily, because your instructor broadcast-emails job postings to all students as employers submit them to BTC.

Impress employers: sign the FERPA release form granting your instructors permission to share academic records, then make sure your performance is worth sharing. Document your project and problem-solving experiences for reference during interviews. Honor all your commitments.

Begin your career: participate in jobshadows and internships while in school to gain experience and references. Take the first Instrumentation job that pays the bills, and give that employer at least two years of good work to pay them back for the investment they have made in you. Employers look at delayed employment, as well as short employment spans, very negatively. Failure to pass a drug test is an immediate disqualifier, as is falsifying any information. Criminal records may also be a problem.

file `howto`

General Values, Expectations, and Standards

Success in this career requires professional integrity, resourcefulness, persistence, close attention to detail, and intellectual curiosity. If you are ever in doubt as to the values you should embody, just ask yourself what kind of a person you would prefer to hire for your own enterprise. Those same values will be upheld within this program.

Learning is the top priority in this program. Every circumstance, every incident, every day will be treated as a learning opportunity, every mistake as a "teachable moment". Every form of positive growth, not just academic ability, will be regarded as real learning.

Responsibility means *ensuring* the desired outcome, not just *trying* to achieve the outcome. If your efforts do not yield the expected results, only you can make it right.

Integrity means being honest and forthright in all your words and actions, doing your very best every time and never taking credit for the achievement of another.

Safety means doing every job correctly and ensuring others are not endangered. Lab safety standards include wearing closed-toed shoes and safety glasses in the lab room during lab hours, wearing ear protection around loud sounds, using ladders to reach high places, using proper lock-ou/tag-out procedures, no energized electrical work above 30 volts without an instructor present in the lab room, and no power tool use without an instructor present in the lab room.

Diligence means exercising self-discipline and persistence in your studies, realizing that hard work is a necessary condition for success. This means, among other things, investing the necessary time and effort in studying, reading instructions, paying attention to details, utilizing the skills and tools you already possess, and avoiding shortcuts.

Mastery means the job is not done until it is done *correctly*: all objectives achieved, all problems solved, all documentation complete, and no errors remaining.

Self-management means allocating your resources (time, equipment, labor) wisely, and not just focusing on the nearest deadline.

Communication means clearly conveying your thoughts and paying attention to what others convey. Remember that no one can read your mind, and so it is incumbent upon you to communicate any and all important information.

Teamwork means working constructively with your classmates so as to maximize their learning as well as your own.

Initiative means recognizing needs and taking action to meet those needs without encouragement or direction from others.

Representation means your actions are a reflection of this program and not just of yourself. Doors of opportunity for all BTC graduates may be opened or closed by your own conduct. Unprofessional behavior during tours, jobshadows, internships, and/or jobs reflects poorly on the program and will negatively bias employers.

Trustworthiness is the result of consistently exercising these values: people will recognize you as someone they can rely on to get the job done, and therefore someone they would want to hire.

Respect means acknowledging the intrinsic value, capabilities, and responsibilities of those around you. Respect may be gained by consistent demonstration of valued behaviors, and it may be lost through betrayal of trust.

Punctuality and Attendance: late arrivals are penalized at a rate of 1% grade deduction per incident. Absence is penalized at a rate of 1% per hour (rounded to the nearest hour) except when employment-related, school-related, weather-related, or required by law (e.g. court summons). Absences may be made up by directing the instructor to apply "sick hours" (12 hours of sick time available per quarter). Classmates may donate their unused sick hours. Sick hours may not be applied to unannounced absences, so be sure to alert your instructor and teammates as soon as you know you will be absent or late. Absence on an exam day will result in a zero score for that exam, unless due to a documented emergency.

Mastery: any assignment or objective labeled as "mastery" must be completed with 100% competence (with multiple opportunities to re-try). Failure to complete any mastery objective(s) by the deadline date caps your grade at a C−. Failure to complete by the end of the *next* school day results in a failing (F) grade for that course.

Time Management: Frivolous activities (e.g. games, social networking, internet surfing) are unacceptable when work is unfinished. Trips to the cafeteria for food or coffee, smoke breaks, etc. must not interfere with team participation.

Orderliness: Keep your work area clean and orderly, discarding trash, returning tools at the end of every lab session, and participating in all scheduled lab clean-up sessions. Project wiring, especially in shared areas such as junction boxes, must not be left in disarray at the end of a lab shift. Label any failed equipment with a detailed description of its symptoms.

Independent Study: the "inverted" instructional model used in this program requires independent reading and problem-solving, where every student must demonstrate their learning at the start of the class session. Question 0 of every worksheet lists practical study tips. The "Inverted Session Formats" pages found in every worksheet outline the format and grading standards for inverted class sessions.

Independent Problem-Solving: make an honest effort to solve every problem before seeking help. When working in the lab, help will not be given to you unless and until you run your own diagnostic tests.

Teamwork: inform your teammates if you need to leave the work area for any reason. Any student regularly compromising team performance through absence, tardiness, disrespect, or other disruptive behavior(s) will be removed from the team and required to complete all labwork individually. The same is true for students found inappropriately relying on teammates.

Communication: check your email account daily for important messages from your instructor. Ask the instructor to clarify any assignment or exam question you find confusing, and be sure to do so express your work clearly and compellingly.

Academic Progress: your instructor will record your academic achievement, as well as comments on any negative behavior, and will share all these records with employers provided you have signed the FERPA release form. You are welcome to see these records at any time, and are encouraged to track your own academic progress using the grade spreadsheet template.

Office Hours: your instructor's office hours are by appointment, except in cases of emergency. Email is the preferred method for setting up an appointment with your instructor to discuss something in private.

Grounds for Failure: a failing (F) grade will be earned in any course if any mastery objectives are past deadline by more than one school day, or if any of the following behaviors are demonstrated: false testimony (lying) to your instructor, cheating on any assignment or assessment, plagiarism (presenting another's work as your own), willful violation of a safety policy, theft, harassment, intoxication, or destruction of property. Such behaviors are grounds for immediate termination in this career, and as such will not be tolerated here.

file `values`

Inverted session formats

The basic concept of an "inverted" learning environment is that the traditional allocations of student time are reversed: instead of students attending an instructor-led session to receive new information and then practicing the application of that information outside of the classroom in the form of homework, students in an inverted class encounter new information outside of the classroom via homework and apply that information in the classroom session under the instructor's tutelage.

A natural question for instructors, then, is what their precise role is in an inverted classroom and how to organize that time well. Here I will list alternate formats suitable for an inverted classroom session, each of them tested and proven to work.

Small sessions

Students meet with instructors in small groups for short time periods. Groups of 4 students meeting for 30 minutes works very well, but groups as large as 8 students apiece may be used if time is limited. Each of these sessions begins with a 5 to 10 minute graded inspection of homework with individual questioning, to keep students accountable for doing the homework. The remainder of the session is a dialogue focusing on the topics of the day, the instructor challenging each student on the subject matter in Socratic fashion, and also answering students' questions. A second grade measures each student's comprehension of the subject matter by the end of the session.

This format also works via teleconferencing, for students unable to attend a face-to-face session on campus.

Large sessions

Students meet with instructors in a standard classroom (normal class size and period length). Each of these sessions begins with a 10 minute graded quiz (closed-book) on the homework topic(s), to keep students accountable for doing the homework. Students may leave the session as soon as they "check off" with the instructor in a Socratic dialogue as described above (instructor challenging each student to assess their comprehension, answering questions, and grading the responses). Students sign up for check-off on the whiteboard when they are ready, typically in groups of no more than 4. Alternatively, the bulk of the class session may be spent answering student questions in small groups, followed by another graded quiz at the end.

Correspondence

This format works for students unable to attend a "face-to-face" session, and who must correspond with the instructor via email or other asynchronous medium. Each student submits a thorough presentation of their completed homework, which the instructor grades for completeness and accuracy. The instructor then replies back to the student with challenge questions, and also answers questions the student may have. As with the previous formats, the student receives another grade assessing their comprehension of the subject matter by the close of the correspondence dialogue.

In all formats, students are held accountable for completion of their homework, "completion" being defined as successfully interpreting the given information from source material (e.g. accurate outlines of reading or video assignments) and constructive effort to solve given problems. It must be understood in an inverted learning environment that students *will* have legitimate questions following a homework assignment, and that it is therefore unreasonable to expect mastery of the assigned subject matter. What is reasonable to expect from each and every student is a basic outline of the source material (reading or video assignments) complete with major terms defined and major concepts identified, plus a good-faith effort to solve every problem. Question 0 (contained in every worksheet) lists multiple strategies for effective study and problem-solving.

Sample rubric for pre-assessments

- **No credit** = Any homework question unattempted (i.e. no effort shown on one or more questions)
- **Half credit** = Misconception(s) on any major topic explained in the assigned reading; answers shown with no supporting work; reading outline missing important topics; unable to explain the reading outline or solution methods represented in written work; failure to follow clear instruction(s); illegible writing
- **Full credit** = Every homework question answered, with any points of confusion clearly articulated; all important concepts from reading assignments accurately expressed in the outline and clearly articulated when called upon by the instructor to explain

The minimum expectation at the start of every student-instructor session is that all students have made a good-faith effort to complete 100% of their assigned homework. This does not necessarily mean all answers will be correct, or that all concepts are fully understood, because one of the purposes of the meeting between students and instructor is to correct remaining misconceptions and answer students' questions. However, experience has shown that without accountability for the homework, a substantial number of students will not put forth their best effort and that this compromises the whole learning process. Full credit is reserved for good-faith effort, where each student thoughtfully applies the study and problem-solving recommendations given to them (see Question 0).

Sample rubric for post-assessments

- **No credit** = Failure to comprehend one or more key concepts; failure to apply logical reasoning to the solution of problem(s)
- **Half credit** = Some misconceptions persist by the close of the session; problem-solving is inconsistent; limited contribution to the dialogue
- **Full credit** = Socratic queries answered thoughtfully; effective reasoning applied to problems; ideas communicated clearly and accurately; responds intelligently to questions and statements made by others in the session; adds new ideas and perspectives

The minimum expectation is that each and every student engages with the instructor and with fellow students during the Socratic session: posing intelligent questions of their own, explaining their reasoning when challenged, and otherwise positively contributing to the discussion. Passive observation and listening is not an option here – every student must be an active participant, contributing something original to every dialogue. If a student is confused about any concept or solution, it is their responsibility to ask questions and seek resolution.

If a student happens to be absent for a scheduled class session and is therefore unable to be assessed on that day's study, they may schedule a time with the instructor to demonstrate their comprehension at some later date (before the end of the quarter when grades must be submitted). These same standards of performance apply equally make-up assessments: either inspection of homework or a closed-book quiz for the pre-assessment, and either a Socratic dialogue with the instructor or another closed-book quiz for the post-assessment.

file `format`

INSTRUCTOR CONTACT INFORMATION:

Tony Kuphaldt
(360)-752-8477 [office phone]
(360)-752-7277 [fax]
`tony.kuphaldt@btc.edu`

DEPT/COURSE #: INST 230

CREDITS: 3 **Lecture Hours:** 11 **Lab Hours:** 44 **Work-based Hours:** 0

COURSE TITLE: Motor Controls

COURSE DESCRIPTION: In this course you will learn how to wire, configure, and use electromechanical contactors to control electric motors and other discrete (on/off) control elements for real processes. You will also learn how to wire, configure, and use variable-frequency motor controls to use three-phase AC motors as final control elements. **Prerequisite courses:** ELTR145 (Digital 2) and MATH&141 (Precalculus 1) with a minimum grade of "C"

COURSE OUTCOMES: Commission, analyze, and efficiently diagnose motor control systems incorporating electromechanical relays and variable-frequency drive (VFD) units.

COURSE OUTCOME ASSESSMENT: Motor control system commissioning, analysis, and diagnosis outcomes are ensured by measuring student performance against mastery standards, as documented in the Student Performance Objectives. Failure to meet all mastery standards by the next scheduled exam day will result in a failing grade for the course.

STUDENT PERFORMANCE OBJECTIVES:

- Without references or notes, within a limited time (3 hours total for each exam session), independently perform the following tasks. Multiple re-tries are allowed on mastery (100% accuracy) objectives, each with a different set of problems:
  → Calculate voltages and currents in a DC series-parallel resistor circuit given source and resistor values, with 100% accuracy (mastery)
  → Sketch proper wire connections for a relay control circuit given a pictorial or schematic diagram of the components, with 100% accuracy (mastery)
  → Determine status of a relay logic circuit given a schematic diagram and switch stimulus conditions, with 100% accuracy (mastery)
  → Calculate current and horsepower ratings of a single-phase electrical motor for a given line voltage with 100% accuracy (mastery)
  → Solve for specified variables in algebraic formulae, with 100% accuracy (mastery)
  → Determine the possibility of suggested faults in a simple circuit given measured values (voltage, current), a schematic diagram, and reported symptoms, with 100% accuracy (mastery)
  → Predict the response of electric motor control systems to component faults and changes in process conditions, given pictorial and/or schematic illustrations
  → Sketch proper power and signal connections between individual motor control components to fulfill a specified control system function, given pictorial and/or schematic illustrations of those instruments
- In a team environment and with full access to references, notes, and instructor assistance, perform the following tasks:
  → Demonstrate proper use of safety equipment and application of safe procedures while using power tools, and working on live systems
  → Communicate effectively with teammates to plan work, arrange for absences, and share responsibilities in completing all labwork
  → Construct and commission a three-phase reversing motor starter system
  → Connect three power transformers together to form a three-phase transformer bank with specified configuration (e.g. Delta-Delta, Delta-Wye)
  → Generate an accurate wiring diagram compliant with industry standards documenting your team's motor control system
  → Construct and test a PLC "trainer" board utilizing a small PLC connected to input switches and indicator lamps
- Independently perform the following tasks on a functioning motor starter system with 100% accuracy (mastery). Multiple re-tries are allowed with different specifications/conditions each time):
  → Properly wire a start/stop motor control circuit, given components randomly selected by the instructor
  → Test for ground faults in a motor starter system using an insulation tester ("megger")
  → Demonstrate how to secure power to a motor starter using proper lock-out and testing procedures
  → Diagnose a random fault placed in another team's motor control system by the instructor within a limited time using no test equipment except a multimeter, logically justifying your steps in the instructor's direct presence

COURSE OUTLINE: A course calendar in electronic format (Excel spreadsheet) resides on the Y: network drive, and also in printed paper format in classroom DMC130, for convenient student access. This calendar is updated to reflect schedule changes resulting from employer recruiting visits, interviews, and other impromptu events. Course worksheets provide comprehensive lists of all course assignments and activities, with the first page outlining the schedule and sequencing of topics and assignment due dates. These worksheets are available in PDF format at `http://www.ibiblio.org/kuphaldt/socratic/sinst`

- INST230 Section 1 (Motors and relay controls): 4 days theory and labwork
- INST230 Section 2 (Solid-state motor controls): 3 days theory and labwork + 1 day for mastery/proportional exams

METHODS OF INSTRUCTION: Course structure and methods are intentionally designed to develop critical-thinking and life-long learning abilities, continually placing the student in an active rather than a passive role.

- **Independent study:** daily worksheet questions specify *reading assignments*, *problems* to solve, and *experiments* to perform in preparation (before) classroom theory sessions. Open-note quizzes and work inspections ensure accountability for this essential preparatory work. The purpose of this is to convey information and basic concepts, so valuable class time isn't wasted transmitting bare facts, and also to foster the independent research ability necessary for self-directed learning in your career.
- **Classroom sessions:** a combination of *Socratic discussion*, short *lectures*, *small-group* problem-solving, and hands-on *demonstrations/experiments* review and illuminate concepts covered in the preparatory questions. The purpose of this is to develop problem-solving skills, strengthen conceptual understanding, and practice both quantitative and qualitative analysis techniques.
- **Lab activities:** an emphasis on constructing and documenting *working projects* (real instrumentation and control systems) to illuminate theoretical knowledge with practical contexts. Special projects off-campus or in different areas of campus (e.g. BTC's Fish Hatchery) are encouraged. Hands-on *troubleshooting exercises* build diagnostic skills.
- **Feedback questions:** sets of *practice problems* at the end of each course section challenge your knowledge and problem-solving ability in current as as well as first year (Electronics) subjects. These are optional assignments, counting neither for nor against your grade. Their purpose is to provide you and your instructor with direct feedback on what you have learned.

STUDENT ASSIGNMENTS/REQUIREMENTS: All assignments for this course are thoroughly documented in the following course worksheets located at:
`http://www.ibiblio.org/kuphaldt/socratic/sinst/index.html`

- `INST230_sec1.pdf`
- `INST230_sec2.pdf`

EVALUATION AND GRADING STANDARDS: (out of 100% for the course grade)

- Completion of all mastery objectives = 50%
- Mastery exam score = 10%
- Proportional exam score = 30%
- Lab questions = 10%
- Quiz penalty = −1% per failed quiz
- Tardiness penalty = −1% per incident (1 "free" tardy per course)
- Attendance penalty = −1% per hour (12 hours "sick time" per quarter)
- Extra credit = +5% per project (assigned by instructor based on individual learning needs)

All grades are criterion-referenced (i.e. no grading on a "curve")

100% ≥ **A** ≥ 95%	95% > **A-** ≥ 90%		
90% > **B+** ≥ 86%	86% > **B** ≥ 83%	83% > **B-** ≥ 80%	
80% > **C+** ≥ 76%	76% > **C** ≥ 73%	73% > **C-** ≥ 70% (minimum passing course grade)	
70% > **D+** ≥ 66%	66% > **D** ≥ 63%	63% > **D-** ≥ 60%	60% > **F**

Absence on a scheduled exam day will result in a 0% score for the proportional exam unless you provide documented evidence of an unavoidable emergency.

If you fail a mastery exam, you must re-take a different version of that mastery exam on a different day. Multiple re-tries are allowed, on a different version of the exam each re-try. There is no penalty levied on your course grade for re-taking mastery exams, but failure to successfully pass a mastery exam by the due date will result in a failing grade (F) for the course.

If any other "mastery" objectives are not completed by their specified deadlines, your overall grade for the course will be capped at 70% (C- grade), and you will have one more school day to complete the unfinished objectives. Failure to complete those mastery objectives by the end of that extra day (except in the case of documented, unavoidable emergencies) will result in a failing grade (F) for the course.

"Lab questions" are assessed in a written exam format, typically on the last scheduled day of the lab project. Grading is as follows: full credit for thorough, correct answers; half credit for partially correct answers; and zero credit for major conceptual errors.

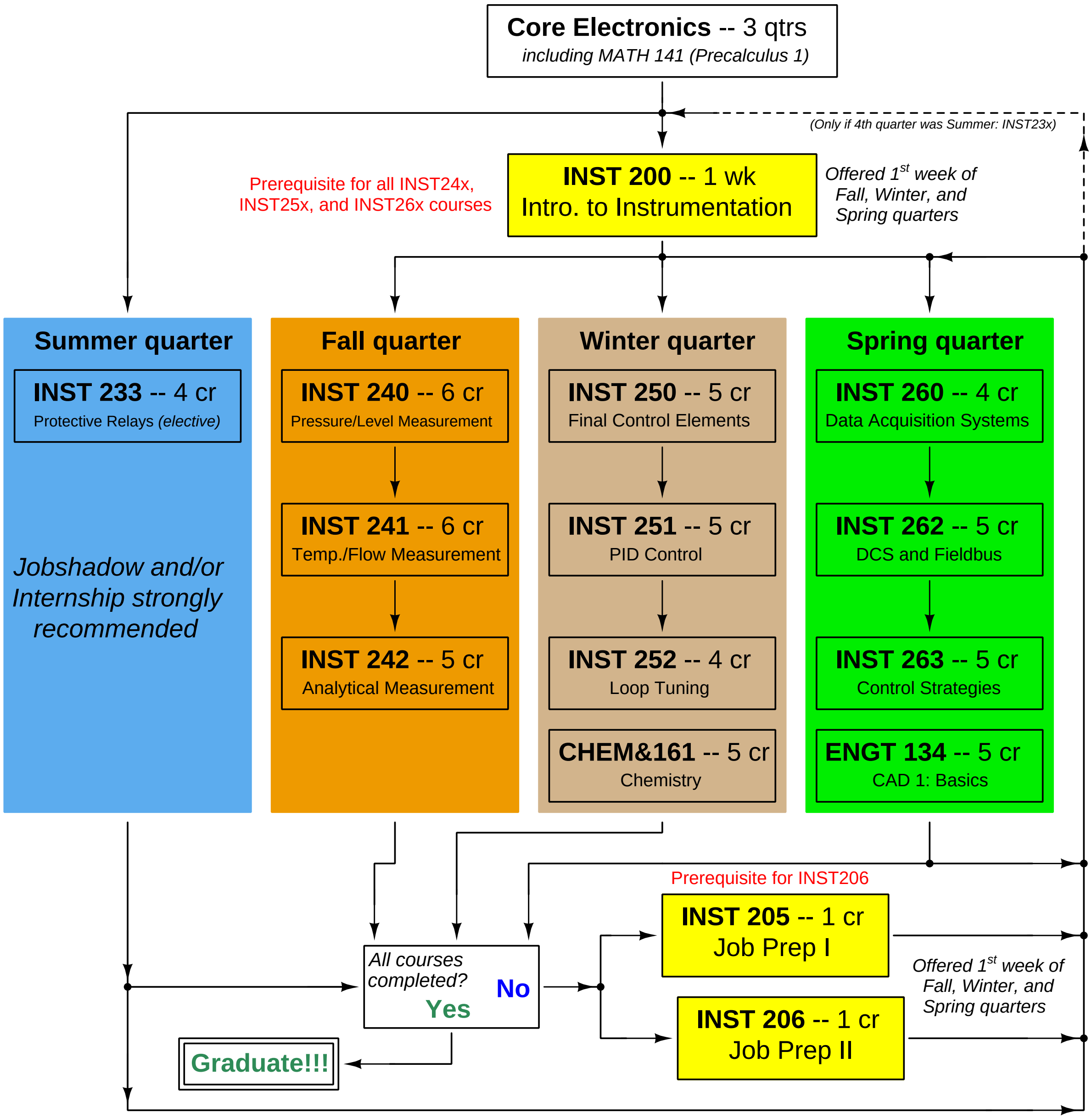
Individual preparation for Socratic dialogue sessions is measured by a "prep quiz" and/or personal inspection of your work by the instructor. A second ("summary") quiz score for every Socratic session marks your participatory dialogue and ability to give reasoned answers to challenge questions on that session's topic(s). In the event of absence, these scores may be credited by having your preparatory work and demonstration of understanding reviewed at any time before the end of the quarter in a one-on-one dialogue with the instructor.

Extra credit opportunities exist for each course, and may be assigned to students upon request. The student and the instructor will first review the student's performance on feedback questions, homework, exams, and any other relevant indicators in order to identify areas of conceptual or practical weakness. Then, both will work together to select an appropriate extra credit activity focusing on those identified weaknesses, for the purpose of strengthening the student's competence. A due date will be assigned (typically two weeks following the request), which must be honored in order for any credit to be earned from the activity. Extra credit may be denied at the instructor's discretion if the student has not invested the necessary preparatory effort to perform well (e.g. lack of preparation for daily class sessions, poor attendance, no feedback questions submitted, etc.).

REQUIRED STUDENT SUPPLIES AND MATERIALS:

- Course worksheets available for download in PDF format
- *Lessons in Industrial Instrumentation* textbook, available for download in PDF format
  → Access worksheets and book at: `http://www.ibiblio.org/kuphaldt/socratic/sinst`
- Ampacity ratings of wire from the *National Electrical Code* (NFPA 70) reference, available for free online viewing at `http://www.nfpa.org`
- NFPA 70E "Standard for Electrical Safety in the Workplace"
- Spiral-bound notebook for reading annotation, homework documentation, and note-taking.
- Instrumentation reference CD-ROM (free, from instructor). This disk contains many tutorials and datasheets in PDF format to supplement your textbook(s).
- Tool kit (see detailed list)
- Simple scientific calculator (non-programmable, non-graphing, no unit conversions, no numeration system conversions), TI-30Xa or TI-30XIIS recommended
- Portable personal computer with Ethernet port and wireless. Windows OS strongly preferred, tablets discouraged.

file `INST230syllabus`


Core Electronics -- 3 qtrs
including MATH 141 (Precalculus 1)
(Only if 4th quarter was Summer: INST23x)
Prerequisite for all INST24x, INST25x, and INST26x courses
INST 200 -- 1 wk
Intro. to Instrumentation
Offered 1st week of Fall, Winter, and Spring quarters
Summer quarter
INST 233 -- 4 cr
Protective Relays *(elective)*
Jobshadow and/or Internship strongly recommended
Fall quarter
INST 240 -- 6 cr
Pressure/Level Measurement
INST 241 -- 6 cr
Temp./Flow Measurement
INST 242 -- 5 cr
Analytical Measurement
Winter quarter
INST 250 -- 5 cr
Final Control Elements
INST 251 -- 5 cr
PID Control
INST 252 -- 4 cr
Loop Tuning
CHEM&161 -- 5 cr
Chemistry
Spring quarter
INST 260 -- 4 cr
Data Acquisition Systems
INST 262 -- 5 cr
DCS and Fieldbus
INST 263 -- 5 cr
Control Strategies
ENGT 134 -- 5 cr
CAD 1: Basics
Prerequisite for INST206
INST 205 -- 1 cr
Job Prep I
INST 206 -- 1 cr
Job Prep II
Offered 1st week of Fall, Winter, and Spring quarters
All courses completed?
No
Yes
Graduate!!!

The particular sequence of courses you take during the second year depends on when you complete all first-year courses and enter the second year. Since students enter the second year of Instrumentation at four different times (beginnings of Summer, Fall, Winter, and Spring quarters), the particular course sequence for any student will likely be different from the course sequence of classmates.

Some second-year courses are only offered in particular quarters with those quarters not having to be in sequence, while others are offered three out of the four quarters and must be taken in sequence. The following layout shows four typical course sequences for second-year Instrumentation students, depending on when they first enter the second year of the program:

Possible course schedules depending on date of entry into 2nd year

Beginning in Summer	*Beginning in Fall*	*Beginning in Winter*	*Beginning in Spring*
July–Aug. **Summer quarter** **INST 233** -- 4 cr Protective Relays *(elective)* *Jobshadow and/or Internship strongly recommended*	Sept.–Dec. **Fall quarter** **INST 200** -- 1 wk Intro. to Instrumentation **INST 240** -- 6 cr Pressure/Level Measurement **INST 241** -- 6 cr Temp./Flow Measurement **INST 242** -- 5 cr Analytical Measurement	Jan.–Mar. **Winter quarter** **INST 200** -- 1 wk Intro. to Instrumentation **INST 250** -- 5 cr Final Control Elements **INST 251** -- 5 cr PID Control **INST 252** -- 4 cr Loop Tuning **CHEM&161** -- 5 cr Chemistry	April–June **Spring quarter** **INST 200** -- 1 wk Intro. to Instrumentation **INST 260** -- 4 cr Data Acquisition Systems **INST 262** -- 5 cr DCS and Fieldbus **INST 263** -- 5 cr Control Strategies **ENGT 134** -- 5 cr CAD 1: Basics
Sept.–Dec. **Fall quarter** **INST 200** -- 1 wk Intro. to Instrumentation **INST 240** -- 6 cr Pressure/Level Measurement **INST 241** -- 6 cr Temp./Flow Measurement **INST 242** -- 5 cr Analytical Measurement	Jan.–Mar. **Winter quarter** **INST 205** -- 1 cr Job Prep I **INST 250** -- 5 cr Final Control Elements **INST 251** -- 5 cr PID Control **INST 252** -- 4 cr Loop Tuning **CHEM&161** -- 5 cr Chemistry	April–June **Spring quarter** **INST 205** -- 1 cr Job Prep I **INST 260** -- 4 cr Data Acquisition Systems **INST 262** -- 5 cr DCS and Fieldbus **INST 263** -- 5 cr Control Strategies **ENGT 134** -- 5 cr CAD 1: Basics	July–Aug. **Summer quarter** **INST 233** -- 4 cr Protective Relays *(elective)* *Jobshadow and/or Internship strongly recommended*
Jan.–Mar. **Winter quarter** **INST 205** -- 1 cr Job Prep I **INST 250** -- 5 cr Final Control Elements **INST 251** -- 5 cr PID Control **INST 252** -- 4 cr Loop Tuning **CHEM&161** -- 5 cr Chemistry	April–June **Spring quarter** **INST 206** -- 1 cr Job Prep II **INST 260** -- 4 cr Data Acquisition Systems **INST 262** -- 5 cr DCS and Fieldbus **INST 263** -- 5 cr Control Strategies **ENGT 134** -- 5 cr CAD 1: Basics	July–Aug. **Summer quarter** **INST 233** -- 4 cr Protective Relays *(elective)* *Jobshadow and/or Internship strongly recommended*	Sept.–Dec. **Fall quarter** **INST 205** -- 1 cr Job Prep I **INST 240** -- 6 cr Pressure/Level Measurement **INST 241** -- 6 cr Temp./Flow Measurement **INST 242** -- 5 cr Analytical Measurement
April–June **Spring quarter** **INST 206** -- 1 cr Job Prep II **INST 260** -- 4 cr Data Acquisition Systems **INST 262** -- 5 cr DCS and Fieldbus **INST 263** -- 5 cr Control Strategies **ENGT 134** -- 5 cr CAD 1: Basics	July–Aug. **Summer quarter** **INST 233** -- 4 cr Protective Relays *(elective)* *Jobshadow and/or Internship strongly recommended*	Sept.–Dec. **Fall quarter** **INST 206** -- 1 cr Job Prep II **INST 240** -- 6 cr Pressure/Level Measurement **INST 241** -- 6 cr Temp./Flow Measurement **INST 242** -- 5 cr Analytical Measurement	Jan.–Mar. **Winter quarter** **INST 206** -- 1 cr Job Prep II **INST 250** -- 5 cr Final Control Elements **INST 251** -- 5 cr PID Control **INST 252** -- 4 cr Loop Tuning **CHEM&161** -- 5 cr Chemistry
Graduation!	***Graduation!***	***Graduation!***	***Graduation!***

file sequence

General tool and supply list

Wrenches

- Combination (box- and open-end) wrench set, 1/4" to 3/4" – *the most important wrench sizes are 7/16", 1/2", 9/16", and 5/8"; get these immediately!*
- Adjustable wrench, 6" handle (sometimes called "Crescent" wrench)
- Hex wrench ("Allen" wrench) set, fractional – 1/16" to 3/8"
- *Optional:* Hex wrench ("Allen" wrench) set, metric – 1.5 mm to 10 mm
- *Optional:* Miniature combination wrench set, 3/32" to 1/4" (sometimes called an "ignition wrench" set)

Note: *when turning any threaded fastener, one should choose a tool engaging the maximum amount of surface area on the fastener's head in order to reduce stress on that fastener. (e.g. Using box-end wrenches instead of adjustable wrenches; using the proper size and type of screwdriver; never using any tool that mars the fastener such as pliers or vise-grips unless absolutely necessary.)*

Pliers

- Needle-nose pliers
- Tongue-and-groove pliers (sometimes called "Channel-lock" pliers)
- Diagonal wire cutters (sometimes called "dikes")

Screwdrivers

- Slotted, 1/8" and 1/4" shaft
- Phillips, #1 and #2
- Jeweler's screwdriver set
- *Optional:* Magnetic multi-bit screwdriver (e.g. Klein Tools model 70035)

Electrical

- Multimeter, Fluke model 87-IV or better
- Alligator-clip jumper wires
- Soldering iron (10 to 40 watt) and rosin-core solder
- Resistor, potentiometer, diode assortments (from first-year lab kits)
- Package of insulated compression-style fork terminals (14 to 18 AWG wire size, #10 stud size)
- Wire strippers/terminal crimpers for 10 AWG to 18 AWG wire and insulated terminals
- *Optional:* ratcheting terminal crimp tool (e.g. Paladin 1305, Ferrules Direct FDT10011, or equivalent)

Safety

- Safety glasses or goggles (available at BTC bookstore)
- Earplugs (available at BTC bookstore)

Miscellaneous

- Simple scientific calculator (non-programmable, non-graphing, no conversions), TI-30Xa or TI-30XIIS recommended. Required for some exams!
- Portable personal computer with Ethernet port and wireless. Windows OS strongly preferred, tablets discouraged.
- Masking tape (for making temporary labels)
- Permanent marker pen
- Teflon pipe tape
- Utility knife
- Tape measure, 12 feet minimum
- Flashlight

An inexpensive source of tools is your local pawn shop. Look for tools with unlimited lifetime guarantees (e.g. *Sears* "Craftsman" brand). Check for BTC student discounts as well!

file `tools`

Methods of instruction

This course develops self-instructional and diagnostic skills by placing students in situations where they are required to research and think independently. In all portions of the curriculum, the goal is to avoid a passive learning environment, favoring instead *active engagement* of the learner through reading, reflection, problem-solving, and experimental activities. The curriculum may be roughly divided into two portions: *theory* and *practical*.

Theory

In the theory portion of each course, students independently research subjects *prior* to entering the classroom for discussion. This means working through all the day's assigned questions as completely as possible. This usually requires a fair amount of technical reading, and may also require setting up and running simple experiments. At the start of the classroom session, the instructor will check each student's preparation with a quiz. Students then spend the rest of the classroom time working in groups and directly with the instructor to *thoroughly* answer all questions assigned for that day, articulate problem-solving strategies, and to approach the questions from multiple perspectives. To put it simply: fact-gathering happens outside of class and is the individual responsibility of each student, so that class time may be devoted to the more complex tasks of critical thinking and problem solving where the instructor's attention is best applied.

Classroom theory sessions usually begin with either a brief Q&A discussion or with a "Virtual Troubleshooting" session where the instructor shows one of the day's diagnostic question diagrams while students propose diagnostic tests and the instructor tells those students what the test results would be given some imagined ("virtual") fault scenario, writing the test results on the board where all can see. The students then attempt to identify the nature and location of the fault, based on the test results.

Each student is free to leave the classroom when they have completely worked through all problems and have answered a "summary" quiz designed to gauge their learning during the theory session. If a student finishes ahead of time, they are free to leave, or may help tutor classmates who need extra help.

The express goal of this "inverted classroom" teaching methodology is to help each student cultivate critical-thinking and problem-solving skills, and to sharpen their abilities as independent learners. While this approach may be very new to you, it is more realistic and beneficial to the type of work done in instrumentation, where critical thinking, problem-solving, and independent learning are "must-have" skills.

Lab

In the lab portion of each course, students work in teams to install, configure, document, calibrate, and troubleshoot working instrument loop systems. Each lab exercise focuses on a different type of instrument, with a eight-day period typically allotted for completion. An ordinary lab session might look like this:

(1) Start of practical (lab) session: announcements and planning
 (a) The instructor makes general announcements to all students
 (b) The instructor works with team to plan that day's goals, making sure each team member has a clear idea of what they should accomplish

(2) Teams work on lab unit completion according to recommended schedule:
(First day) Select and bench-test instrument(s)
(One day) Connect instrument(s) into a complete loop
(One day) Each team member drafts their own loop documentation, inspection done as a team (with instructor)
(One or two days) Each team member calibrates/configures the instrument(s)
(Remaining days, up to last) Each team member troubleshoots the instrument loop

(3) End of practical (lab) session: debriefing where each team reports on their work to the whole class

Troubleshooting assessments must meet the following guidelines:

- Troubleshooting must be performed *on a system the student did not build themselves.* This forces students to rely on another team's documentation rather than their own memory of how the system was built.
- Each student must individually demonstrate proper troubleshooting technique.
- Simply finding the fault is not good enough. Each student must consistently demonstrate sound reasoning while troubleshooting.
- If a student fails to properly diagnose the system fault, they must attempt (as many times as necessary) with different scenarios until they do, reviewing any mistakes with the instructor after each failed attempt.

Distance delivery methods

Sometimes the demands of life prevent students from attending college 6 hours per day. In such cases, there exist alternatives to the normal 8:00 AM to 3:00 PM class/lab schedule, allowing students to complete coursework in non-traditional ways, at a "distance" from the college campus proper.

For such "distance" students, the same worksheets, lab activities, exams, and academic standards still apply. Instead of working in small groups and in teams to complete theory and lab sections, though, students participating in an alternative fashion must do all the work themselves. Participation via teleconferencing, video- or audio-recorded small-group sessions, and such is encouraged and supported.

There is no recording of hours attended or tardiness for students participating in this manner. The pace of the course is likewise determined by the "distance" student. Experience has shown that it is a benefit for "distance" students to maintain the same pace as their on-campus classmates whenever possible.

In lieu of small-group activities and class discussions, comprehension of the theory portion of each course will be ensured by completing and submitting detailed answers for *all* worksheet questions, not just passing daily quizzes as is the standard for conventional students. The instructor will discuss any incomplete and/or incorrect worksheet answers with the student, and ask that those questions be re-answered by the student to correct any misunderstandings before moving on.

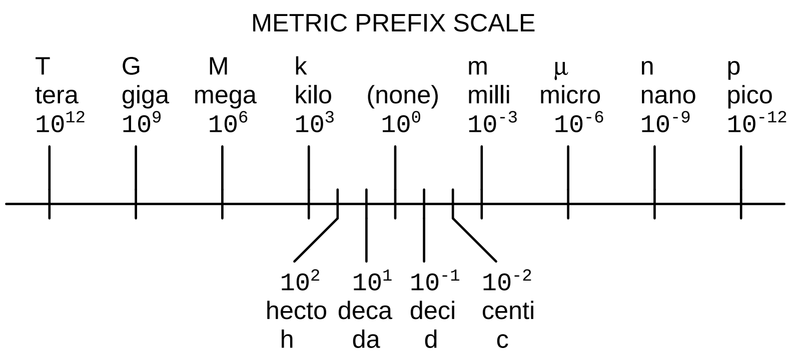
Labwork is perhaps the most difficult portion of the curriculum for a "distance" student to complete, since the equipment used in Instrumentation is typically too large and expensive to leave the school lab facility. "Distance" students must find a way to complete the required lab activities, either by arranging time in the school lab facility and/or completing activities on equivalent equipment outside of school (e.g. at their place of employment, if applicable). Labwork completed outside of school must be validated by a supervisor and/or documented via photograph or videorecording.

Conventional students may opt to switch to "distance" mode at any time. This has proven to be a benefit to students whose lives are disrupted by catastrophic events. Likewise, "distance" students may switch back to conventional mode if and when their schedules permit. Although the existence of alternative modes of student participation is a great benefit for students with challenging schedules, it requires a greater investment of time and a greater level of self-discipline than the traditional mode where the student attends school for 6 hours every day. No student should consider the "distance" mode of learning a way to have more free time to themselves, because they will actually spend more time engaged in the coursework than if they attend school on a regular schedule. It exists merely for the sake of those who cannot attend during regular school hours, as an alternative to course withdrawal.

file `distance`

Metric prefixes and conversion constants

- **Metric prefixes**
- Yotta = 10^{24} Symbol: Y
- Zeta = 10^{21} Symbol: Z
- Exa = 10^{18} Symbol: E
- Peta = 10^{15} Symbol: P
- Tera = 10^{12} Symbol: T
- Giga = 10^{9} Symbol: G
- Mega = 10^{6} Symbol: M
- Kilo = 10^{3} Symbol: k
- Hecto = 10^{2} Symbol: h
- Deca = 10^{1} Symbol: da
- Deci = 10^{-1} Symbol: d
- Centi = 10^{-2} Symbol: c
- Milli = 10^{-3} Symbol: m
- Micro = 10^{-6} Symbol: μ
- Nano = 10^{-9} Symbol: n
- Pico = 10^{-12} Symbol: p
- Femto = 10^{-15} Symbol: f
- Atto = 10^{-18} Symbol: a
- Zepto = 10^{-21} Symbol: z
- Yocto = 10^{-24} Symbol: y



- **Conversion formulae for temperature**
- ^{o}F = (^{o}C)(9/5) + 32
- ^{o}C = (^{o}F - 32)(5/9)
- ^{o}R = ^{o}F + 459.67
- K = ^{o}C + 273.15

Conversion equivalencies for distance

1 inch (in) = 2.540000 centimeter (cm)

1 foot (ft) = 12 inches (in)

1 yard (yd) = 3 feet (ft)

1 mile (mi) = 5280 feet (ft)

Conversion equivalencies for volume

1 gallon (gal) = 231.0 cubic inches (in^3) = 4 quarts (qt) = 8 pints (pt) = 128 fluid ounces (fl. oz.) = 3.7854 liters (l)

1 milliliter (ml) = 1 cubic centimeter (cm^3)

Conversion equivalencies for velocity

1 mile per hour (mi/h) = 88 feet per minute (ft/m) = 1.46667 feet per second (ft/s) = 1.60934 kilometer per hour (km/h) = 0.44704 meter per second (m/s) = 0.868976 knot (knot – international)

Conversion equivalencies for mass

1 pound (lbm) = 0.45359 kilogram (kg) = 0.031081 slugs

Conversion equivalencies for force

1 pound-force (lbf) = 4.44822 newton (N)

Conversion equivalencies for area

1 acre = 43560 square feet (ft^2) = 4840 square yards (yd^2) = 4046.86 square meters (m^2)

Conversion equivalencies for common pressure units (either all gauge or all absolute)

1 pound per square inch (PSI) = 2.03602 inches of mercury (in. Hg) = 27.6799 inches of water (in. W.C.) = 6.894757 kilo-pascals (kPa) = 0.06894757 bar

1 bar = 100 kilo-pascals (kPa) = 14.504 pounds per square inch (PSI)

Conversion equivalencies for absolute pressure units (only)

1 atmosphere (Atm) = 14.7 pounds per square inch absolute (PSIA) = 101.325 kilo-pascals absolute (kPaA) = 1.01325 bar (bar) = 760 millimeters of mercury absolute (mmHgA) = 760 torr (torr)

Conversion equivalencies for energy or work

1 british thermal unit (Btu – "International Table") = 251.996 calories (cal – "International Table") = 1055.06 joules (J) = 1055.06 watt-seconds (W-s) = 0.293071 watt-hour (W-hr) = 1.05506 x 10^{10} ergs (erg) = 778.169 foot-pound-force (ft-lbf)

Conversion equivalencies for power

1 horsepower (hp – 550 ft-lbf/s) = 745.7 watts (W) = 2544.43 british thermal units per hour (Btu/hr) = 0.0760181 boiler horsepower (hp – boiler)

Acceleration of gravity (free fall), Earth standard

9.806650 meters per second per second (m/s^2) = 32.1740 feet per second per second (ft/s^2)

Physical constants

Speed of light in a vacuum (c) = 2.9979×10^8 meters per second (m/s) = 186,281 miles per second (mi/s)

Avogadro's number (N_A) = 6.022×10^{23} per mole (mol^{-1})

Electronic charge (e) = 1.602×10^{-19} Coulomb (C)

Boltzmann's constant (k) = 1.38×10^{-23} Joules per Kelvin (J/K)

Stefan-Boltzmann constant (σ) = 5.67×10^{-8} Watts per square meter-Kelvin^4 ($\text{W/m}^2 \cdot \text{K}^4$)

Molar gas constant (R) = 8.314 Joules per mole-Kelvin (J/mol-K)

Properties of Water

Freezing point at sea level = 32^oF = 0^oC

Boiling point at sea level = 212^oF = 100^oC

Density of water at 4^oC = 1000 kg/m^3 = 1 g/cm^3 = 1 kg/liter = 62.428 lb/ft^3 = 1.94 slugs/ft^3

Specific heat of water at 14^oC = 1.00002 calories/g$\cdot^o$C = 1 BTU/lb$\cdot^o$F = 4.1869 Joules/g$\cdot^o$C

Specific heat of ice $\approx$ 0.5 calories/g$\cdot^o$C

Specific heat of steam $\approx$ 0.48 calories/g$\cdot^o$C

Absolute viscosity of water at 20^oC = 1.0019 centipoise (cp) = 0.0010019 Pascal-seconds (Pa$\cdot$s)

Surface tension of water (in contact with air) at 18^oC = 73.05 dynes/cm

pH of pure water at 25^o C = 7.0 (*pH scale = 0 to 14*)

Properties of Dry Air at sea level

Density of dry air at 20^oC and 760 torr = 1.204 mg/cm^3 = 1.204 kg/m^3 = 0.075 lb/ft^3 = 0.00235 slugs/ft^3

Absolute viscosity of dry air at 20^oC and 760 torr = 0.018 centipoise (cp) = 1.8×10^{-5} Pascal-seconds (Pa$\cdot$s)

How to get the most out of academic reading:

- Articulate your thoughts as you read (i.e. "have a conversation" with the author). This will develop *metacognition*: active supervision of your own thoughts. Write your thoughts as you read, noting points of agreement, disagreement, confusion, epiphanies, and connections between different concepts or applications. These notes should also document important math formulae, explaining in your own words what each formula means and the proper units of measurement used.
- Outline, don't highlight! Writing your own summary or outline is a far more effective way to comprehend a text than simply underlining and highlighting key words. A suggested ratio is one sentence of your own thoughts per paragraph of text read. Note points of disagreement or confusion to explore later.
- Work through all mathematical exercises shown within the text, to ensure you understand all the steps.
- Imagine explaining concepts you've just learned to someone else. Teaching forces you to distill concepts to their essence, thereby clarifying those concepts, revealing assumptions, and exposing misconceptions. Your goal is to create the simplest explanation that is still technically accurate.
- Write your own questions based on what you read, as though you are a teacher preparing to test students' comprehension of the subject matter.

How to effectively problem-solve and troubleshoot:

- Rely on principles, not procedures. Don't be satisfied with memorizing steps – learn *why* those steps work. Each one should make logical sense and have real-world meaning to you.
- Sketch a diagram to help visualize the problem. Sketch a graph showing how variables relate. When building a real system, always prototype it on paper and analyze its function *before* constructing it.
- Identify what it is you need to solve, identify all relevant data, identify all units of measurement, identify any general principles or formulae linking the given information to the solution, and then identify any "missing pieces" to a solution. Annotate all diagrams with this data.
- Perform "thought experiments" to explore the effects of different conditions for theoretical problems. When troubleshooting, perform *diagnostic tests* rather than just visually inspect for faults.
- Simplify the problem and solve that simplified problem to identify strategies applicable to the original problem (e.g. change quantitative to qualitative, or visa-versa; substitute easier numerical values; eliminate confusing details; add details to eliminate unknowns; consider simple limiting cases; apply an analogy). Often you can add or remove components in a malfunctioning system to simplify it as well and better identify the nature and location of the problem.
- Work "backward" from a hypothetical solution to a new set of given conditions.

How to manage your time:

- Avoid procrastination. Work now and play later, or else you will create trouble for yourself. Schedule your work appropriate to the *place* you're in as well: e.g. don't waste lab time doing things that could be done anywhere else, when there is work to be done that requires the lab.
- Eliminate distractions. Kill your television and video games. Study in places where you can concentrate.
- Use your "in between" time productively. Don't leave campus for lunch. Arrive to school early. If you finish your assigned work early, begin working on the next assignment.

Above all, cultivate persistence. Persistent effort is necessary to master anything non-trivial. The keys to persistence are (1) having the desire to achieve that mastery, and (2) realizing challenges are normal and not an indication of something gone wrong. A common error is to equate *easy* with *effective*: students often believe learning should be easy if everything is done right. The truth is that mastery never comes easy!

file `question0`

Creative Commons License

Simple explanation of Attribution License:

The licensor (Tony Kuphaldt) permits others to copy, distribute, display, and otherwise use this work. In return, licensees must give the original author(s) credit. For the full license text, please visit `http://creativecommons.org/licenses/by/4.0/` on the internet.

More detailed explanation of Attribution License:

Under the terms and conditions of the Creative Commons Attribution License, you may make freely use, make copies, and even modify these worksheets (and the individual "source" files comprising them) without having to ask me (the author and licensor) for permission. The one thing you must do is properly credit my original authorship. Basically, this protects my efforts against plagiarism without hindering the end-user as would normally be the case under full copyright protection. This gives educators a great deal of freedom in how they might adapt my learning materials to their unique needs, removing all financial and legal barriers which would normally hinder if not prevent creative use.

Nothing in the License prohibits the sale of original or adapted materials by others. You are free to copy what I have created, modify them if you please (or not), and then sell them at any price. Once again, the only catch is that you must give proper credit to myself as the original author and licensor. Given that these worksheets will be continually made available on the internet for free download, though, few people will pay for what you are selling unless you have somehow added value.

Nothing in the License prohibits the application of a more restrictive license (or no license at all) to derivative works. This means you can add your own content to that which I have made, and then exercise full copyright restriction over the new (derivative) work, choosing not to release your additions under the same free and open terms. An example of where you might wish to do this is if you are a teacher who desires to add a detailed "answer key" for your own benefit but *not* to make this answer key available to anyone else (e.g. students).

Note: the text on this page is not a license. It is simply a handy reference for understanding the Legal Code (the full license) - it is a human-readable expression of some of its key terms. Think of it as the user-friendly interface to the Legal Code beneath. This simple explanation itself has no legal value, and its contents do not appear in the actual license.

file `license`

Question 1

We will begin our introduction to the second year of the Instrumentation program by brainstorming responses to a few questions:

(1) What are your goals in this program? Why did you enroll in it and what do you expect to get out of it?

(2) What career options exist within the field of instrumentation and control?

(3) What knowledge and skills are most important for your success in this career? Or, to state it differently, what benefit do employers get in return for the wages they pay you?

file i00001

Question 2

Use a computer to navigate to the "Socratic Instrumentation" website:

`http://www.ibiblio.org/kuphaldt/socratic/sinst`

When you get there, click on the link for the quarter (Summer, Fall, Winter, or Spring) you are enrolled in, and download the INST200 "Introduction to Instrumentation" course worksheet. Today's classroom session will cover Day 1 of this worksheet.

Near the very beginning of this document, as is the case for *all* the 200-level Instrumentation course worksheets, you will find a page titled "How To . . .". Locate this page and read it thoroughly, as you will be quizzed on its contents throughout the INST200 course. The "How to . . ." tips make reference to a "Question 0" which is another page found in every course worksheet. Read the points listed in Question 0 as well.

Your instructor will also hand out copies of a release form ("FERPA form") which you may sign to grant permission to share your academic performance records with employers. This is voluntary, not mandatory. Without signed consent from student, federal law prohibits any instructor from sharing academic records with anyone but the student and appropriate college employees.

Your instructor will also have electronic copies (e.g. flash drive and/or CD-ROM) of the "Instrumentation Reference" on hand for you to copy to your personal computer. This is a collection of files, mostly obtained from various manufacturers' websites with their permission, of tutorials and reports and technical manuals which you will be assigned to read throughout the second-year courses. The purpose of this Reference is to provide you with fast, off-line access so that you need not search the internet for these assigned documents. There is a file in the root directory of this Reference named "`00_index_OPEN_THIS_FILE.html`" you should open using a web browser. The hyperlinks within this HTML index file make it much easier to find the document(s) you're looking for than it would be scanning the various directories within the Reference to peruse filenames.

Suggestions for Socratic discussion

- One of the purposes of this exercise is to practice active reading strategies, where you interact with the text to identify and explore important principles. An effective strategy is to write any thoughts that come to mind as you are reading the text. Describe how this active reading strategy might be useful in daily homework assignments.
- For each and every one of the points listed in the "How To . . ." and "Question 0" pages, identify why these points are important to your ultimate goal of becoming an instrument technician.
- Identify how the INST200-level course design and expectations differ from what you have experienced in the past as students, and explain why these differences exist.

file i00002

Question 3

Near the beginning of every course worksheet there are some pages titled "General Values, Expectations, and Standards". Your instructor will read these with you and answer any questions you have about them. Feel free to read this document in advance and bring questions with you to class for answering. These expectations reference "Question 0" and the "Inverted Session Formats" pages which are also found in every course worksheet, and which you will want to read through as well.

Suggestions for Socratic discussion

- For each and every one of the points listed in the "General Responsibilities" pages, identify why these points are important to your ultimate goal of becoming an instrument technician.
- Identify how the INST200-level course design and expectations differ from what you have experienced in the past as students, and explain why these differences exist.
- One of the purposes of this exercise is to practice active reading strategies, where you interact with the text to identify and explore important principles. An effective strategy is to write any thoughts that come to mind as you are reading the text. Describe how this active reading strategy might be useful in daily homework assignments.

file i00003

Question 4

One of the unique features of this program is the inclusion of *mastery exams*, where students must answer questions with 100% accuracy in order to pass. Conventional "proportional" exams allow students to pass if a certain minimum score is achieved. The problem with this testing strategy is that students may not actually learn *all* the concepts they're supposed to, but may still pass the exam if they are strong enough in the other concepts covered in that assessment. The purpose of mastery exams is to guarantee proficiency in *all* critical concepts and not just *some*.

Your instructor will hand out copies of the mastery exam for the INST200 "Introduction to Instrumentation" course, covering several critical concepts of circuit analysis taught in the first year of the Instrumentation program. Do your best to answer all the questions correctly. If you get any incorrect on the first attempt, the instructor will mark which *sections* (not which *questions*) you missed and return it to you for one more attempt. If a mastery exam is not passed by the second attempt, it counts as a failed exam.

Mastery exams may be re-taken any number of times with no grade penalty. The purpose is to give students the constructive feedback and practice that they need in order to master all the concepts represented on the exam. Every mastery exam must be passed before the next scheduled exam is given in order to receive a passing grade for that course, a period of approximately 2 weeks. If any student is not able to pass a mastery exam with 100% accuracy by the deadline date, they will receive an "F" grade for that course, and must re-take the course again during some future quarter.

The INST200 mastery exam is given for the purpose of exposing students to this unique type of assessment. Failing to pass the INST200 mastery exam will not result in a failing grade for the INST200 course, but students should be warned that poor performance on this exam often marks trouble in future Instrumentation courses, since so much of the second year's material builds on what was taught during the first year.

file i01230

Question 5

Locate the question in your worksheet outlining the **lab project** for this course section. What information is given to you here to help you construct the lab project? Which objectives must be completed individually, versus as a team? How does a "mastery" objective differ from a "proportional" objective?

file i03856

Question 6

Read the "Teaching Technical Theory" section of Appendix D ("How to Use This Book – Some Advice for Teachers") in your *Lessons In Industrial Instrumentation* textbook. This will serve as the basis for a discussion on why the second-year Instrumentation courses are not lecture-based.

Imagine a child wishing to learn how to ride a bicycle. Seeking knowledge on the subject, the child approaches an adult asking for that adult to explain how to ride a bike. The adult responds with a detailed and thorough explanation of bicycle riding, including all the relevant safety rules. *After this explanation concludes, will the child be able to ride a bicycle?* Now imagine that same child reading a book on bicycle riding. The book is well-written and filled with clear illustrations to aid understanding. *After finishing this book, will the child be able to ride a bicycle?* Now imagine that same child watching a demonstration video on bicycle riding. The video is professionally shot, with very clear views on technique. The actor in the video does a great job explaining all the important aspects of bicycle riding. *After watching the video in its entirety, will the child be able to ride a bicycle?*

It should be obvious at this point that there is more to learning how to ride a bicycle than merely being shown how to do so. Bike riding is a skill born of *practice*. Instruction may be *necessary* to learn how to ride a bicycle safely, but instruction in itself is not *sufficient* to learn how to ride a bicycle safely – you must actively attempt riding a bicycle before all the pieces of information come together such that you will be proficient. *What is it about bicycle riding that necessitates <u>practice</u> in order to learn?*

Now imagine someone wishing to learn how to write poetry. Seeking knowledge on the subject, this person consults poets for advice, reads books of poetry and books about writing poetry, and even listens to audio recordings of poets presenting their work in public. *After all this instruction and research, will the person be a proficient poet?*

Here we have the same problem we had with learning to ride a bicycle: instruction may be a *necessary* part of learning to write poems, but instruction in itself is not *sufficient* to become a poet. One must actively write their own poems to become good at it. *What is it about poetry that necessitates <u>practice</u> in order to learn how to write it?*

The fundamental principle here is that *we master that which we practice*, because the brain strengthens neural pathways through repeated use. There is nothing unique about bicycle riding or poetry in this regard: if you wish to master any skill you must repeatedly *do* that skill. The problem with learning about bicycle-riding or poetry from other people is that you aren't *doing* any bicycle riding or poetry yourself. The most valuable assistance any learner can receive is prompt and constructive feedback during the learner's practice. Think of a child attempting to ride a bicycle with an adult present to observe and give practical advice; or of a person learning poetry, submitting their poems to an audience for review and then considering that feedback before writing their next poem.

When we research which skills are most valuable to instrument technicians, we find *self-directed learning* and *general problem-solving* top the list. These skills, like any other, require intensive practice to master. Furthermore, that practice will be optimized with prompt and expert feedback. In order to optimally prepare students to become instrument technicians, then, those students must be challenged to learn on their own and to individually solve problems, with the instructor coaching them on both activities.

Here is where schools tend to cheat students: the majority of class time is spent presenting information to students, rather than giving students opportunity to practice their problem-solving skills. This is primarily the consequence of *lecture* being the dominant mode of teaching, where a live instructor must spend hour upon hour verbally presenting information to students, leaving little or no time for those students to solve problems and sharpen their critical thinking skills. Assigned homework does a poor job of providing practice because the student doesn't receive detailed feedback on their problem-solving strategies, and also because many students cheat themselves by receiving inappropriate help from their classmates. Furthermore, lecture is the antithesis of self-directed learning, being entirely directed by a subject matter expert. The skills practiced by students during a lecture (e.g. taking dictation on lengthy presentations) have little value in the career of an instrument technician. More time in school could be spent practicing more relevant skills, but only if some other mode of instruction replaces lecture.

Not only does lecture displace more valuable activities in the classroom, but lecture isn't even that good of an instructional technique. Among the serious shortcomings of lecture are the following:

- Students' attentions tend to drift over the span of any lecture of significant length.
- Lecture works well to communicate facts and procedures but fails at getting students to think for themselves, because the focus and pace of any lecture is set by the lecturer and not the students.
- Lecture instills a false sense of confidence in students, because complex tasks always look easier than they are when you watch an expert do it without trying it yourself. (An oft-heard quote from students in lecture-based classes: *"I understand things perfectly during lecture, but for some reason I just can't seem to do the homework on my own!"*)
- A lecturer cannot customize ("differentiate") instruction for individual students. Rather, everyone gets the exact same presentation (e.g. the same examples, the same pace) regardless of their diverse needs. The pace of lecture is perhaps the most obvious example of this problem: since the lecturer can only present at one pace, he or she is guaranteed to bore some students by going to slow for them and/or lose others by going too fast for them.
- Students cannot "rewind" a portion of lecture they would like to have repeated without asking the entire class to repeat as well.
- Students' must simultaneously dictate notes while trying to watch *and* listen *and* think along with the instructor, a difficult task at best. Multitasking is possible only for simple tasks, none of them requiring intense focus.
- If the instructor commits some form of verbal error and doesn't realize it (which is very common because it's difficult to simultaneously present and self-evaluate), it is incumbent upon the students to identify the error and ask for clarification.
- The instructor cannot accurately perceive how each and every student is understanding the presentation, because the instructor is too busy presenting. Body language during the lecture isn't a reliable enough indicator of student understanding, and the time taken by lecture precludes the instructor visiting every student to inspect their work.
- Lecture instills an attitude of dependence on students by reinforcing the notion they need to personally consult an expert in order to learn anything new. This discourages students from even trying to learn complex things on their own.

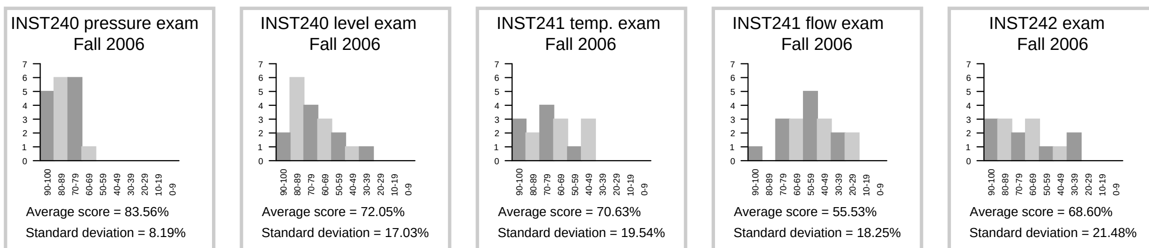
For these reasons – the fact that lecture displaces class time better spent coaching students to solve problems, as well as the many problems of lecture as an instructional mode – there is almost no lecture in any of the 200-level Instrumentation courses at BTC. Instead, students learn the basic facts and procedures of the subject matter through reading assignments prior to class, then spend class time solving problems and demonstrating their understanding of each day's major topic(s) before leaving. This is called an *inverted classroom* because the classroom and homework roles are swapped: what is traditionally lectured on in class is instead done on the students' time outside of class, while the problem-solving traditionally done as homework is instead completed during class time while the instructor is available to coach. This format is highly effective not only for learning the basic concepts of instrumentation, but also for improving technical reading and critical thinking skills, simply because *it requires students to practice the precise skills they must master*.

The primary reason *reading* was chosen as the preferred mode of instruction is feedback from employers as well as observations of student behavior, both sources revealing an aversion to technical reading. Some employers (most notably the BP oil refinery in Carson, California) noted reading comprehension as being the weakest area when testing BTC students during past recruiting trips. Also, a failure to reference equipment manuals when working on real systems is a chronic problem both for novice technicians in a wide range of industries as well as students learning in a lab environment. Given the fact that far more high-quality technical information is available for continued learning in this career than high-quality videos, reading comprehension is a vital skill for technicians to keep their knowledge up to date as technology advances.

Prior to 2006 all 200-level Instrumentation courses were strictly taught by lecture. Making matters worse, many of the courses had no textbook, and homework was seldom assigned. All 200-level exams prioritized rote memorization and execution of procedural problem-solving over creative problem-solving and synthesis of multiple concepts. It was common for second-year students to flounder when presented with a new piece of equipment or a new type of problem, because no instructor can teach procedures to cover any and all possible challenges.

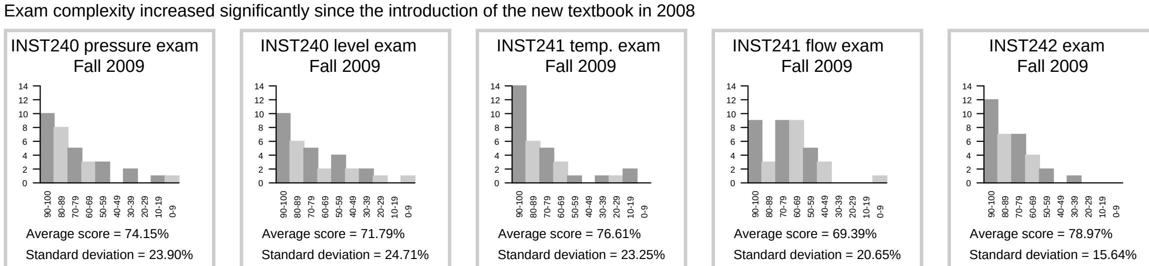
Since 2006 the 200-level Instrumentation courses have gradually morphed from lecture to "inverted" format, with measurable gains in learning. Proportional exam scores from the Fall quarter courses (INST240, INST241, and INST242 – those courses where the content has remained most stable over this time span) demonstrate this, each histogram showing the number of students (vertical axis) achieving a certain exam score (horizontal axis):

Fall 2006: limited text resources for students (no standard textbook for the curriculum), classroom format a mixture of lecture and group discussion



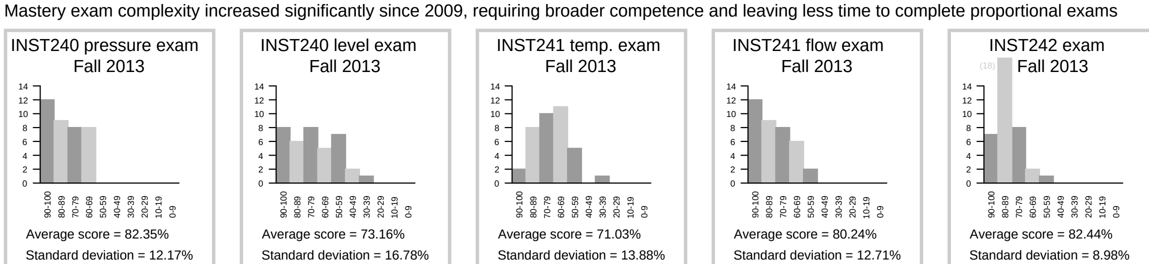
Cumulative exam score average for Fall quarter 2006 = 70.07%
Cumulative exam score standard deviation for Fall 2006 = 19.27%

Fall 2009: *Lessons In Industrial Instrumentation* textbook available to students, classroom format still a mixture of lecture and group discussion
Exam complexity increased significantly since the introduction of the new textbook in 2008



Cumulative exam score average for Fall quarter 2009 = 74.18%
Cumulative exam score standard deviation for Fall 2009 = 21.88%

Fall 2013: *Lessons in Industrial Instrumentation* textbook greatly expanded, classroom format fully inverted (i.e. no lecture)
Mastery exam complexity increased significantly since 2009, requiring broader competence and leaving less time to complete proportional exams



Cumulative exam score average for Fall quarter 2013 = 77.85%
Cumulative exam score standard deviation for Fall 2013 = 13.89%

Note the general improvement in average exam scores (2009) toward the end of the quarter, despite the exams being more complex than they were in 2006. Students were held accountable for the assigned textbook reading with graded "prep quizzes" at the beginning of each class session. Note also how the standard deviations increased, representing a greater degree of "spread" between student performance on these exams. The increased standard deviation shows some students falling behind their peers, since lecture was not providing for their needs with a more challenging curriculum.

In the third set of histograms (2013) we see general increases in average scores as well as marked improvements in standard deviation across the board (showing fewer students "left behind" their peers). The inverted classroom format allows the instructor to spend one-on-one time with each and every student to probe for misconceptions and offer assistance when needed. This kind of differentiated instruction is impossible in a lecture format. Even more remarkable is the fact that the exam complexity increased since 2009, with longer mastery exams (reviewing concepts from previous courses including first-year circuit principles) and more complex proportional exams. In 2013 the exams so fully exhausted the 3-hour testing period that graded results could no longer be given before the end of the day, and instead had to wait until the following day. Yet, despite this increased rigor exam scores increased and standard deviation narrowed.

One of the most striking improvements realized since abandoning lecture is the ease of which students grasp some of the more complex concepts throughout the year. These concepts used to be difficult to convey in a lecture format (mostly due to pacing problems, since different students would get "stuck" at different points in the presentation), and so long as some lecture existed in the classroom students would tend to give up when they encountered difficult concepts in the assigned reading (knowing they could rely on the instructor to lecture on these tough concepts in class):

- INST230 course: Three-phase electric power system calculations
- INST230 course: Normally-open versus normally-closed contact status
- INST240 course: Interface liquid level measurement (hydrostatic and displacer)
- INST240/250 courses: Force-balance versus motion-balance pneumatic mechanisms
- INST241 course: Coriolis mass flowmeters
- INST242 course: Gas chromatograph operation
  → Not only are students able to fully grasp basic GC operation in only one day, but they are also able to tackle multi-column GCs as well!
- INST242 course: Non-dispersive optical analyzers (NDIR, Luft detectors, etc.)
  → Comprehension of this topic used to be a real struggle, with a good percentage of students failing to grasp filter cells and Luft detectors by the end of the first day. Now this concept comes easily to all in one day.
- INST250 course: Fluid power system analysis (hydraulic and pneumatic diagrams)
- INST250 course: Split-ranged control valve sequencing
- INST250 course: Control valve characterization
  → Comprehension of this topic is so much better now that I've had to modify that day's learning activities to provide more challenge than in past years.
- INST252/263 courses: Feedforward control strategies
  → Dynamic compensation in particular used to be such a struggle to teach that most students really didn't seem to "get" the concept after repeated explanations. Now it's no more challenging than any other control concept we tackle in the program.
- INST252 course: Loop stability analysis (based on trend recordings)
- INST260 course: Data acquisition hardware connections (e.g. differential vs. single-ended connections)
- INST262 course: FOUNDATION Fieldbus and wireless (radio) digital communications
  → The first year I taught FOUNDATION Fieldbus using an inverted classroom, my students knew the topic better than our guest lecturer who I invited to present on the subject! The students' only exposure to FOUNDATION Fieldbus at that point was one night's study prior to the guest's appearance.
- INST263 course: Selector and override controls

This improvement in student learning has been verified by industry representatives, when they are invited to come to BTC to review certain complex topics such as Fieldbus, WirelessHART, and control valves. The general feedback they give is that BTC students are unusually well-prepared on these subjects. The "secret" of course is that students learning in an inverted classroom format spend more time immersed in the subject matter, and the feedback they receive from their instructors in class is better tailored to their individual learning needs.

Another significant gain realized since abandoning lecture is the immediate placement of inexperienced BTC Instrumentation graduates in jobs typically reserved for engineers with 4-year degrees. This simply did not happen when BTC's Instrumentation program was lecture-based, and it is due to the fact that students explicitly learn higher-order thinking skills when they must gather information on their own outside of class and then demonstrate critical thinking before an instructor every day. This has happened once in December 2011, again in December 2012, again in March 2013, and again in August 2013.

Yet, despite the gains realized by abandoning lecture in favor of an "inverted" teaching format, some students are highly resistant to the concept. Some of the critical comments routinely heard from students against the inverted format are as follows:

(1) *"I learn better in a lecture format."*

(2) *"My learning style is visual, which means I need to* <u>see</u> *someone solve the problems for me."*

(3) *"When I arrive to class after doing the assigned reading and trying to solve the homework problems, I'm completely lost."*

Discuss each of these comments in detail. Here are some starting points for conversation:

(1) What does it mean to learn something *better*? How may a student measure how well they've learned something new? What, exactly, is it that is learned better in lecture? Is there anything significant that students *don't* learn in a lecture?

(2) Would someone with an *auditory* or *kinesthetic* learning style fare any better in an inverted classroom? Does a visual learning style preclude effective reading, or independent learning? Are learning styles real or merely perceived? Are learning styles immutable (i.e. permanent), or is it possible for people to cultivate new learning styles?

(3) What does it mean if a student is lost after completing the homework for an inverted class, assuming a significant number of their classmates are *not* lost? What would be an appropriate course of action to take in response to this condition?

<u>file i00004</u>

Question 7

You may find the course structure and format of the INST courses to be quite different from what you have experienced elsewhere in your education. For each of the following examples, discuss and explain the rationale. What do you think is the greater purpose for each of these course standards and policies?

- Homework consists of studying new subjects prior to arriving to class for the theory sessions. Students' primary source of new information is in the form of written materials: textbooks, reports, and manufacturer's literature. Daily quizzes at the start of each class session hold students accountable for this preparatory learning. *Why study new subjects outside of class, instead of doing normal homework that reviews subjects previously covered in class? Why the strong emphasis on reading as a mode of learning?*

- Classroom sessions are not lecture-oriented. Rather, classroom sessions place students in an active role discussing, questioning, and investigating what they're learned from their independent studies. Learning new facts (knowledge) and how to interpret them (comprehension) is the students' responsibility, and it happens before class rather than during class. Class time is devoted to higher-level thinking (application, analysis, synthesis, and evaluation). *What's wrong with lecture, especially when the overwhelming majority of classes in the world are taught this way?*

- Students are expected to track their own academic progress using a computer spreadsheet to calculate their own course grades as they progress through each school quarter. *Why not simply present the grades to students?*

- Students must explicitly apply "sick hours" to their absences (this is not automatically done by the instructor!), and seek donations from classmates if they exceed their allotment for a quarter. *Why not simply allow a fixed number of permitted absence for each student, or let the instructor judge the merits of each student's absence on a case-by-case basis?*

- Mastery exams, where students must answer all questions with 100% accuracy. *What's wrong with regular exams, where a certain minimum percentage of correct answers is all that's necessary to pass?*

- Students may submit optional, ungraded assignments called "feedback questions" to the instructor at the end of most course sections in order to check their preparedness for the higher-level thinking challenges of the upcoming exam. *Why in the world would anyone do work that doesn't contribute to their grade?*

- Troubleshooting exercises in lab and diagnostic questions in homework, where students must demonstrate sound reasoning in addition to properly identifying the problem(s). *Isn't it enough that the student simply finds the fault?*

- Extra credit is offered for students wishing to improve their grades, but this extra credit is always in the form of practical and realistic work relevant to the specific course in which the extra credit is desired. *Why doesn't unrelated work count?*

  file i03484

Question 8

Explain the difference between a *mastery* assessment and a *proportional-graded* assessment. Given examples of each in the course(s) you are taking.

file i00113

Question 9

Participation is always an important factor in student success, both in being able to learn enough to pass the assessments given in a course, and also to fulfill certain policy expectations. It is vital that students learn to manage their time and life outside of school so that their time in school is well-spent. This carries over to work ethic and the ability to contribute fully on the job. Your instructor's duty is to prepare you for the rigors of the workplace as instrument technicians, and the policies of the courses are set up to reflect this reality.

Explain the attendance policy in these courses, according to the syllabi.

file i00115

Question 10

If and when you are unable to attend school for any reason, you need to contact both your instructor and your team-mates. Explain why.

file i00116

Question 11

You are required to prepare for the classroom (theory) session by completing any reading assignments and/or attempting to answer worksheet questions assigned for each day, before arriving to class. This necessarily involves substantial independent research and problem-solving on your part.

What should you do if you encounter a question that completely mystifies you, and you have no idea how to answer it? By the same token, what should you do if you encounter a section of the required reading that you just can't seem to understand?

file i00122

Question 12

Watch the US Chemical Safety Board video on the 2005 Texas City oil refinery explosion (available on such Internet video sites as YouTube, and at the USCSB website directly), and answer the following questions:

- What factors caused the explosion to occur?
- How was instrumentation involved in this accident?
- What precautions could have prevented the accident?

Now, shift your focus to this program of study you are engaged in here. Given the context of what you have just seen (dangerous environments, complex systems), identify some of the skills and traits you will need at the workplace as an instrument technician, and identify how you may gain these skills and traits while in school.

file i03852

Question 13

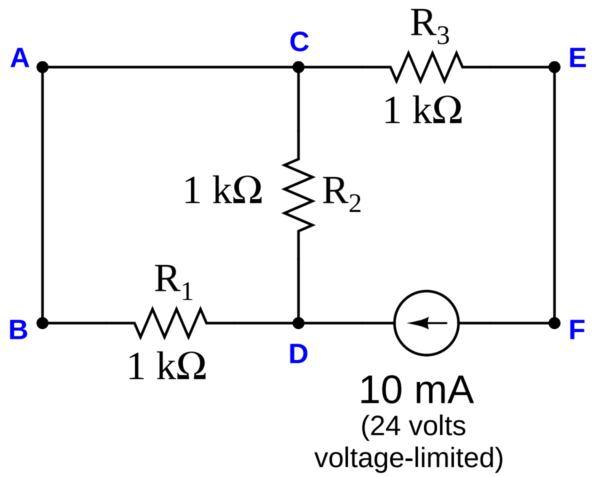
Read and discuss the bullet-point suggestions given in "Question 0" of this worksheet on how to maximize your reading effectiveness. Then, apply these tips to an actual document: pages 81 through 89 of the *Report of the President's Commission on The Accident at Three Mile Island*, where the prologue to the "Account of the Accident" chapter explains the basic workings of a nuclear power plant.

After taking about half an hour in class to actively read these nine pages – either individually or in groups – discuss what you were able to learn about nuclear power plant operation from the text, and also how active reading helps you maximize the learning experience.

file i03861

Question 14

Suppose an ammeter inserted between test point **C** and the nearest lead of resistor R_2 registers 10 mA in this series-parallel circuit:



Identify the likelihood of each specified fault for this circuit. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this circuit.

Fault	**Possible**	**Impossible**
R_1 failed open		
R_2 failed open		
R_3 failed open		
R_1 failed shorted		
R_2 failed shorted		
R_3 failed shorted		
Current source dead		

Suggestions for Socratic discussion

- Identify which fundamental principles of electric circuits apply to each step of your analysis of this circuit. In other words, be prepared to explain the reason(s) "why" for every step of your analysis, rather than merely describing those steps.
- This type of problem-solving question is common throughout the Instrumentation course worksheets. What specific skills will you build answering questions such as this? How might these skills be practical in your chosen career?
- An assumption implicit in this activity is that it is more likely a single fault occurred than multiple, coincidental faults. Identify realistic circumstances where you think this would be a valid assumption. Hint: research the philosophical proverb called *Occam's Razor* for more information! Are there any realistic circumstances where the assumption of only one fault would not be wise?

This question is typical of those in the "Fault Analysis of Simple Circuits" worksheet found in the *Socratic Instrumentation* practice worksheet collection (online), except that all answers are provided for those questions. Feel free to use this practice worksheet to supplement your studies on this very important topic.

file i04489

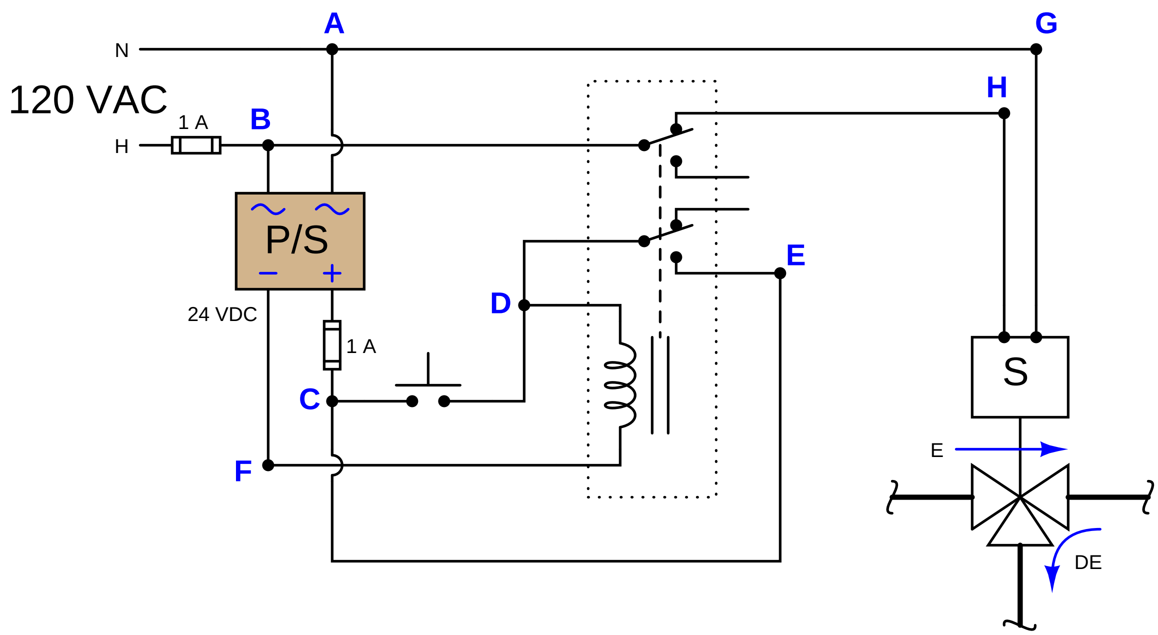
Question 15

An important concept in education is something called *schema*: the body of knowledge, expectations, and assumptions that someone uses to interpret any form of communication they are receiving, whether that communication be in the form of speech, text, or even something as abstract as art. One does not approach an action-adventure novel in the same way or with the same expectations that one would approach instructions for filing tax returns with the IRS. One does not interpret and appreciate a live jazz band in the same way they would interpret and appreciate choral music. We have different schema for understanding and appreciating these different forms of communication, even if they occur in the same medium (e.g. printed text, or audible tones).

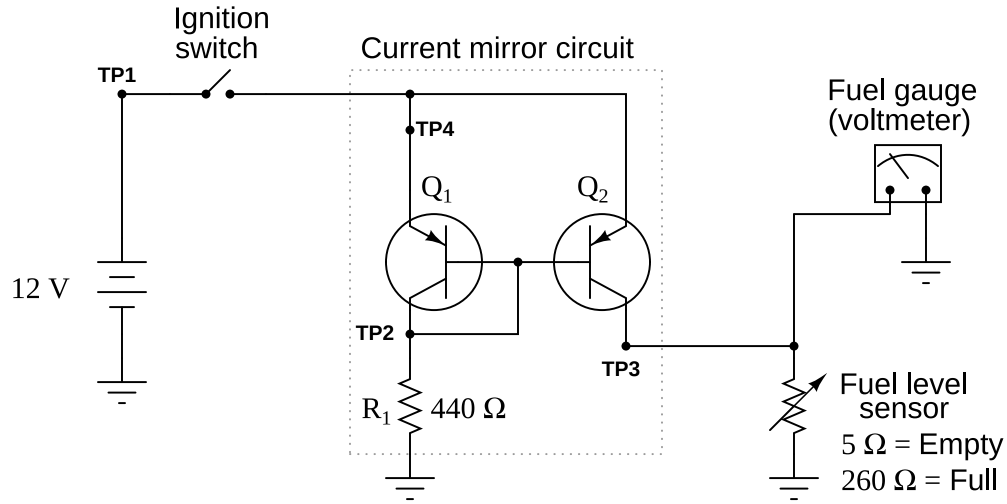
Industrial system diagrams also have *schema* associated with them. One does not interpret a P&ID in the same manner that one interprets an electronic schematic or a block diagram, despite their many similarities. This exercise will ask you to identify the meanings of similar symbols used in several types of diagrams, in order to expose some of the schema you have (or that you are in the process of building).

Reference the following diagrams, and then answer the comparison/contrast questions that follow:

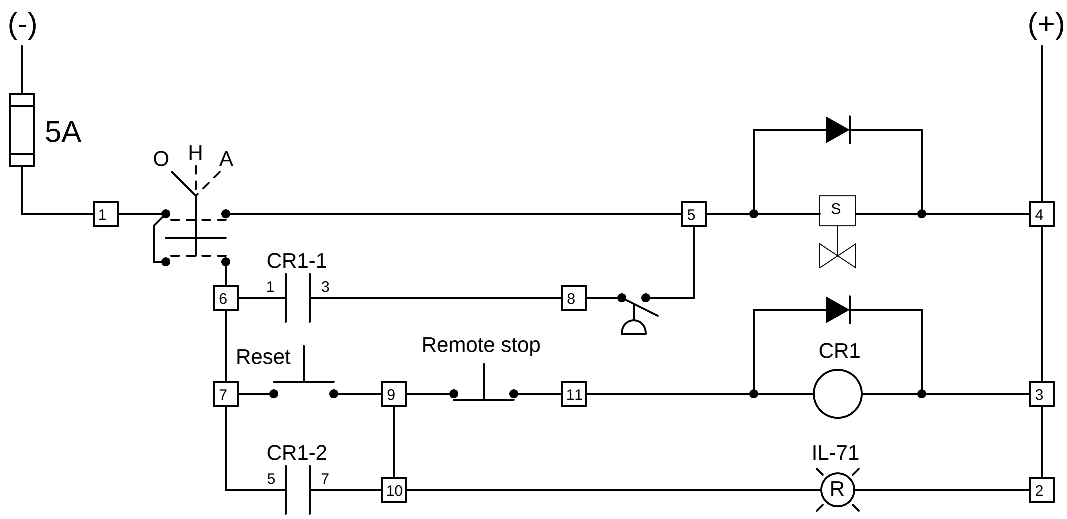
Schematic diagram of a relay circuit



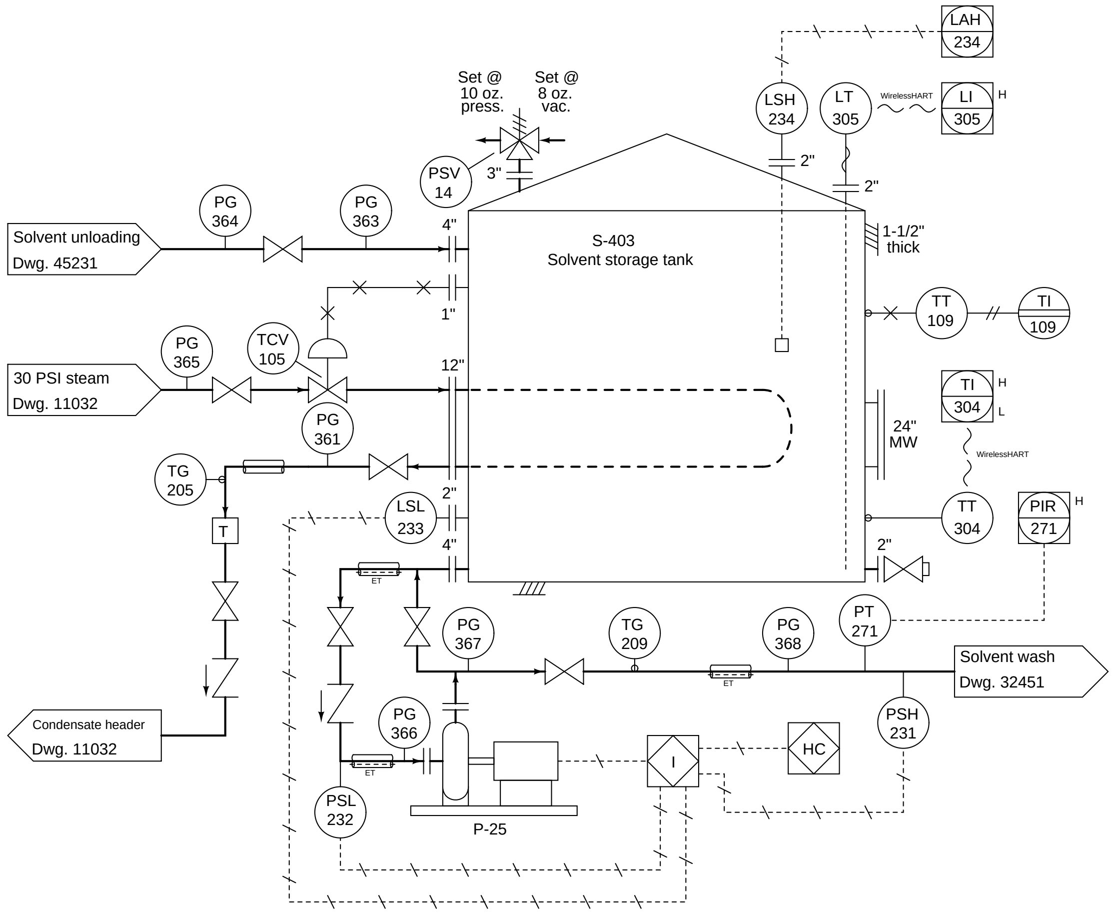
Schematic diagram of a fuel tank level sensor circuit



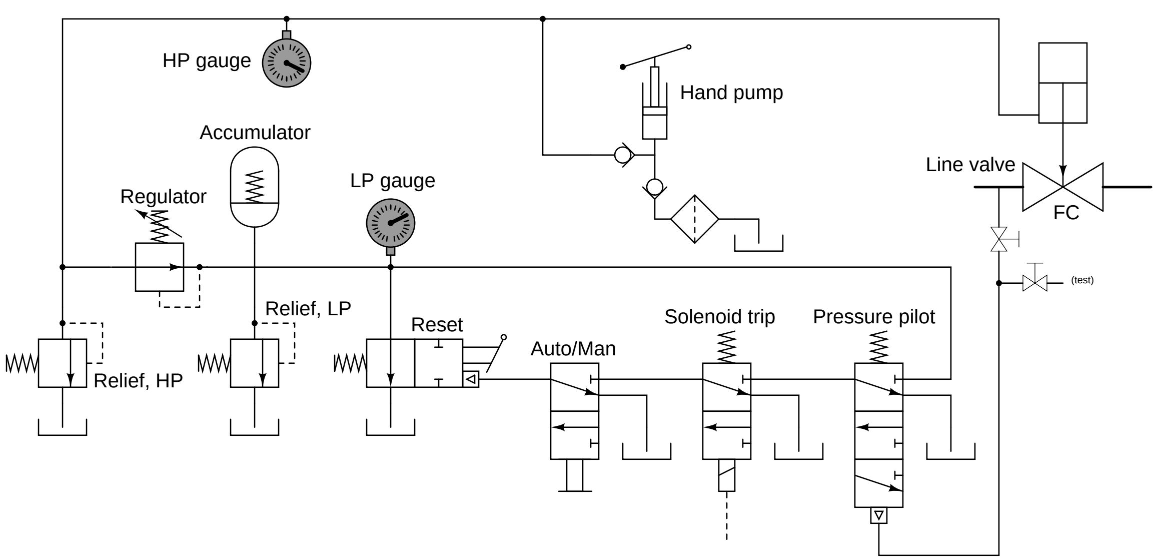
Ladder diagram of a solenoid valve control circuit



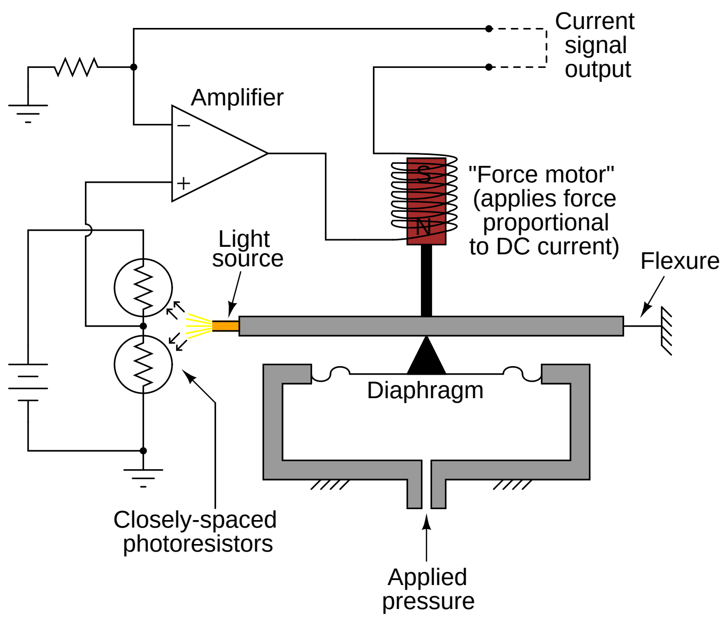
P&ID of a solvent storage tank



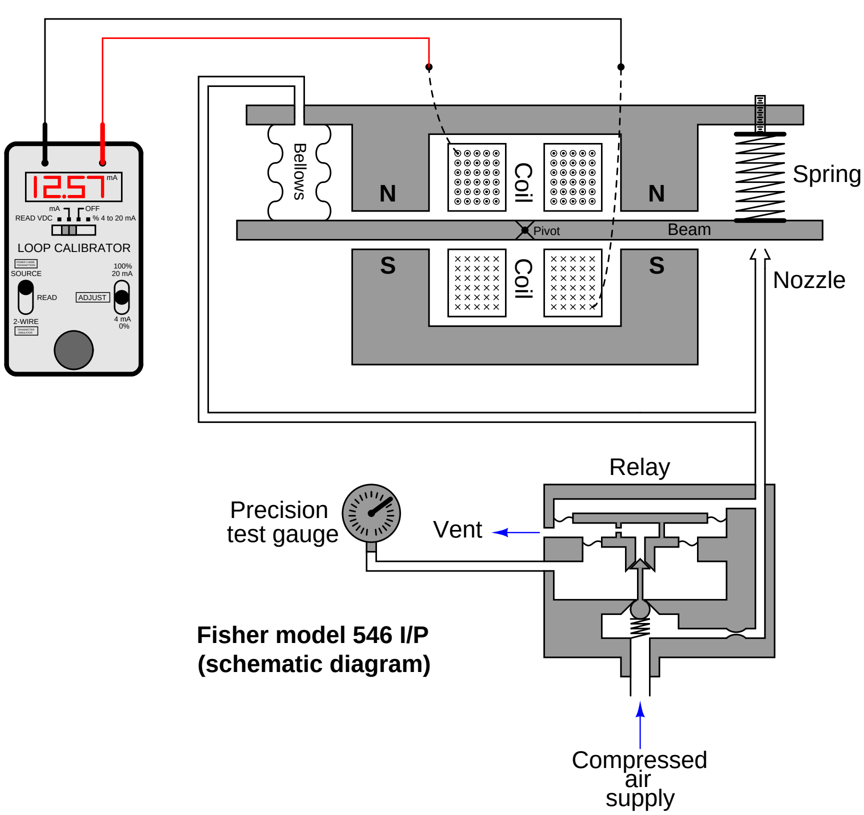
Schematic diagram of a hydraulic valve control system



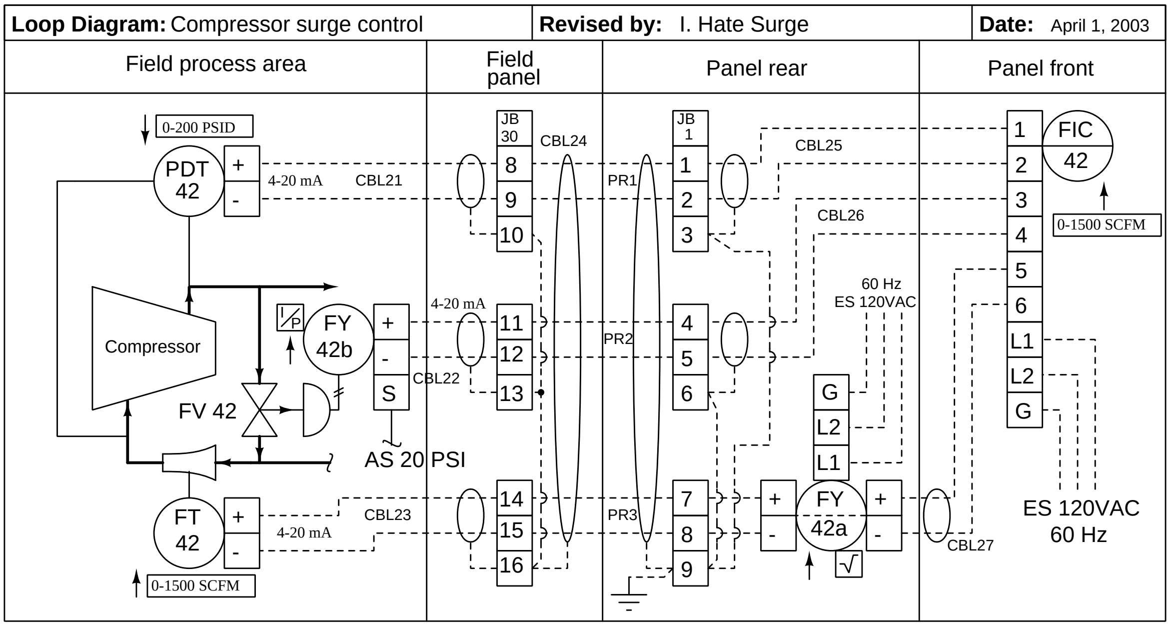
Schematic/pictorial diagram of a pressure transmitter



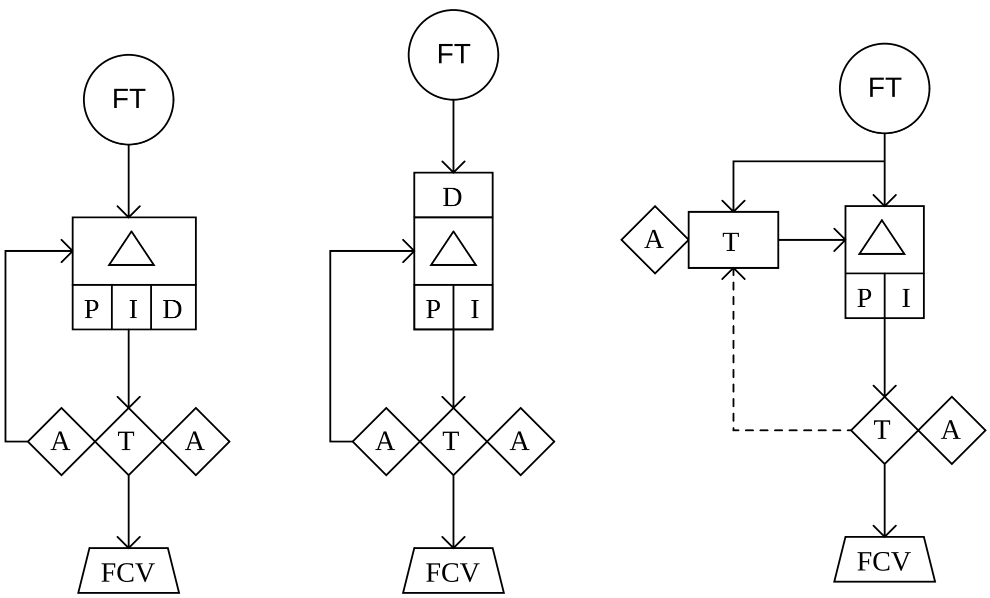
Pictorial diagram of an I/P transducer



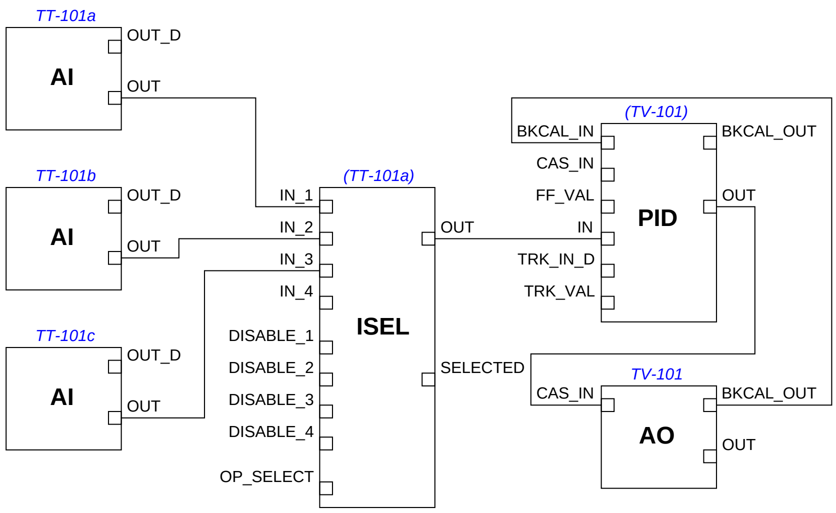
Loop diagram of a compressor surge control system



Functional diagram of control loops



FOUNDATION Fieldbus function block diagram



Questions:

- Identify the meaning(s) of all *dashed lines* in these diagrams
- Identify the meaning(s) of all *arrows* in these diagrams
- Identify the meaning(s) of all *triangles* in these diagrams
- Identify the meaning(s) of all *boxes* in these diagrams
- Identify the meaning(s) of all *circles* in these diagrams
- Identify how directions of motion are indicated in each diagram (if at all)
- Identify how sources of energy are indicated in each diagram (if at all)

file i02683

Question 16

The nameplate on an electric compressor provides the following data:

- 4160 V / 60 Hz
- Three-phase
- 850 HP
- 1800 RPM
- Max. Discharge Pressure = 84 PSIG
- Max. Flow = 1280 SCFM

Answer the following questions based on this nameplate data:

Identify whether this is an *induction* motor or a *synchronous* motor. If it were the *other* type of motor, how would the nameplate data differ?

Determine the number of *poles* in the stator of this motor. Does it have 2 poles, 4 poles, 6 poles, or more poles?

Calculate the *slip* speed of this motor.

file i01233

Question 17

Question 18

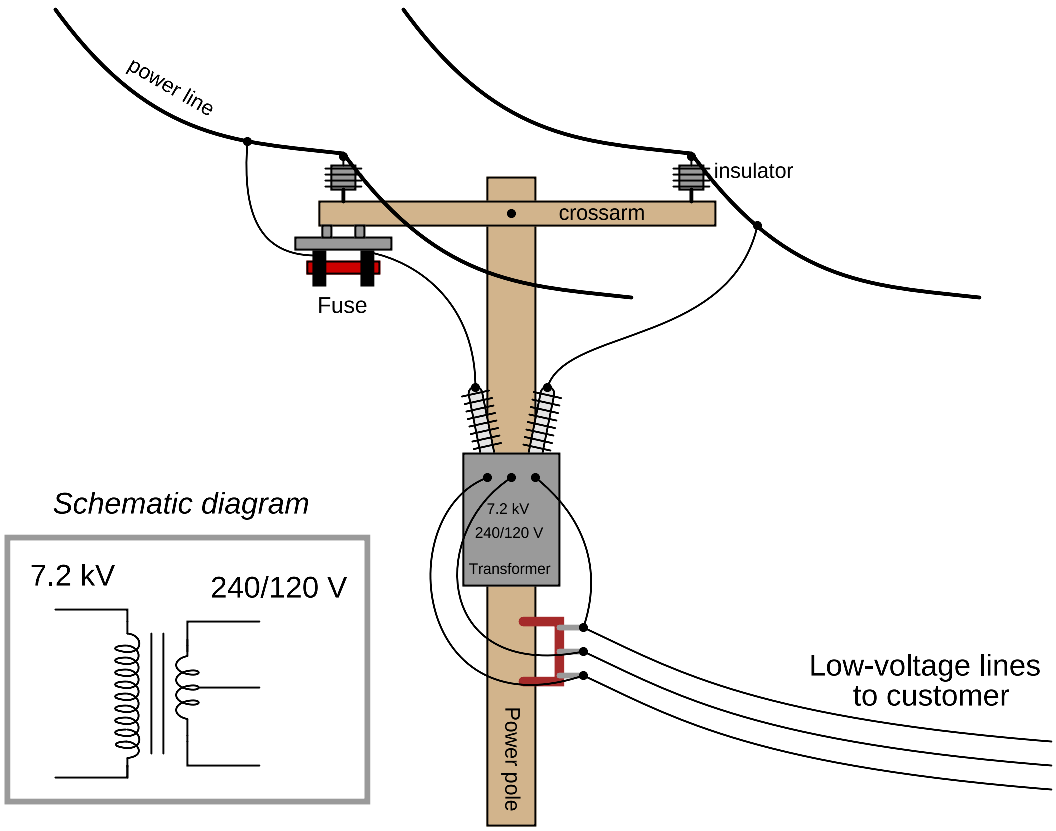
Question 19

Question 20

Question 21

Electrical *transformers* are extensively used in AC power grid systems, the point being to transmit electrical power over long distances at high voltage levels and low current levels so as to limit the size of the metal conductor wires (i.e. cheaper and lighter wiring) and then step voltage down to safer levels (while boosting current) at the points of use. Transformers installed at large electrical generating stations ("power plants") step up voltage from the generator level (tens of kilovolts) to the transmission level (hundreds of kilovolts). Substation transformers step the voltage back down to the tens-of-kilovolts level for distribution through neighborhoods, and finally distribution transformers step the voltage down once more to household and business levels (120, 240, and/or 480 volts).

Determine the following about this power distribution transformer, such as the kind seen on power poles near homes and businesses in the United States:



- How can we tell from the schematic diagram that this transformer is a voltage *step-down* unit?
- The meaning of the "240/120" designation.
- The amount of current through the fuse at a customer load of 11 kW.

Suggestions for Socratic discussion

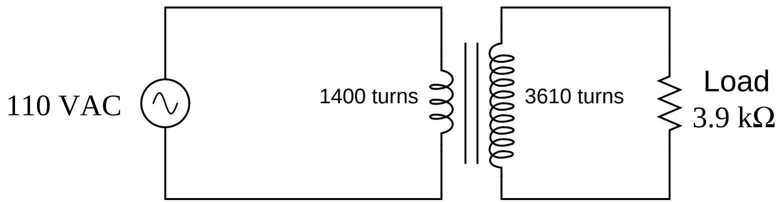
- Why do you suppose the secondary winding of this power transformer is center-tapped?
- What purpose does it serve to build AC power distribution systems with transformers in them to step voltages up and down at different locations? Why not just build a power system with a consistent voltage level everywhere?

- Only one fuse is shown on the high-voltage side of this transformer circuit. What does the lack of a second fuse tell us about the two high-voltage powerline conductors?

file i04754

Question 22

Calculate the source current and load current in this transformer circuit:



$I_{source} =$ $I_{load} =$

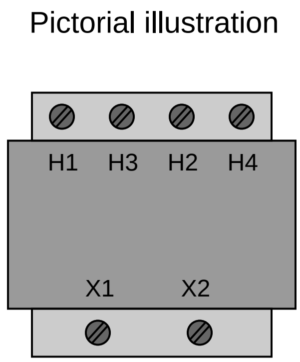
Suggestions for Socratic discussion

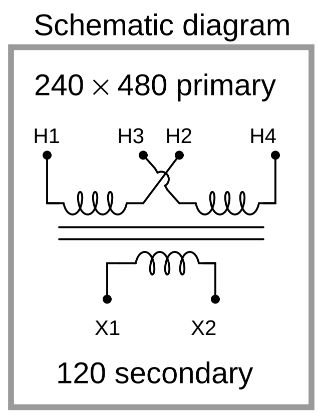
- Identify which fundamental principles of electric circuits apply to each step of your analysis of this circuit. In other words, be prepared to explain the reason(s) "why" for every step of your analysis, rather than merely describing those steps.
- Would this transformer be referred to as a *step-up* or a *step-down*, and why?
- Can a step-down transformer be used as a step-up, and vice-versa? Why or why not?

file i04757

Question 23

A very common form of transformer used in industrial control circuits is the *control power transformer*, shown in both pictorial and schematic forms. Most commonly, the primary winding actually consists of *two* coils which may be connected in different ways depending on the amount of voltage available from the AC power source:





Determine first how 240 VAC power would be connected to the primary winding terminals. After this, determine how a higher line voltage of 480 VAC power would be connected to the primary winding terminals.

Next, identify how a multimeter could be used to test the windings of this transformer, both for *open* as well as *shorted* faults.

Finally, determine how you would use a piece of test equipment called an *insulation tester* (often referred to by the brand name "Megger") to check the transformer windings for a short to ground (to the iron core of the transformer), and how this particular type of test equipment differs from a regular ohmmeter.

Suggestions for Socratic discussion

- Explain why the H2/H3 terminals are "crossed over" as they are shown in the schematic diagram.
- Determine how this transformer could be re-designed to provide two different secondary voltage options (240 VAC vs. 120 VAC) as well as two different primary voltage options.

file i00267

Question 24

Read and outline the "Polyphase AC Power" section of the "AC" chapter in your *Lessons In Industrial Instrumentation* textbook, skipping the subsection on "Symmetrical Components".

The purpose of your outline is to foster close reading of the text, to facilitate quick referencing of specific points within the text, to record questions you have have about the ideas found in the text, and to demonstrate your skill in written communication. Your outline must meet the following standards for full credit: *every major idea contained in the text should be represented in your outline, entirely in your own words (i.e. no copying of text), written legibly enough that others can easily read it.* A suggestion is one sentence of your own per paragraph of source text. Helpful additions include:

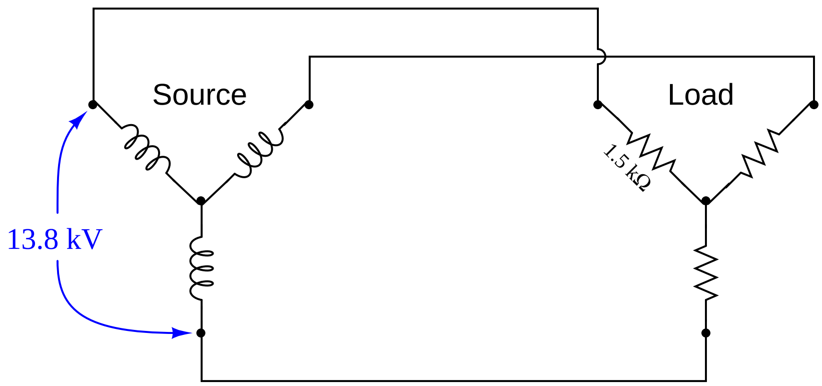
- Noting questions or points of confusion you have from the reading
- Page numbers from the source text for quick reference during discussion
- Images copied from the text (or sketched by you) to illustrate concepts

A note-taking technique you will find far more productive in your academic reading than mere highlighting or underlining is to write your own *outline* of the text you read. A section of your *Lessons In Industrial Instrumentation* textbook called "Marking Versus Outlining a Text" describes the technique and the learning benefits that come from practicing it. This approach is especially useful when the text in question is dense with facts and/or challenging to grasp. Ask your instructor for help if you would like assistance in applying this proven technique to your own reading.

file i04759

Question 25

Calculate all voltages, currents, and total power in this balanced Y-Y system:



- V_{line} =
- I_{line} =
- $V_{phase(source)}$ =
- $I_{phase(source)}$ =
- $V_{phase(load)}$ =
- $I_{phase(load)}$ =
- P_{total} =

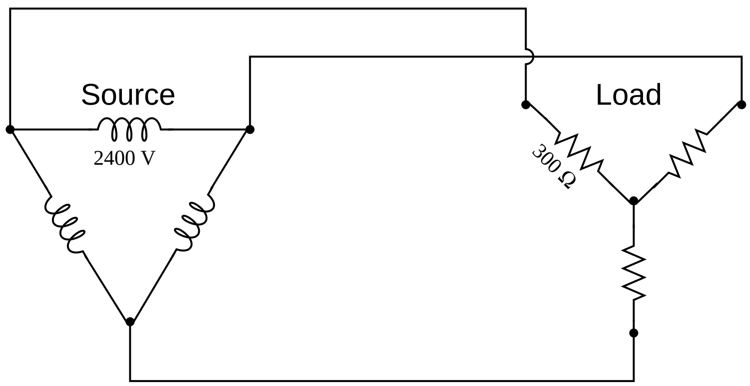
Suggestions for Socratic discussion

- Identify which fundamental principles of electric circuits apply to each step of your analysis of this circuit. In other words, be prepared to explain the reason(s) "why" for every step of your analysis, rather than merely describing those steps.
- Suppose the center of the wye-connected load were connected to earth ground. Determine the amount of voltage between each terminal of the wye-connected source and earth ground.

file i01994

Question 26

Calculate all voltages, currents, and total power in this balanced Delta-Y system:



- $E_{line} =$
- $I_{line} =$
- $E_{phase(source)} =$
- $I_{phase(source)} =$
- $E_{phase(load)} =$
- $I_{phase(load)} =$
- $P_{total} =$

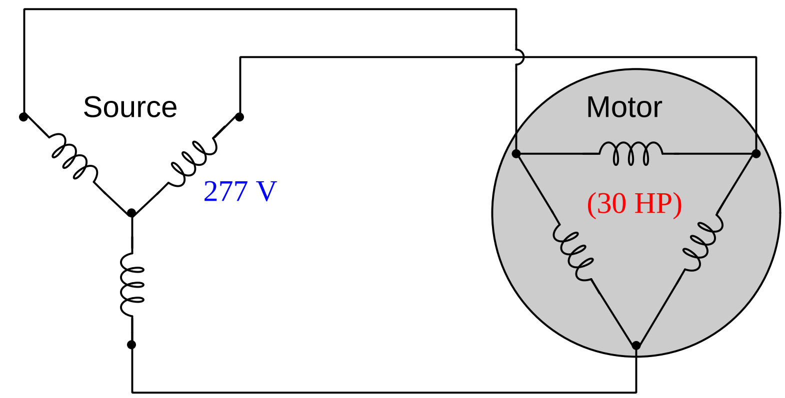
Suggestions for Socratic discussion

- Identify which fundamental principles of electric circuits apply to each step of your analysis of this circuit. In other words, be prepared to explain the reason(s) "why" for every step of your analysis, rather than merely describing those steps.
- Identify two currents in this circuit that are guaranteed to be equal in value, even if the source and load happened to be imbalanced.
- Identify two currents in this circuit that are unequal in value, and explain why one of them is larger than the other.
- Identify two voltages in this circuit that are guaranteed to be equal in value, even if the source and load happened to be imbalanced.
- Identify two voltages in this circuit that are unequal in value, and explain why one of them is larger than the other.
- Suppose the center of the wye-connected load were connected to earth ground. Determine the amount of voltage between each vertex of the delta-connected source and earth ground.
- Suppose one of the vertices of the delta-connected source were connected to earth ground. Determine the amount of voltage between each terminal of the wye-connected load and earth ground.
- Suppose one of the vertices of the delta-connected source were connected to earth ground. Determine the amount of voltage between the center point of the wye-connected load and earth ground.

file i02270

Question 27

Calculate all voltages, currents, and total power in this balanced three-phase system where a Wye-connected source provides electrical power to a 30 horsepower Delta-connected motor. Assume the motor operates at full load (100% power) with perfect power factor and perfect efficiency:



- E_{line} =
- I_{line} =
- $E_{phase(source)}$ =
- $I_{phase(source)}$ =
- $E_{phase(load)}$ =
- $I_{phase(load)}$ =
- P_{total} =

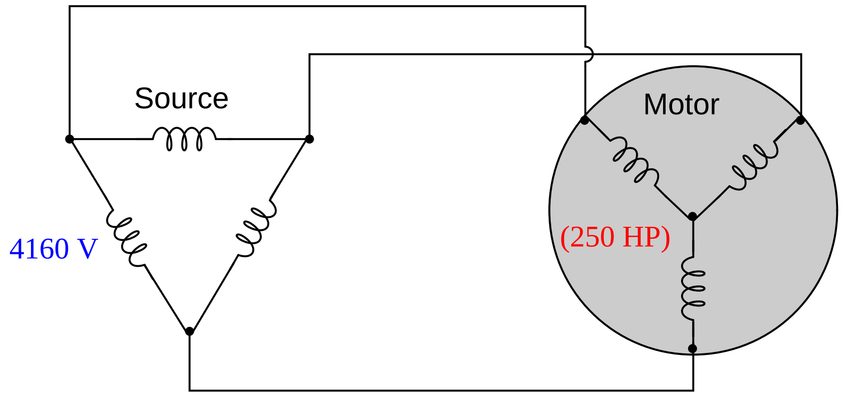
Suggestions for Socratic discussion

- Identify which fundamental principles of electric circuits apply to each step of your analysis of this circuit. In other words, be prepared to explain the reason(s) "why" for every step of your analysis, rather than merely describing those steps.
- Identify two currents in this circuit that are guaranteed to be equal in value, even if the source and load happened to be imbalanced.
- Identify two currents in this circuit that are unequal in value, and explain why one of them is larger than the other.
- Identify two voltages in this circuit that are guaranteed to be equal in value, even if the source and load happened to be imbalanced.
- Identify two voltages in this circuit that are unequal in value, and explain why one of them is larger than the other.
- How might the results differ if the motor were not 100% efficient?
- How might the results differ if the power factor were less than 1?

file i02440

Question 28

Calculate all voltages, currents, and total power in this balanced three-phase system where a Delta-connected source provides electrical power to a 250 horsepower Y-connected motor. Assume the motor operates at full load (100% power) with perfect power factor and perfect efficiency:



- E_{line} =
- I_{line} =
- $E_{phase(source)}$ =
- $I_{phase(source)}$ =
- $E_{phase(load)}$ =
- $I_{phase(load)}$ =
- P_{total} =

Suggestions for Socratic discussion

- Identify which fundamental principles of electric circuits apply to each step of your analysis of this circuit. In other words, be prepared to explain the reason(s) "why" for every step of your analysis, rather than merely describing those steps.
- Identify two currents in this circuit that are guaranteed to be equal in value, even if the source and load happened to be imbalanced.
- Identify two currents in this circuit that are unequal in value, and explain why one of them is larger than the other.
- Identify two voltages in this circuit that are guaranteed to be equal in value, even if the source and load happened to be imbalanced.
- Identify two voltages in this circuit that are unequal in value, and explain why one of them is larger than the other.
- How might the results differ if the motor output the same amount of mechanical power, but at a lesser efficiency level (i.e. $<$ 100%)?
- How might the results differ if the power factor were less than 1?

file i02448

Question 29

Read and outline the "Cable Routing" subsection of the "Electrical Signal and Control Wiring" section of the "Instrument Connections" chapter in your *Lessons In Industrial Instrumentation* textbook.

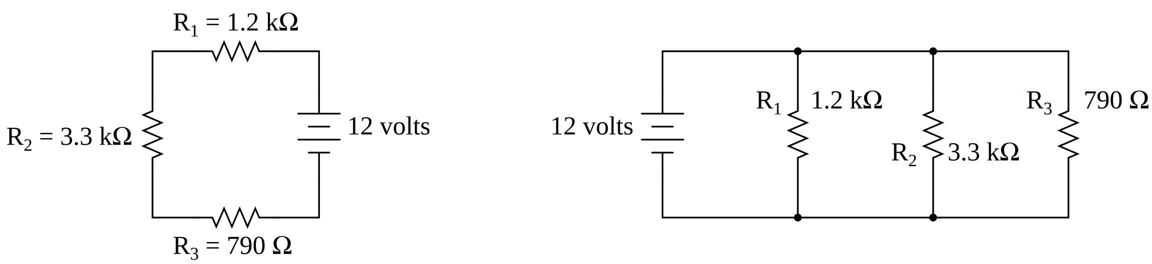
The purpose of your outline is to foster close reading of the text, to facilitate quick referencing of specific points within the text, to record questions you have have about the ideas found in the text, and to demonstrate your skill in written communication. Your outline must meet the following standards for full credit: *every major idea contained in the text should be represented in your outline, entirely in your own words (i.e. no copying of text), written legibly enough that others can easily read it.* A suggestion is one sentence of your own per paragraph of source text. Helpful additions include:

- Noting questions or points of confusion you have from the reading
- Page numbers from the source text for quick reference during discussion
- Images copied from the text (or sketched by you) to illustrate concepts

file i01702

Question 30

Calculate all resistor voltages and currents in these two circuits, also labeling all voltage polarities (+ and − symbols) next to each component in both circuits:



Quantity	Series circuit	Parallel circuit
V_{R1}		
V_{R2}		
V_{R3}		
I_{R1}		
I_{R2}		
I_{R3}		

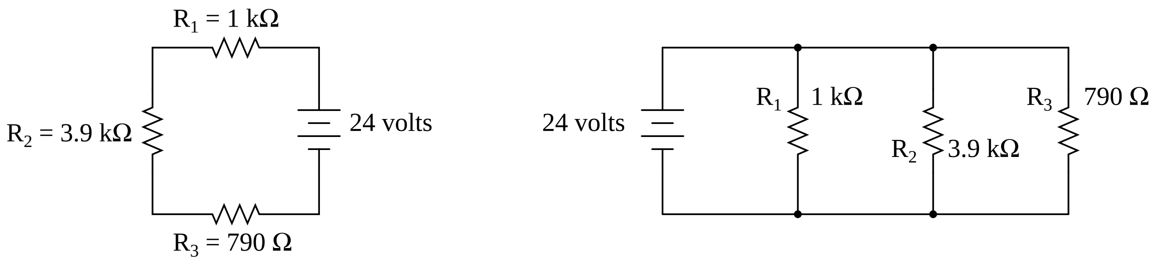
Suggestions for Socratic discussion

- Predict the effects resulting from various wiring and component faults in this system (e.g. *opens* or *shorts*).
- A useful analytical technique for any DC electric circuit is to identify all electrical sources and loads in the circuit, annotate the diagram with arrowheads showing the directions of all currents, and also with "+" and "−" symbols (and/or curved arrows) showing the polarities of all component voltages. Show how this helps you analyze the circuit shown in this question.

file i02769

Question 31

Calculate all resistor voltages and currents in these two circuits, also labeling all voltage polarities (+ and − symbols) next to each component in both circuits:



Quantity	Series circuit	Parallel circuit
V_{R1}		
V_{R2}		
V_{R3}		
I_{R1}		
I_{R2}		
I_{R3}		

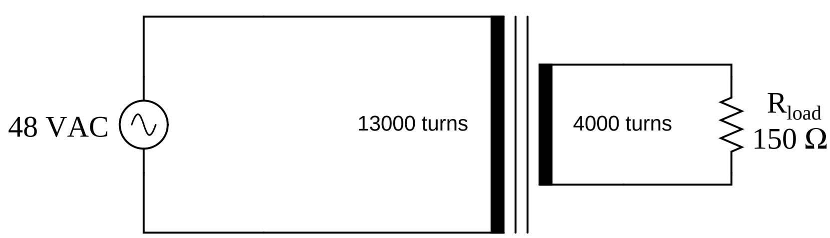
Suggestions for Socratic discussion

- Predict the effects resulting from various wiring and component faults in this system (e.g. *opens* or *shorts*).
- Describe some of the problem-solving techniques you could (or did) apply to this question.

file i02828

Question 32

Calculate all listed values for this transformer circuit:



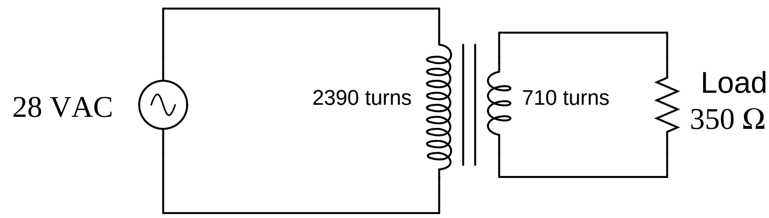
- $V_{primary} =$
- $V_{secondary} =$
- $I_{primary} =$
- $I_{secondary} =$

Explain whether this is a *step-up*, *step-down*, or *isolation* transformer, and also explain what distinguishes the "primary" winding from the "secondary" winding in any transformer.

file i04758

Question 33

Calculate the load current and load voltage in this transformer circuit:



$I_{load} =$ $V_{load} =$

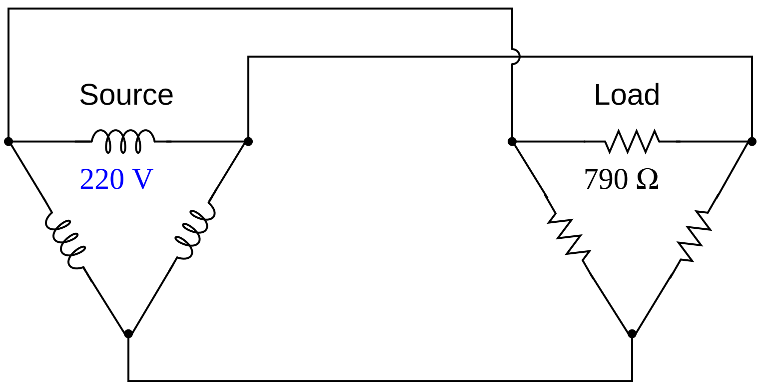
Suggestions for Socratic discussion

- How do the input and output *power* levels in a transformer circuit compare? Voltages and currents may be stepped up and down, but what about watts? Explain why.

file i04756

Question 34

Calculate all voltages, currents, and total power in this balanced Delta-Delta system:



- E_{line} =
- I_{line} =
- $E_{phase(source)}$ =
- $I_{phase(source)}$ =
- $E_{phase(load)}$ =
- $I_{phase(load)}$ =
- P_{total} =

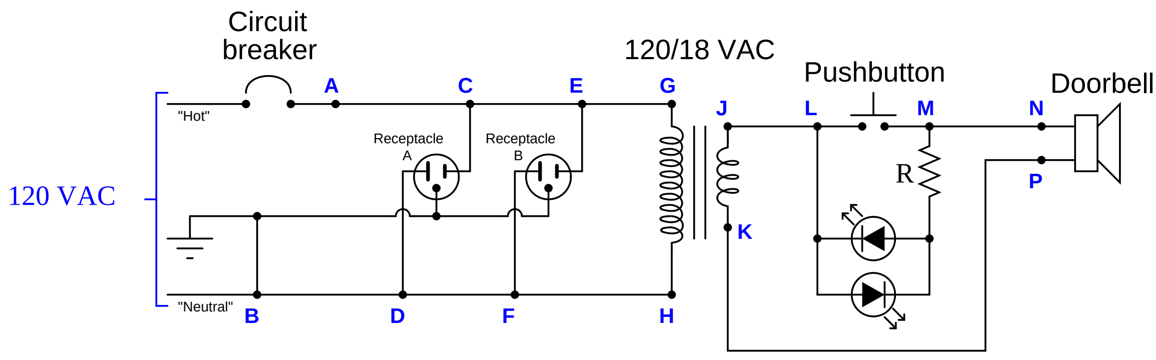
Suggestions for Socratic discussion

- Explain how you may double-check your quantitative answer(s) with a high degree of confidence (i.e. something more rigorous than simply re-working the problem again in the same way).
- Identify two currents in this circuit that are guaranteed to be equal in value, even if the source and load happened to be imbalanced.
- Identify two voltages in this circuit that are guaranteed to be equal in value, even if the source and load happened to be imbalanced.

file i02362

Question 35

This doorbell refuses to make any sound when the pushbutton is pressed. An electrician begins to diagnose the problem, measuring 120 volts AC between the "hot" and "neutral" terminals on receptacle "A", and 0 volts AC between terminals **L** and **M** when the pushbutton is not being pressed.



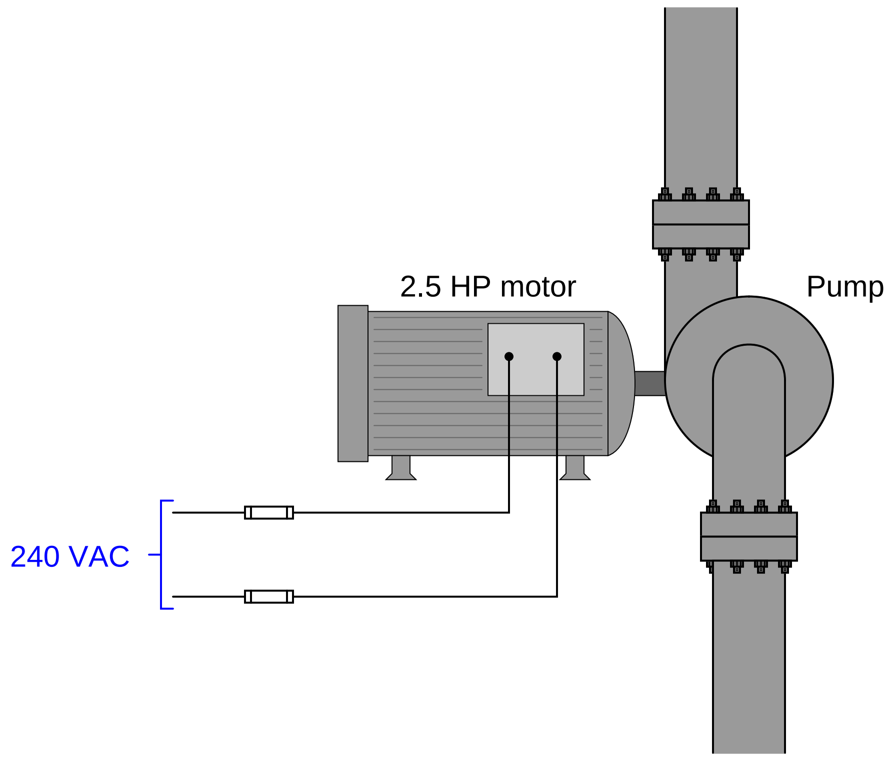
Identify the likelihood of each specified fault for this circuit. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this circuit.

Fault	Possible	Impossible
Circuit breaker tripped		
Transformer primary winding failed open		
Transformer secondary winding failed open		
Resistor failed open		
Resistor failed shorted		
Open wire between K and P		
Doorbell unit failed open		
Doorbell unit failed shorted		

file i01112

Question 36

Suppose a 2.5 horsepower electric motor powered by 240 VAC (single-phase) power is used to turn a pump:



Using the conversion factor of 746 watts to one horsepower, calculate the amount of AC current drawn by the motor at full power (assuming perfect efficiency).

If the motor were only 90% efficient (90% of the applied power performing mechanical work, and 10% of the applied power wasted in the form of heat), how much AC current would it draw at full power then?

Program a computer spreadsheet (e.g. Microsoft Excel) to calculate the same ideal and real current values requested above. Build the spreadsheet page so that all the given values in this problem (2.5 HP, 240 VAC, and 90% motor efficiency) may be edited by the user, allowing the spreadsheet to be used to calculate ideal and real motor currents for a variety of different motor scenarios.

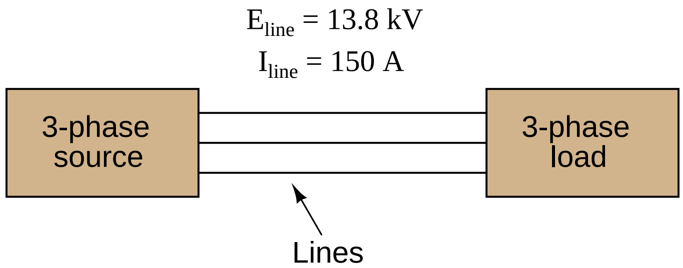
Suggestions for Socratic discussion

- Identify which fundamental principles of science, technology, and/or math apply to each step of your solution to this problem. In other words, be prepared to explain the reason(s) "why" for every step of your solution, rather than merely describing those steps.
- In any electrical device less than 100% efficient, where does the "lost" energy go?
- What design alterations might be made to an electric motor to increase its efficiency?
- Describe the benefit of using computer spreadsheet programs such as Excel to perform calculations such as this, based on your experience using a spreadsheet to model this simple motor circuit. How helpful do you think this might be on the job?

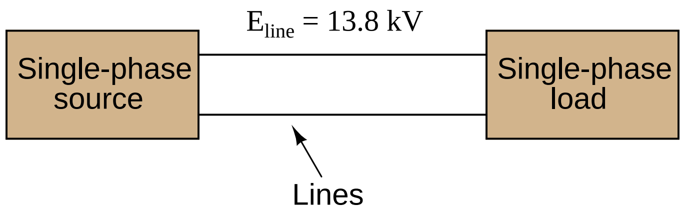
file i04755

Question 37

A balanced, three-phase power system has a line voltage of 13.8 kV volts and a line current of 150 amps. How much power is being delivered to the load (assuming a power factor of 1)?



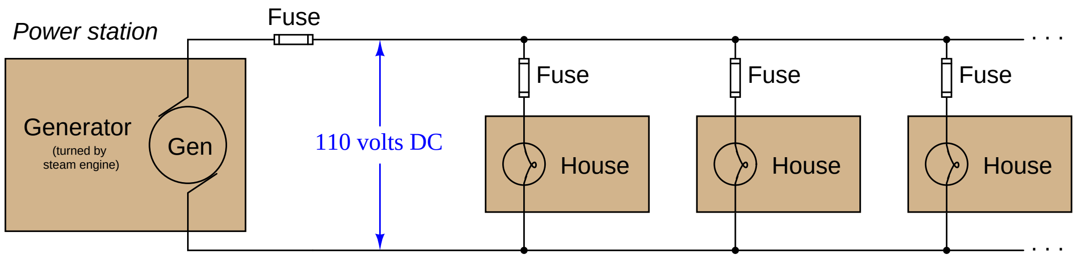
A 13.8 kV single-phase system could be designed to provide the same amount of power to a load, but it would require heavier-gauge (more expensive!) conductors. Determine the extra percentage of expense in wire cost (based on the weight of the wires) resulting from the use of single-phase instead of three-phase.



file i02297

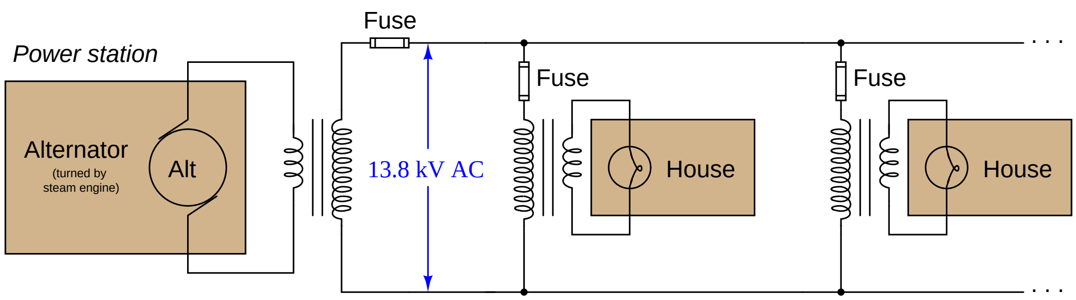
Question 38

Thomas Edison's original power generating station and distribution system used direct current (DC) at 110 volts in distributing electrical power to loads within a city:



Supposing the total power load on the generating station was 18 kilowatts, calculate the amount of current in the main power lines at the power station.

Modern electrical power systems use alternating current (AC) instead of DC, with much greater line voltages than Edison's DC system. The following schematic shows a (very) simplified diagram of an AC power system complete with transformers:



Supposing the exact same load (18 kW) on the power station, calculate the amount of current in the main (13.8 kV) power lines at the power station, then explain the advantage of using AC, transformers, and high voltage for power distribution. In which of these two hypothetical power systems are the power line conductors allowed to be smaller (skinnier) wire, and why?

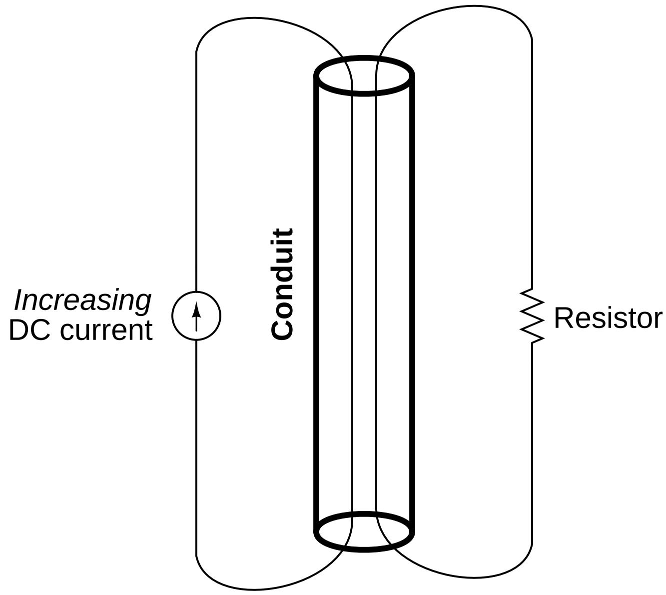
Suggestions for Socratic discussion

- Identify which fundamental principles of electric circuits apply to each step of your analysis of this circuit. In other words, be prepared to explain the reason(s) "why" for every step of your analysis, rather than merely describing those steps.
- Can a transformers boost *power* (watts) up and down like it can voltage or current? Why or why not?
- Why are transformers only used in AC power systems, not DC?
- Is there any way to "fool" a transformer into functioning on DC?
- Explain what will happen in the AC circuit if the transformer's primary winding fails open.
- Explain what will happen in the AC circuit if the transformer's secondary winding fails open.

file i04753

Question 39

Two wires lay parallel to each other inside an electrical conduit. Through one of these wires runs a steadily increasing direct current:



Determine the following about the induced effect in the other wire:

- The direction of induced current in the second wire (please trace *conventional* flow!)
- The polarity of voltage drop across the resistor

Then, explain why the induced effects would be as you described, and not the other way (opposite direction, opposite polarity).

file i02403

Question 40

Question 41

Read and outline the "AC Induction Motors" subsection of the "On/Off Electric Motor Control Circuits" section of the "Discrete Control Elements" chapter in your *Lessons In Industrial Instrumentation* textbook.

The purpose of your outline is to foster close reading of the text, to facilitate quick referencing of specific points within the text, to record questions you have have about the ideas found in the text, and to demonstrate your skill in written communication. Your outline must meet the following standards for full credit: *every major idea contained in the text should be represented in your outline, entirely in your own words (i.e. no copying of text), written legibly enough that others can easily read it.* A suggestion is one sentence of your own per paragraph of source text. Helpful additions include:

- Noting questions or points of confusion you have from the reading
- Page numbers from the source text for quick reference during discussion
- Images copied from the text (or sketched by you) to illustrate concepts

file i04492

Question 42

You task is to work in a team to disassemble a small AC induction "squirrel cage" electric motor. Identify the following components of the motor once disassembled:

- Rotor
- Stator
- Stator windings
- "Squirrel-cage" rotor bars
- Shorting rings (on either end of "squirrel-cage" rotor)
- Bearings
- Keyway (on motor shaft)
- Power terminals

Either with the motor assembled or disassembled, use your multimeter to measure terminal-to-terminal winding resistance. How many ohms do you read from T1 to T2, or from T2 to T3, or from T1 to T3? Should these resistance measurements be the same or different from one another?

Either with the motor assembled or disassembled, use your multimeter to measure terminal-to-frame winding resistance. How many ohms do you read from T1 to frame, or from T2 to frame, or from T1 to frame? Should these resistance measurements be the same or different from one another?

Feel free to photograph the disassembled motor with a digital camera for your own future reference. Reassemble the motor (ensuring the shaft still spins freely) when done.

Suggestions for Socratic discussion

- Explain the purpose of the shorting rings on the rotor. Why must the rotor bars be electrically shorted to each other?
- What might happen to the motor if one of the rotor bar connections to a shorting ring happened to open?
- Does your AC induction motor use a *starting capacitor*? If so, why? If not, why not?

file i04493

Question 43

The nameplate on an electric water pump provides the following data:

- 110 V / 60 Hz
- Single-phase
- 1/2 HP
- 3400 RPM
- Max. Lift = 22 ft
- Max. Head = 115 ft
- Max. Flow = 12 Gal/min
- 1" outlet

Answer the following questions based on this nameplate data:

Calculate the amount of line current expected in the motor's power wiring.

Identify whether this is an *induction* motor or a *synchronous* motor. If it were the *other* type of motor, how would the nameplate data differ?

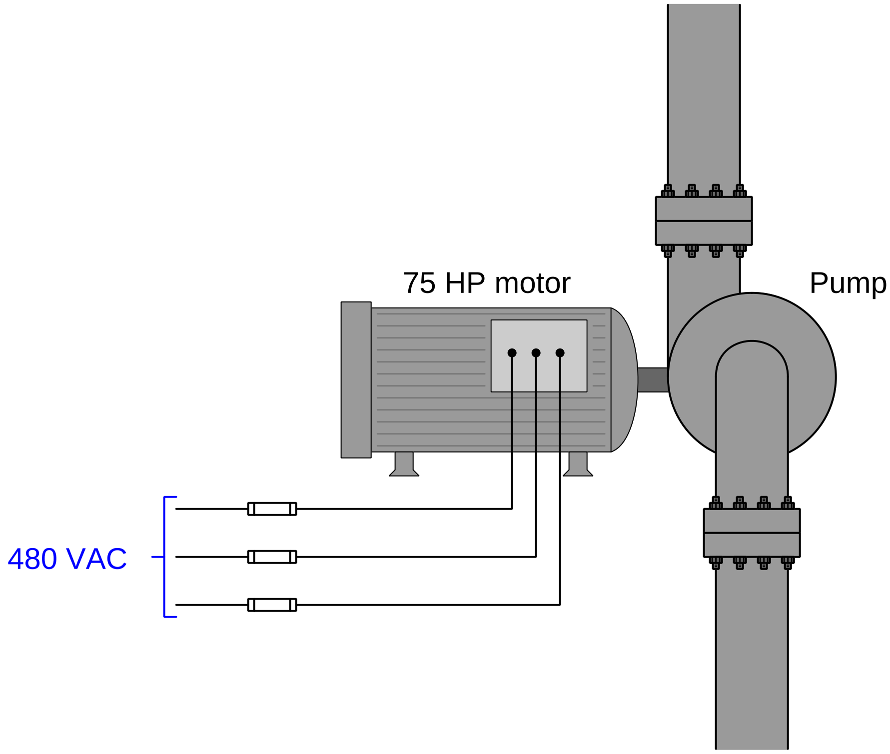
Determine the number of *poles* in the stator of this motor. Does it have 2 poles, 4 poles, 6 poles, or more poles?

Calculate the *slip* speed of this motor.

file i01232

Question 44

Suppose a 75 horsepower electric motor powered by three-phase 480 VAC power is used to turn a pump:



Using the conversion factor of 746 watts to one horsepower, calculate the amount of AC line current drawn by the motor at full power (assuming perfect efficiency).

If the motor were only 92% efficient (92% of the applied power performing mechanical work, and 8% of the applied power wasted in the form of heat), how much AC current would it draw at full power then?

Program a computer spreadsheet (e.g. Microsoft Excel) to calculate the same ideal and real current values requested above. Build the spreadsheet page so that all the given values in this problem (75 HP, 480 VAC, and 92% motor efficiency) may be edited by the user, allowing the spreadsheet to be used to calculate ideal and real motor currents for a variety of different motor scenarios.

file i04249

Question 45

Read selected portions of the NFPA 70E document "Standard for Electrical Safety in the Workplace" and answer the following questions:

Annex K ("General Categories of Electrical Hazards") is a short appendix section of this document, giving some background information on *electric shock*, *arc flash*, and *arc blast*. Read the definitions given for these hazards, and then define them using your own words.

Article 100 ("Definitions") of this document defines some key terms used throughout the standard. Read the definitions given for the following terms and then define them using your own words:

- Risk assessment
- Incident energy
- Arc flash suit
- Ground fault
- Qualified person
- "Working on"

file i03013

Question 46

Read selected portions of the NFPA 70E document "Standard for Electrical Safety in the Workplace" and answer the following questions:

Annex C ("Limits of Approach") and Article 130 of this standard set limits for how close one can be to various electrical hazards. Research the NFPA 70E standard's definitions given for the following terms and then define them using your own words:

- Arc flash boundary
- Limited approach boundary
- Restricted approach boundary

Article 130 provides tables specifying limited approach boundary and restricted approach boundary distances for a variety of circuit voltages and types. Identify the boundary distances for each of these circuits, assuming all conductors within are non-moving:

- 480 VAC motor control circuit ("bucket")
- 110 VAC control power wiring for a PLC
- 125 VDC uninterruptible "station power" for a substation facility
- 4160 VAC motor control circuit

Suggestions for Socratic discussion

- One of the informational notes in the 2015 edition of NFPA 70E, Article 130.4(B), reads *"In certain instances, the arc flash boundary might be a greater distance from the energized electrical conductors or circuit parts than the limited approach boundary. The shock protection boundaries and the arc flash boundary are independent of each other."* Explain why this is, linking your answer to fundamental principles of electric circuits.

file i03014

Question 47

Read selected portions of the NFPA 70E document "Standard for Electrical Safety in the Workplace" and answer the following questions:

Article 120 of this document ("Establishing an Electrically Safe Work Condition") outlines the requirements for two different types of lockout/tagout procedures: a *simple* and a *complex* procedure. Annex G provides a sample procedure for an industrial workplace meeting the requirements of the "simple" procedure type. Read these sections and then write your own outline of a simple lockout/tagout procedure.

What criteria make a lockout/tagout procedure "complex" rather than "simple"?

Suggestions for Socratic discussion

- As with NFPA 70 (the *National Electrical Code*), NFPA 70E does not intrinsically possess the force of law. That is to say, NFPA has no legal power of its own to declare or to enforce professional standards. However, the Authority Having Jurisdiction (AHJ) in the area where the work is being done has the ability to adopt any version of the NFPA's standards as enforceable law. Generally, local government agencies specify which version of the NFPA document(s) they adopt as law, and enjoy a certain freedom of interpretation of those standards. Why is this important for you as a technical worker to know?
- An important safety policy at many industrial facilities is something called *stop-work authority*, which means any employee has the right to stop work they question as unsafe. Describe a scenario involving electrical power where one might invoke stop-work authority.

file i03015

Question 48

Read selected portions of the NFPA 70E document "Standard for Electrical Safety in the Workplace" and answer the following questions:

Article 130 specifies *Arc Flash PPE Category* ratings for work done on different classifications of electrical circuits. Identify this rating for a 480 volt motor control system, where a technician wishes to remove the front panel and take some voltage measurements on the live system. Then, identify what the particular Arc Flash PPE Category number means in terms of the actual protective clothing necessary for doing this job.

For those looking for a challenge, perform an arc flash boundary analysis for an open 208 VAC motor starter circuit, such as the type we build in the lab during this course. Assume the following:

- 3 kVA transformer bank feeding the motor starter
- Transformers have 5% impedance rating
- Fault-clearing time is $\frac{1}{2}$ cycle at 60 Hz with fuses on the 208 VAC lines

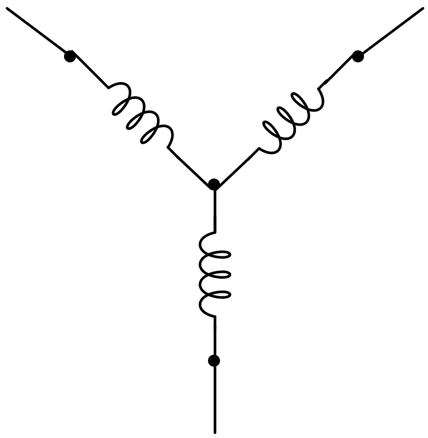
Suggestions for Socratic discussion

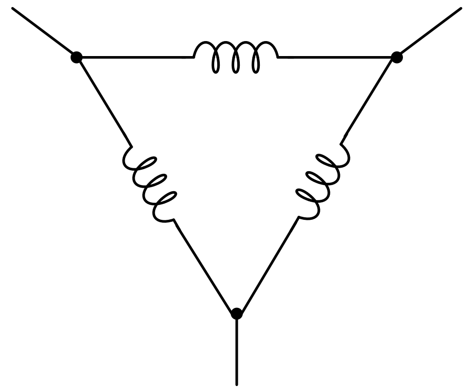
- Section 130.5(C) mentions two different (and exclusive) methods for determining proper PPE to guard against arc flash. Which of these two methods is implied in the Arc Flash PPE Category question (above), and how does the *other* method work?

file i03016

Question 49

Three-phase motors and generators alike are manufactured in two basic forms: *Wye* (Y) and *Delta* (Δ):





Mark in the above diagrams where the following electrical quantities would be measured (hint: each coil shown in the diagram is called a *phase* winding, and each conductor connecting the motor or generator to something else in the three-phase system is called a *line*):

- Phase voltage
- Line voltage

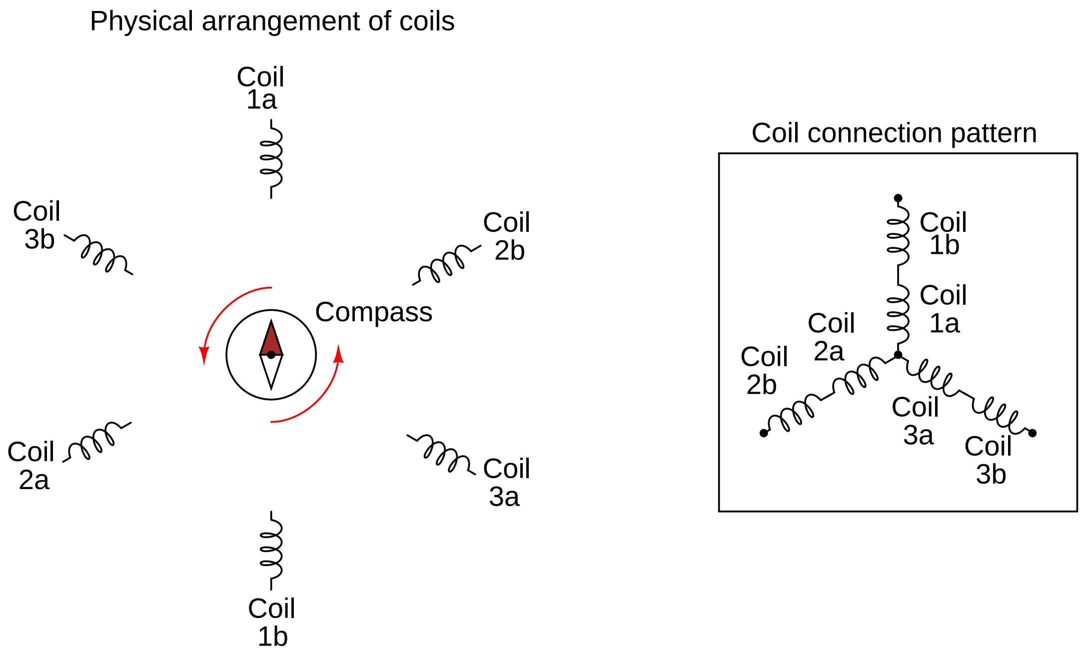
- Phase current
- Line current

In which circuit (Wye or Delta) are the phase and line currents equal? In which circuit (Wye or Delta) are the phase and line voltages equal? Explain both answers, in terms that anyone with a basic knowledge of electricity could understand (i.e. using the properties of *series* and *parallel* connections). Where phase and line quantities are *un*equal, determine which is larger.

file i03258

Question 50

If a set of six electromagnet coils were spaced around the periphery of a circle and energized by 3-phase AC power, and a magnetic compass were placed in the center of that circle, the compass needle would rotate because it would experience a rotating magnetic field produced by these coils:



Explain why the magnetic field produced by the stator coils appears to rotate, and also calculate the rotational speed of this field if the 3-phase AC power frequency is 60 Hz. Based on the rotation shown (by the arrows), what is the *phase sequence* of the AC power applied to the motor?

Also, determine what would have to be changed in this scenario for the compass needle to spin at only *half* the speed it does now.

Also, determine what would have to be changed in this scenario for the compass needle to spin in the *reverse direction* as it does now.

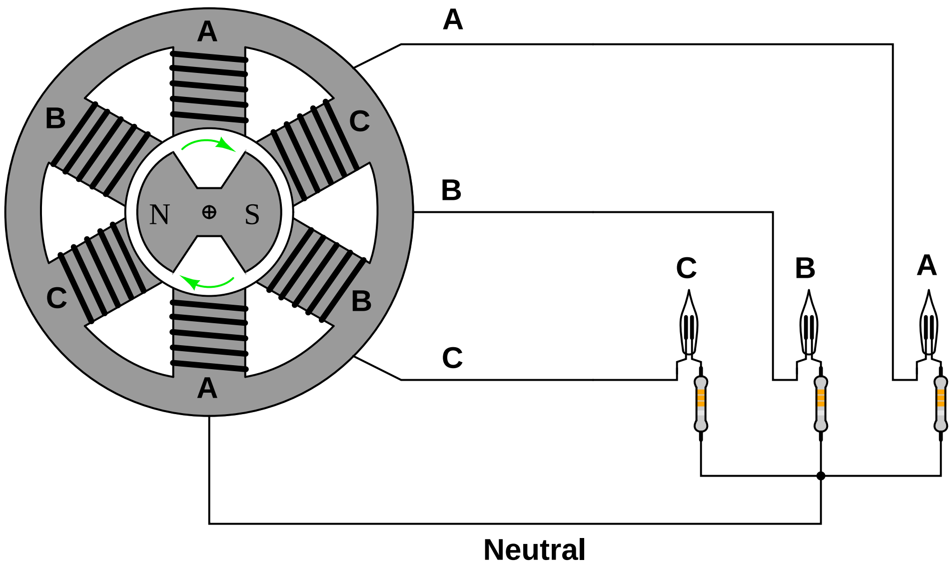
Suggestions for Socratic discussion

- Why does a real three-phase motor have its three phase coils built in pairs, as is shown here? Why not just have three coils instead of six?
- Suppose that one of the lines in the three-phase power source feeding this motor were to fail open, preventing current through one of the sets of coils in the stator of this motor. Would the compass needle still spin? Why or why not?
- What would the stator coil arrangement look like for a *four* phase electric motor?

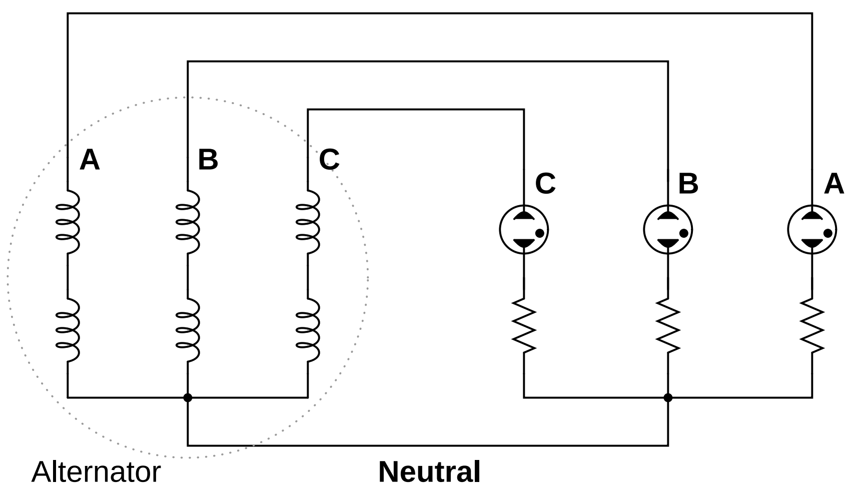
file i01443

Question 51

Suppose a set of three neon light bulbs were connected to a 3-phase alternator with the three stator winding sets labeled **A**, **B**, and **C**:



The schematic diagram for this alternator/lamp system is as follows:



If the alternator spins fast enough (clockwise, as shown), the AC voltage induced in its windings will be enough to cause the neon lamps to "blink" on and off. Most likely this blinking will be too fast to discern with the naked eye.

However, if we were to video-record the blinking and play back the recording at a slow speed, we should be able to see the sequence of light flashes. Determine the apparent "direction" of the lamps' blinking (from right-to-left or from left-to-right), and relate that sequence to the voltage peaks of each alternator coil pair.

Furthermore, determine how to reverse the blinking sequence just by reconnecting wires between the alternator and the neon lamps.

file i03257

Question 52

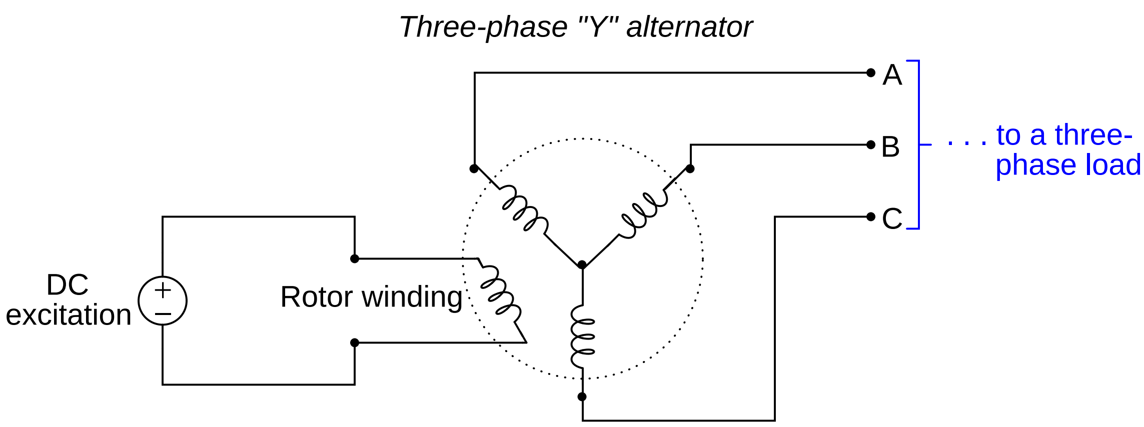
A *stroboscope* is a bright strobe light designed to be used for measuring the shaft speed of a rotating machine. When flashed at the same frequency as the shaft's rotation, the effect is to make the shaft look as though it is stationary even while it is spinning.

Suppose a stroboscope is used to "freeze" the rotation of an AC motor's shaft, and the flash frequency is noted to be 29.3 Hz. Calculate the speed of the motor shaft, and then determine both the number of poles inside this motor and whether or not it is an *induction* motor or a *synchronous* motor.

file i04786

Question 53

This is a schematic diagram of a *Y-connected* three-phase generator (with the rotor winding shown):



How much AC voltage will appear between any two of the lines (V_{AB}, V_{BC}, or V_{AC}) if each stator coil inside the alternator outputs 277 volts? Draw a phasor diagram showing how the phase (winding) and line voltages relate.

How much AC current will each of the lines (I_A, I_B, or I_C) conduct to a load (not shown) if each stator coil inside the alternator outputs 17 amps of current to a load?

How much power will be delivered to a load given the stator coil voltages and currents described above?

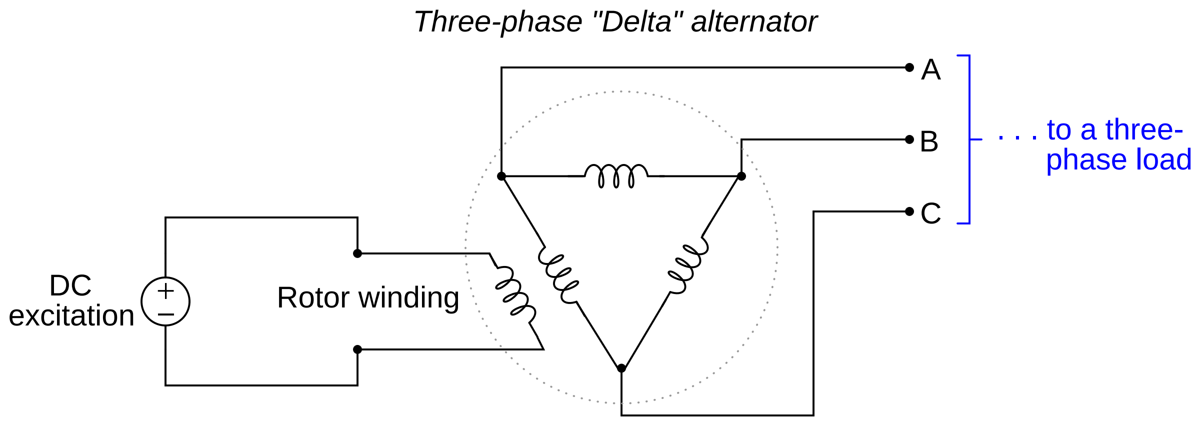
Suggestions for Socratic discussion

- Explain how you may double-check your quantitative answer(s) with a high degree of confidence (i.e. something more rigorous than simply re-working the problem again in the same way).
- Explain the purpose of the *rotor winding* shown in the diagram. Does this winding generate power or receive power from an external source?
- Explain the purpose of the *DC excitation* shown in the diagram. What would the generator do without this DC circuit in place and functioning?

file i02294

Question 54

This is a schematic diagram of a *Delta-connected* three-phase generator (with the rotor winding shown):



How much AC current will each of the lines (I_A, I_B, or I_C) conduct to a load (not shown) if each stator coil inside the alternator outputs 17 amps of current?

How much AC voltage will appear between any two of the lines (V_{AB}, V_{BC}, or V_{AC}) if each stator coil inside the alternator outputs 240 volts?

How much power will be delivered to a load given the stator coil voltages and currents described above?

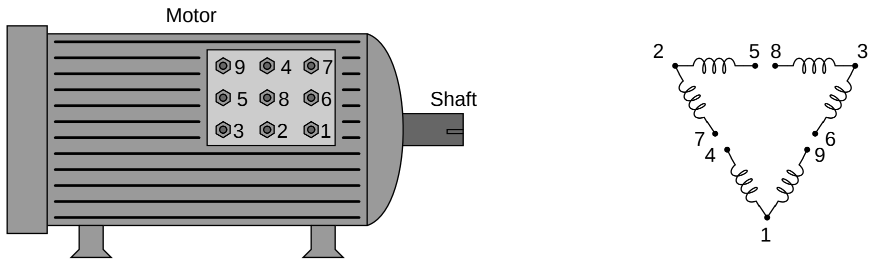
Suggestions for Socratic discussion

- Explain how you may double-check your quantitative answer(s) with a high degree of confidence (i.e. something more rigorous than simply re-working the problem again in the same way).
- Explain the purpose of the *rotor winding* shown in the diagram. Does this winding generate power or receive power from an external source?
- Explain the purpose of the *DC excitation* shown in the diagram. What would the generator do without this DC circuit in place and functioning?

file i02295

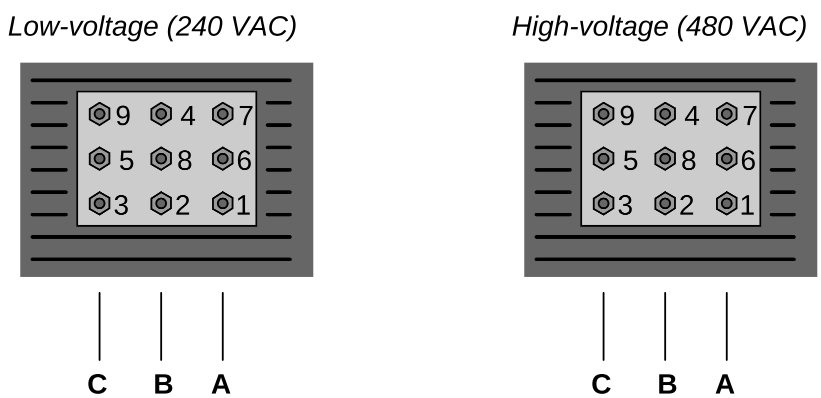
Question 55

Three-phase electric motors are often equipped with a set of electrical terminals for configuring different voltage ranges and/or base speeds. Different configurations consist of different patterns of "jumper" wires connecting these terminals together. For example, here is an illustration of a three-phase electric motor with nine stud-and-nut terminals for connecting a set of six wire windings (coils) in two different configurations: one for low voltage (240 volts AC) and one for high voltage (480 volts AC):



When connecting the terminals for high-voltage operation, the goal is to have a "delta" configuration with two series-connected windings in each side of the triangle. When connecting the terminals for low-voltage operation, the goal is to have two parallel "delta" winding sets.

Sketch the proper power conductor and jumper connections for low-voltage operation and for high-voltage operation:



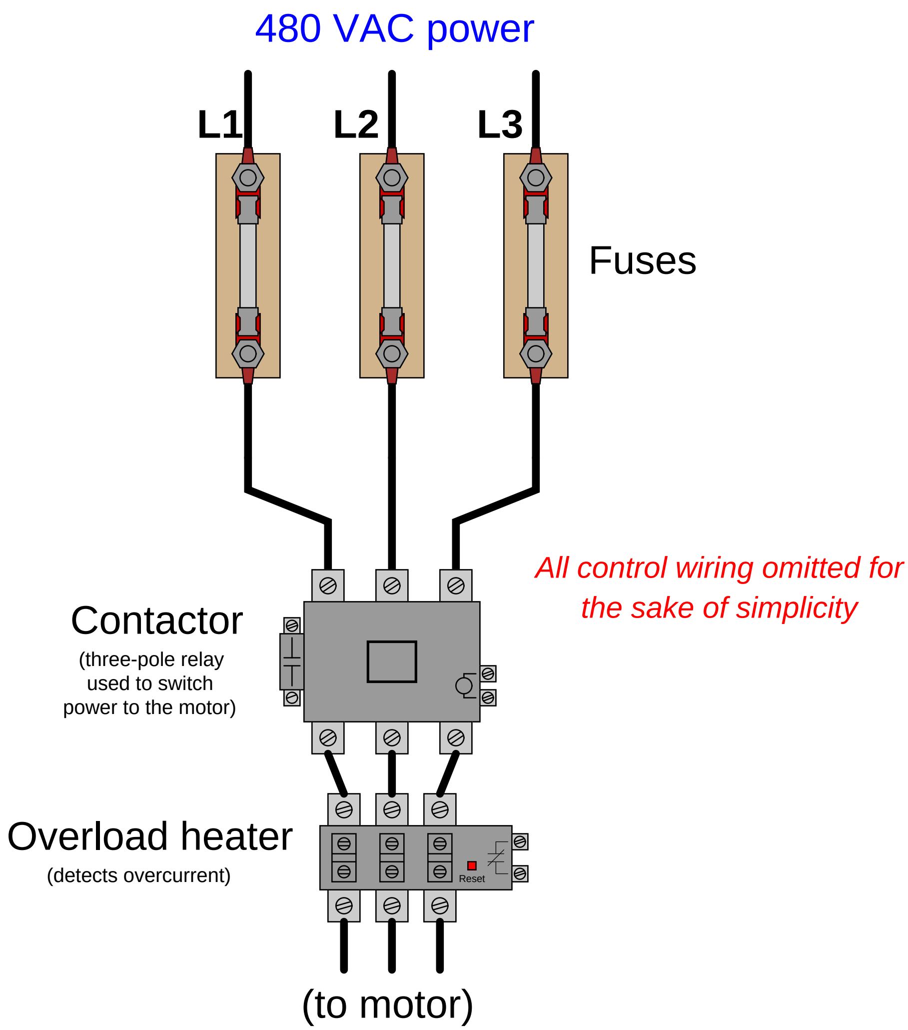
Suggestions for Socratic discussion

- Why do you think an electric motor manufacturer would equip one of their motors with the capability of dual-voltage operation?

<u>file i02298</u>

Question 56

An electrician goes to troubleshoot a three-phase motor starter ("bucket") that is not functioning. When the operator presses the "Start" switch, the motor refuses to start up. Thinking that perhaps one of the main fuses is blown, the electrician measures AC voltage across each fuse, measuring 0 volts drop for each one. Upon seeing this, he declares all three fuses to be good, and that the trouble must lie elsewhere in the circuit (e.g. bad motor, failed contactor, etc.).



Explain what is wrong with the electrician's reasoning, and how it is possible to measure 0 volts across a fuse that is actually blown.

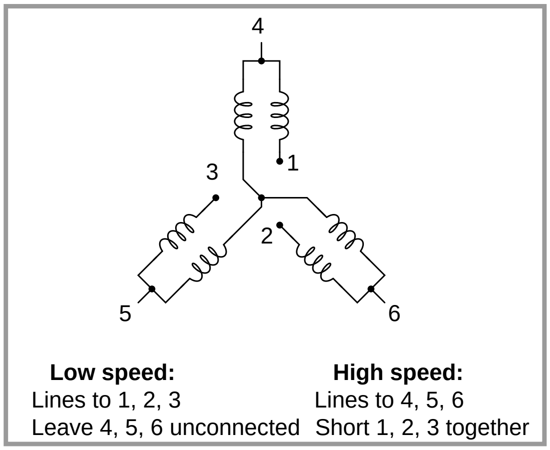
Suggestions for Socratic discussion

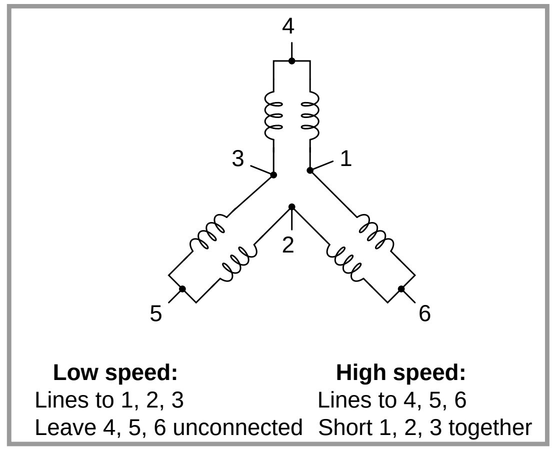
- Identify which fundamental principles of electric circuits apply to each step of your analysis of this circuit. In other words, be prepared to explain the reason(s) "why" for every step of your analysis, rather than merely describing those steps.
- This is an example of a logical fallacy known as *illicit conversion*. A general example of this fallacy goes like this: "All rabbits are mammals, therefore all mammals are rabbits." Explain how the electrician's association of 0 volts with a good fuse is an example of this fallacy.

file i03737

Question 57

The following diagrams show windings for different *two-speed* induction AC motors, along with connection instructions for each of the operating speeds:





Identify the "wye" or "delta" configurations for each of these motors, in each of their speeds.

Also, explain the principle behind the two speeds of each motor. Hint: the "low speed" configuration runs at half the speed as the "high speed" configuration.

Suggestions for Socratic discussion

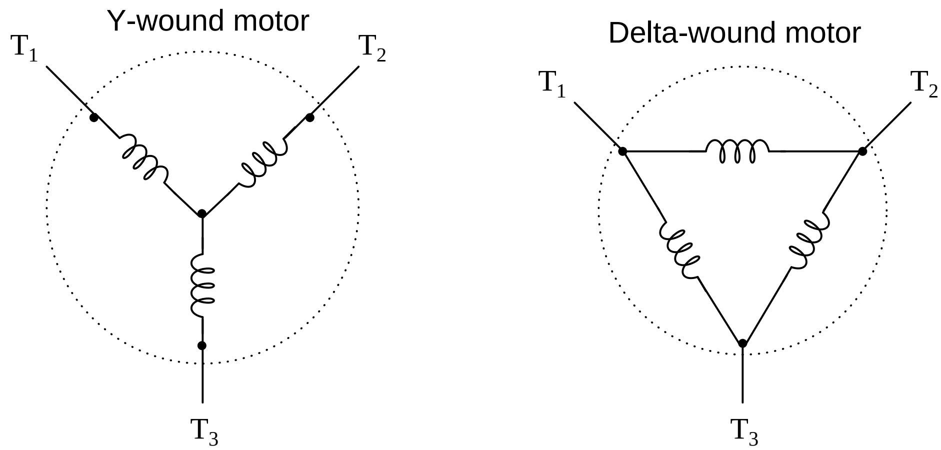
- A helpful problem-solving technique to apply in this case is to mark the coils with polarity (+,−) symbols as if they were being energized by DC, in order to better picture how the coils in each pair relate to each other.

file i02137

Question 58

Suppose one of the windings in a three-phase AC motor were suspected to be partially shorted, as though the electrical varnish insulation on several adjacent turns of the winding burned through allowing those turns to directly contact each other. This would result in that one winding having less electrical resistance than the other two windings.

Explain how you would use basic electrical test equipment to confirm a partially-shorted motor winding. Provide two different answers: one for a Y-wound motor, and one for a Delta-wound motor:



Also, determine how you would use a piece of test equipment called a *megger* to check the windings for a short to ground (the metal frame of the motor), and how this particular type of test equipment differs from a regular ohmmeter.

Suggestions for Socratic discussion

- A good problem-solving technique to apply in cases where we need to determine the effect of a change is to consider *limiting cases*. Instead of asking ourselves what would happen if the resistance of one stator winding changed slightly (e.g. a partial short), we ask ourselves what would happen if the resistance changed *dramatically* (e.g. a direct short). Explain how this problem-solving technique helps simplify this particular scenario, making it easier to solve.
- Identify how a megger might be improperly used, in such a way that it damages the equipment it is supposed to test. Hint: think equipment containing *semiconductor* components!

file i04494

Question 59

Calculate the mechanical power output by an electric motor (in units of horsepower) as is delivers 1250 lb-ft of torque at 850 RPM. Then, calculate the line current for this motor if it is a 3-phase unit operating at a line voltage of 480 volts. Assume 92% efficiency for the motor.

Suggestions for Socratic discussion

- How might the results differ if the motor were 100% efficient instead of 92% efficient?
- Explain how you may double-check your quantitative answer(s) with a high degree of confidence (i.e. something more rigorous than simply re-working the problem again in the same way).
- Suppose we were to alter this problem to describe a diesel engine turning a three-phase *generator* with an efficiency of 92%, at 1250 lb-ft of torque and a shaft speed of 850 RPM. At a line voltage of 480 volts, how much line current could we expect the generator to output? Is the answer the same as in the case of the motor? Explain why or why not.

file i01434

Question 60

Question 61

Read and outline the "Relay Control Systems" chapter in your *Lessons In Industrial Instrumentation* textbook in its entirety.

The purpose of your outline is to foster close reading of the text, to facilitate quick referencing of specific points within the text, to record questions you have have about the ideas found in the text, and to demonstrate your skill in written communication. Your outline must meet the following standards for full credit: *every major idea contained in the text should be represented in your outline, entirely in your own words (i.e. no copying of text), written legibly enough that others can easily read it.* A suggestion is one sentence of your own per paragraph of source text. Helpful additions include:

- Noting questions or points of confusion you have from the reading
- Page numbers from the source text for quick reference during discussion
- Images copied from the text (or sketched by you) to illustrate concepts

file i04500

Question 62

You task is to work in a team to remove the protective cover from an "ice-cube" control relay used for industrial control circuitry. Identify the following components of the device once the cover is removed:

- Moving contacts
- Stationary contacts
- Armature (moving iron piece)
- Coil terminals
- Coil voltage rating
- Contact voltage, current, and/or horsepower ratings

Feel free to connect the coil of the uncovered relay to a DC voltage source to watch its operation. Feel free also to photograph the disassembled contactor with a digital camera for your own future reference. Reassemble the contactor (ensuring the armature still moves freely) when done. Be sure to bring appropriate tools to class for this exercise (e.g. phillips and slotted screwdrivers, multimeter).

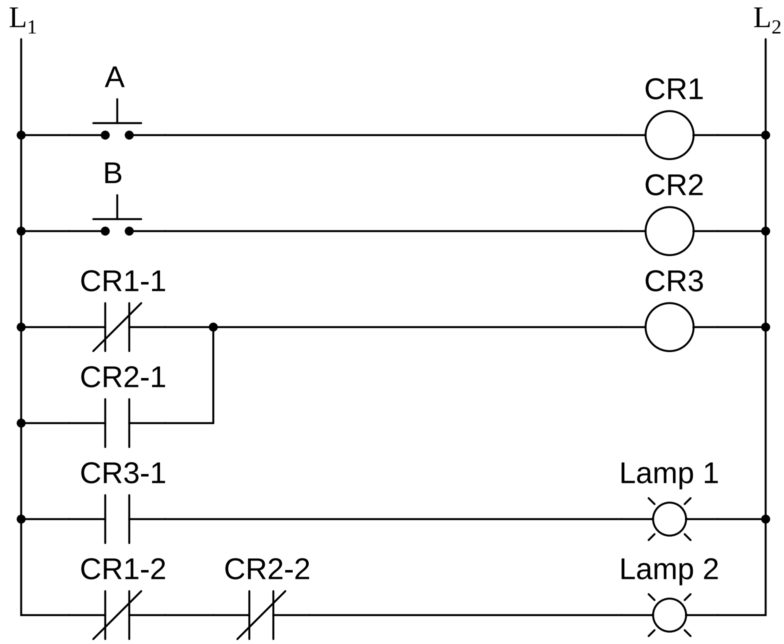
Suggestions for Socratic discussion

- Identify potential points of failure inside the relay you are examining. For each proposed fault, identify the effect(s) of that fault on the relay's operation.
- Describe a procedure you might use to clean the contact surfaces inside a relay if they were to become dirty with use and exposure.
- Demonstrate how you could use a multimeter to identify pin assignments on an electromechanical relay if it did not have a transparent case, and if the pinout diagram were obscured from view.

file i04733

Question 63

Predict how the operation of this relay logic circuit will be affected as a result of the following faults. Consider each fault independently (i.e. one at a time, no coincidental faults):



- Pushbutton switch A fails open:
- Relay coil CR2 fails open:
- Relay contact CR1-1 fails open:
- Relay contact CR2-1 fails shorted:
- Relay contact CR2-2 fails shorted:

For each of these conditions, explain *why* the resulting effects will occur.

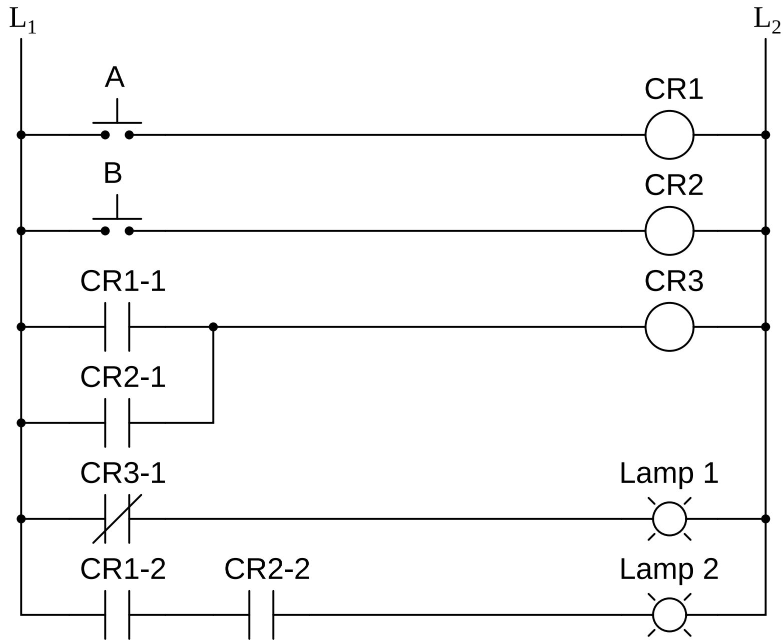
Suggestions for Socratic discussion

- Identify how ladder-logic type diagrams differ from standard electronic schematics, particularly with regard to how electromechanical relay coils and contacts are shown in each.
- For each of the specified faults, identify how it could be diagnosed using a multimeter.
- Identify how a technician could force Lamp 1 to energize regardless of switch status.

file i02319

Question 64

There is a problem somewhere in this relay logic circuit. Lamp 2 operates exactly as it should, but lamp 1 never turns on. Identify all possible failures in the circuit that could cause this problem, and then explain how you would troubleshoot the problem as efficiently as possible (taking the least amount of electrical measurements to identify the specific problem).



Next, suppose an electrician tried to force lamp 1 to energize by connecting a temporary jumper wire in parallel with that lamp. Explain why this strategy will *not* work, and in fact will likely cause damage to the circuit.

Suggestions for Socratic discussion

- Identify how ladder-logic type diagrams differ from standard electronic schematics, particularly with regard to how electromechanical relay coils and contacts are shown in each.
- Suppose you were asked to diagnose the problem in this circuit without using any test equipment, but simply by observing and listening to the circuit function. Knowing that an electromechanical relay typically makes a soft "click" sound when its coil changes state, explain how you could isolate certain faults in this circuit without a multimeter.
- Explain why a relay *coil* failing shorted will not necessarily yield the same results as a relay *contact* failing shorted.

file i02320

Question 65

Read and outline the "Motor Contactors" subsection of the "On/Off Electric Motor Control Circuits" section of the "Discrete Control Elements" chapter in your *Lessons In Industrial Instrumentation* textbook.

The purpose of your outline is to foster close reading of the text, to facilitate quick referencing of specific points within the text, to record questions you have have about the ideas found in the text, and to demonstrate your skill in written communication. Your outline must meet the following standards for full credit: *every major idea contained in the text should be represented in your outline, entirely in your own words (i.e. no copying of text), written legibly enough that others can easily read it.* A suggestion is one sentence of your own per paragraph of source text. Helpful additions include:

- Noting questions or points of confusion you have from the reading
- Page numbers from the source text for quick reference during discussion
- Images copied from the text (or sketched by you) to illustrate concepts

file i04495

Question 66

Read and outline the "Motor Protection" subsection of the "On/Off Electric Motor Control Circuits" section of the "Discrete Control Elements" chapter in your *Lessons In Industrial Instrumentation* textbook.

The purpose of your outline is to foster close reading of the text, to facilitate quick referencing of specific points within the text, to record questions you have have about the ideas found in the text, and to demonstrate your skill in written communication. Your outline must meet the following standards for full credit: *every major idea contained in the text should be represented in your outline, entirely in your own words (i.e. no copying of text), written legibly enough that others can easily read it.* A suggestion is one sentence of your own per paragraph of source text. Helpful additions include:

- Noting questions or points of confusion you have from the reading
- Page numbers from the source text for quick reference during discussion
- Images copied from the text (or sketched by you) to illustrate concepts

file i04496

Question 67

Read and outline the "Motor Control Circuit Wiring" subsection of the "On/Off Electric Motor Control Circuits" section of the "Discrete Control Elements" chapter in your *Lessons In Industrial Instrumentation* textbook.

The purpose of your outline is to foster close reading of the text, to facilitate quick referencing of specific points within the text, to record questions you have have about the ideas found in the text, and to demonstrate your skill in written communication. Your outline must meet the following standards for full credit: *every major idea contained in the text should be represented in your outline, entirely in your own words (i.e. no copying of text), written legibly enough that others can easily read it.* A suggestion is one sentence of your own per paragraph of source text. Helpful additions include:

- Noting questions or points of confusion you have from the reading
- Page numbers from the source text for quick reference during discussion
- Images copied from the text (or sketched by you) to illustrate concepts

file i04497

Question 68

You task is to work in a team to disassemble a contactor (and overload heater block) used for starting an AC induction motor. Identify the following components of the device once disassembled:

- Moving contacts
- Stationary contacts
- Arc shields
- Armature (moving iron piece)
- Overload heaters
- Coil terminals
- Contact voltage, current, and/or horsepower ratings

Feel free to photograph the disassembled contactor with a digital camera for your own future reference. Reassemble the contactor (ensuring the armature still moves freely) when done. Be sure to bring appropriate tools to class for this exercise (e.g. phillips and slotted screwdrivers, multimeter).

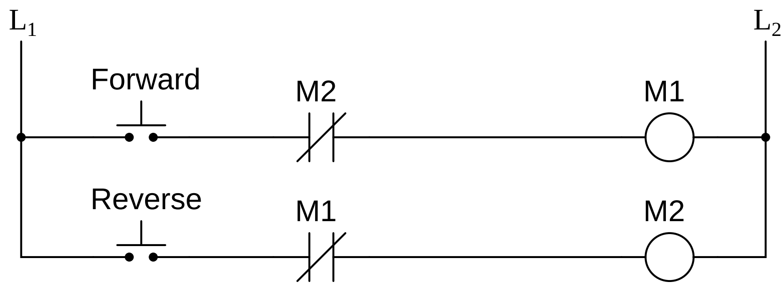
Suggestions for Socratic discussion

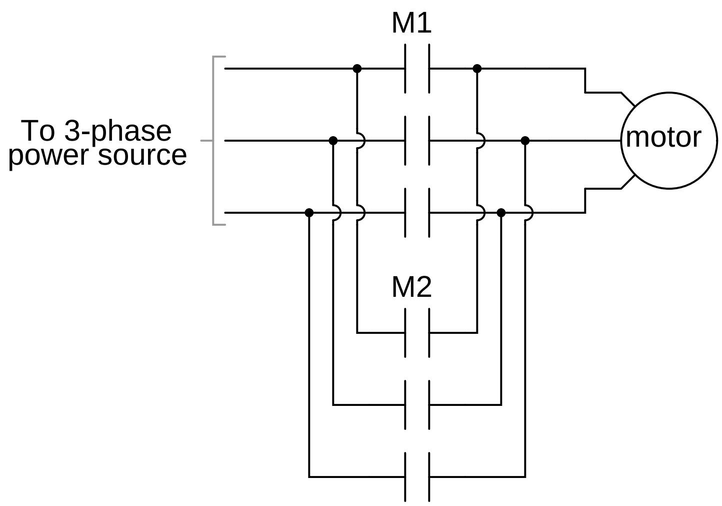
- Identify potential points of failure inside the contactor you are examining. For each proposed fault, identify the effect(s) of that fault on the contactor's operation.
- Explain how the arc shields function, not just to serve as a barrier between the arcing contacts and any nearby people, but also how the shields prevent a phase-to-phase arc from developing between adjacent contacts.
- Describe a procedure you might use to clean the contact surfaces inside a motor contactor if they were to become dirty or pitted with use.
- Demonstrate how you could use a multimeter to verify proper contact operation inside a contactor.

file i04499

Question 69

The direction of rotation for a three-phase AC electric motor may be reversed by swapping any two of the three power conductor connections. With this in mind, explain how this reversing motor control circuit works:





In particular, what is the function of the two normally-closed "M" contacts (called *interlock* contacts) in the control circuit? What do you think might happen if those contacts were not there?

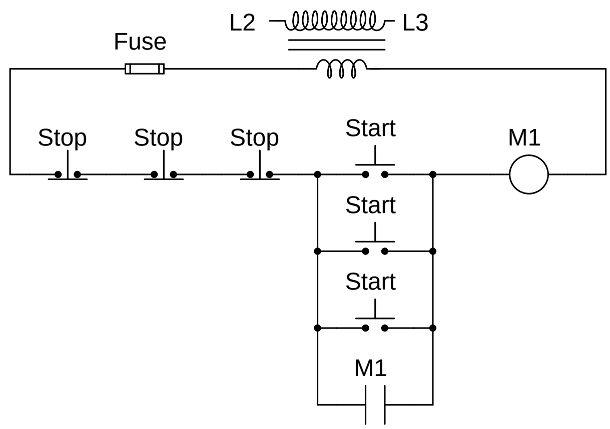
Suggestions for Socratic discussion

- Explain *why* reversing any two phase conductors supplying AC power to an induction motor will cause it to reverse direction.
- Explain what *arc flash* is, and how to protect yourself from it while working on high-voltage motor control circuits such as this one.
- Suppose an electrician tries to force the motor to spin in its forward direction by connecting a temporary jumper wire across relay coil M1. Will this accomplish the desired result? Explain why or why not, and also identify any potential safety hazards in doing this.
- Suppose an electrician tries to force the motor to spin in its forward direction by connecting a temporary jumper wire across the "Forward" pushbutton. Will this accomplish the desired result? Explain why or why not, and also identify any potential safety hazards in doing this.
- Suppose an electrician tries to force the motor to spin in its forward direction by connecting three temporary jumper wires across the M1 contacts. Will this accomplish the desired result? Explain why or why not, and also identify any potential safety hazards in doing this.

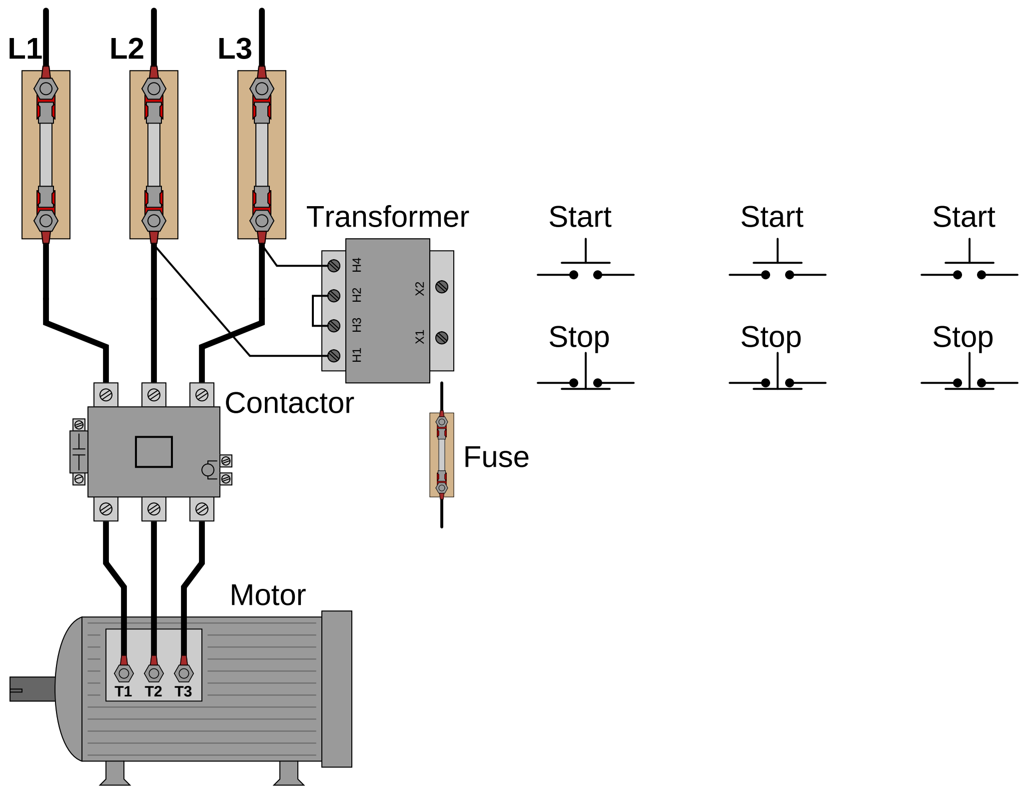
file i01391

Question 70

Suppose we wish to have three separate pushbutton start/stop stations for operators to use in controlling a single three-phase electric motor. The control circuit wiring schematic shows how this will work:



Sketch the necessary connecting wires to build this control circuit:

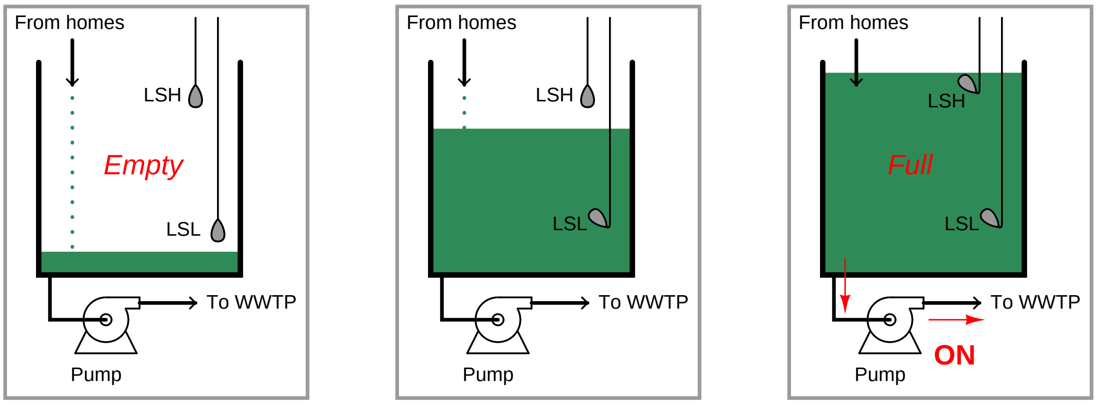


Suggestions for Socratic discussion

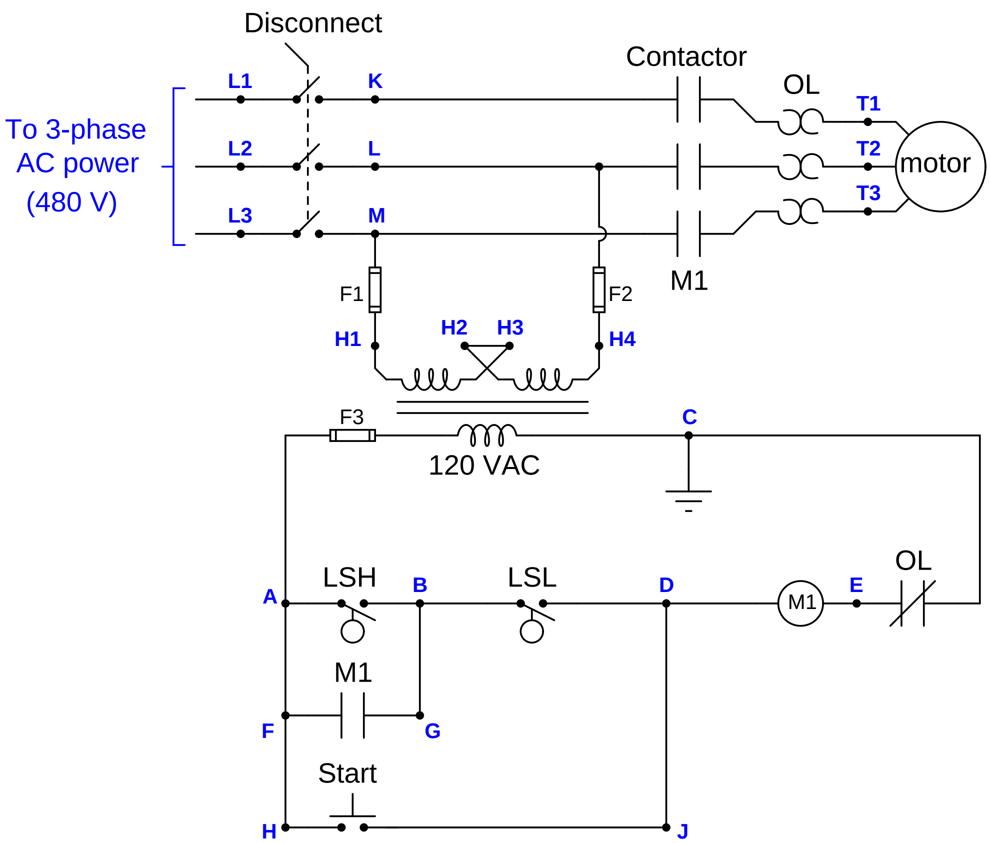
- An overload contact has been omitted from this motor control system for simplicity's sake. Identify where one would be properly inserted into the schematic diagram, and also in the pictorial diagram.
- After you have sketched wires to make a complete diagram, try to predict the effects of various faults in the circuit (e.g. switch contacts failing open or shorted ; wires breaking).

Question 71

A *lift station* is an underground reservoir with an automatically-controlled electric pump that collects and transports sewage from neighborhoods to a centralized wastewater treatment plant (usually located miles away):



The wiring diagram for a simple lift station pump control circuit is shown here:



An electrician needs to perform some routine "megger" measurements on the electric pump motor. "Megger" is the brand name of a high-voltage ohmmeter used to check the integrity of electrical insulation in electric motors, transformers, and other devices with wire coils subject to faults due to corrosion, vibration, or overheating. Here, the electrician will check resistance between each of the motor's terminals (T1, T2, T3) and the metal frame of the motor, ensuring there are many millions of ohms (open) as the wire insulation should provide.

Like all ohmmeter tests, a "megger" check must be performed on a device that is unpowered. For this reason, and also for personal safety, the electrician must ensure no power will get to the motor during his test.

Before commencing the test, the electrician follows this procedure to ensure the motor is in a *zero energy state*:

(1) Turn off the disconnect switch
(2) Place a padlock and a danger tag on the switch's handle to ensure it cannot turn on
(3) Push the "Start" pushbutton switch to check that the pump does *not* start up
(4) Use an AC voltmeter to verify 0 volts between the following test points:
  (*a*) Voltage between terminals K and L
  (*b*) Voltage between terminals K and M
  (*c*) Voltage between terminals L and M
  (*d*) Voltage between terminals K and earth ground
  (*e*) Voltage between terminals L and earth ground
  (*f*) Voltage between terminals M and earth ground
(5) Use the same AC voltmeter to verify 480 volts between any two of the L1, L2, and L3 test points

Explain the rationale behind each step in this sequence. Although this many steps may appear to be a bit paranoid, there is actually logical justification for each one.

Suppose another electrician looked at this diagram and declared, *"We don't actually have to turn the disconnect switch off – we can prevent power from getting to the motor's terminals just by just pulling any one of the fuses in this circuit! If the M1 coil can't energize with 120 volts, then the M1 contactor relay cannot close, which effectively locks out 480 volt power from getting to the motor."*

What would be your response to this electrician's suggestion, and why?

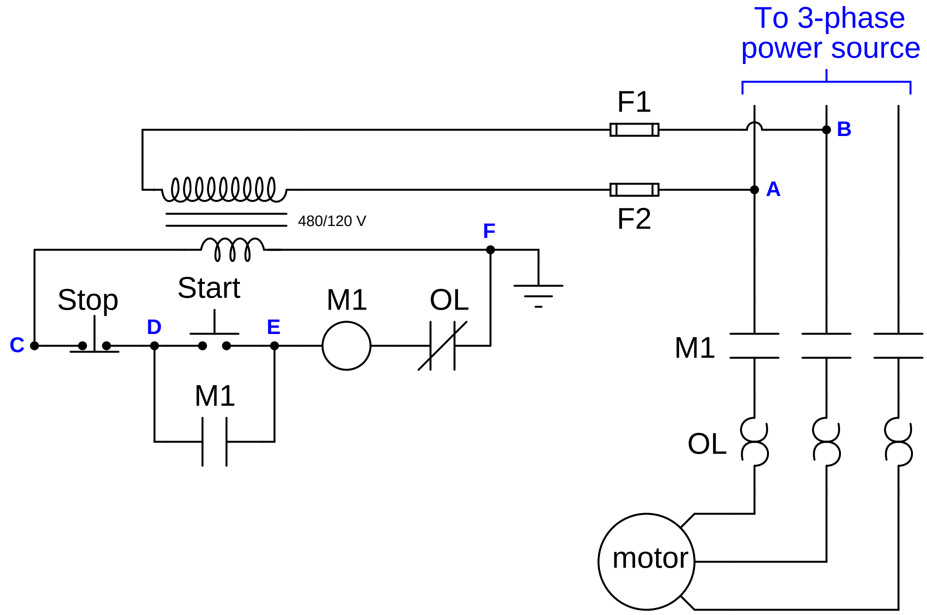
Suggestions for Socratic discussion

- A good logical technique for justifying each step in the lock-out/tag-out sequence is to think of a dangerous condition (such as a test equipment fault) that would go undetected if that step were skipped. If you can think of just one possible failure uniquely detected by a step, then that step is justified beyond any doubt!
- What sort of information do you think the electrician should write on the danger tag?
- Why do you suppose it is necessary to use high voltage to test the insulation integrity of an electric motor? Why not just use a regular ohmmeter that only uses a few volts between the test probes?

file i03403

Question 72

This motor-control "bucket" has a problem: the motor refuses to start when the "Start" pushbutton is pressed. A voltmeter connected to test points **C** and **E** indicates 118 volts AC with no pushbuttons pressed:



Identify the likelihood of each specified fault for this circuit. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this circuit.

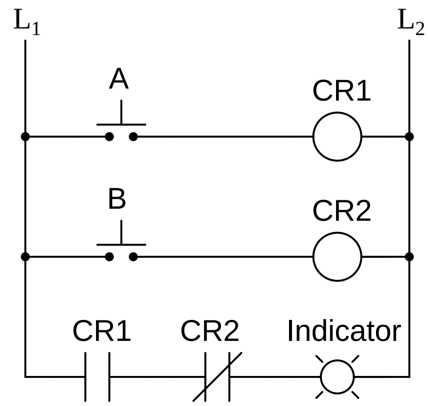
Fault	**Possible**	**Impossible**
Fuse F1 blown		
Fuse F2 blown		
Start switch failed open		
Stop switch failed open		
M1 coil failed open		
M1 auxiliary contact failed open		
M1 power contact(s) failed open		
OL contact failed open		
Start switch failed shorted		
Stop switch failed shorted		
Transformer secondary failed shorted		

Finally, identify the *next* diagnostic test or measurement you would make on this system. Explain how the result(s) of this next test or measurement help further identify the location and/or nature of the fault.

file i02398

Question 73

Complete the truth table for the following relay logic circuit, and then complete a second truth table for the same circuit with relay coil CR2 failed open:



Truth table (good circuit)

A	B	Output
0	0	
0	1	
1	0	
1	1	

Truth table (with fault)

A	B	Output
0	0	
0	1	
1	0	
1	1	

Assume a "1" state for a switch means it is being pressed, and a "0" state means it is unpressed. Explain *why* the truth table will be modified as a result of the fault.

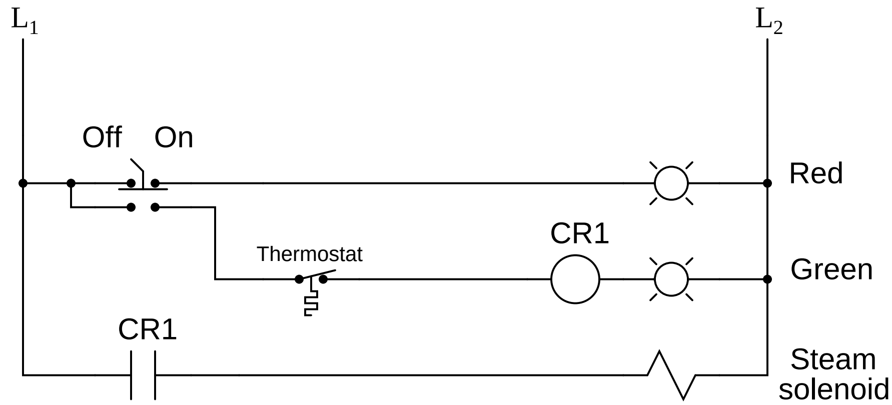
Suggestions for Socratic discussion

- Identify how ladder-logic type diagrams differ from standard electronic schematics, particularly with regard to how electromechanical relay coils and contacts are shown in each.
- Suppose the indicator lamp in this circuit *never* energized, regardless of the switch states. Identify soe possible faults that could account for this circuit behavior, and how you could confirm those faults using a multimeter.

file i02318

Question 74

The following ladder logic diagram (for a steam heater control) contains a serious mistake:



This is a mistake I've seen many students make. Explain what the mistake is, and draw a corrected version of this relay circuit.

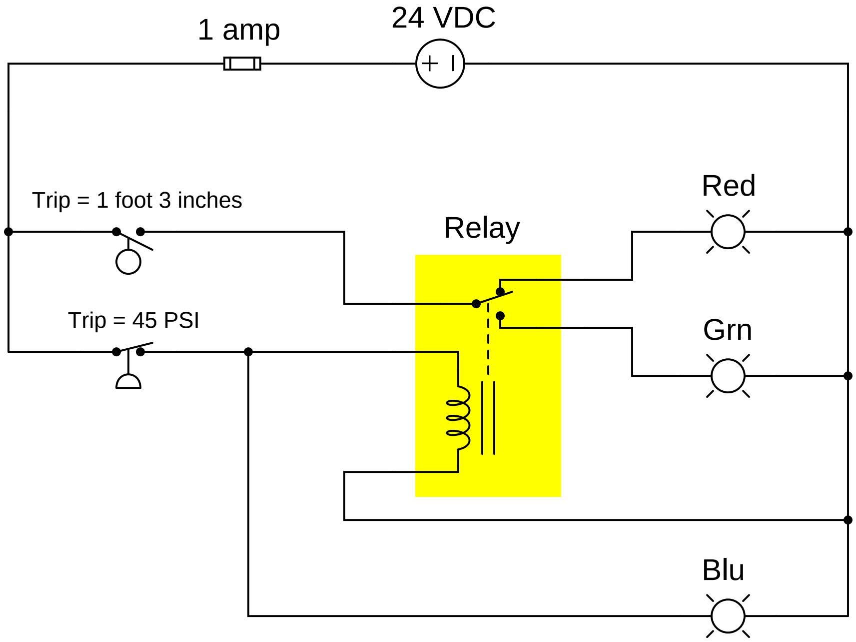
Suggestions for Socratic discussion

- Why do you suppose this is a common mistake for students to make when sketching a ladder logic diagram? Despite it being in error, there is a certain logic to it.
- If a real circuit were wired in this manner, what would it do? How would it behave?
- If a real circuit were wired in this manner, how could you diagnose the nature of the problem using a multimeter?

file i02322

Question 75

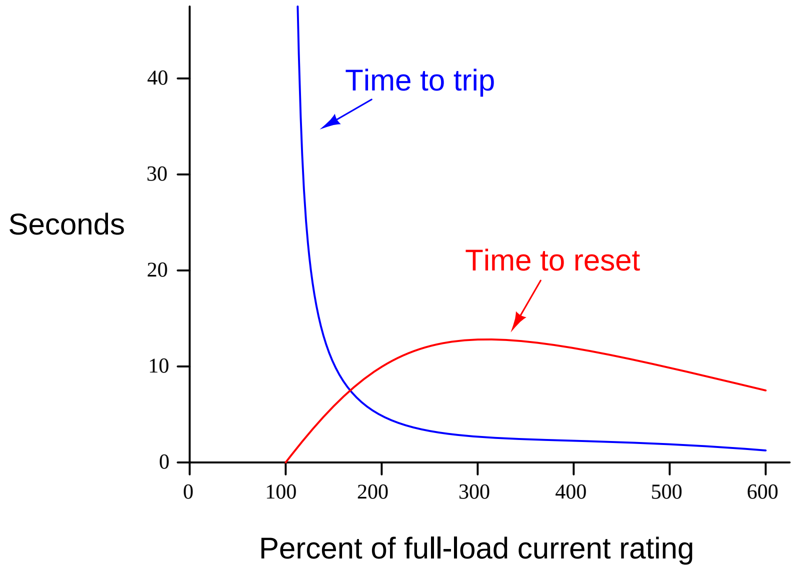
Explain the operation of this circuit:



file i02304

Question 76

Shown here is a typical set of "curves" for an overload heater, such as is commonly used to provide overcurrent protection for AC electric motors:



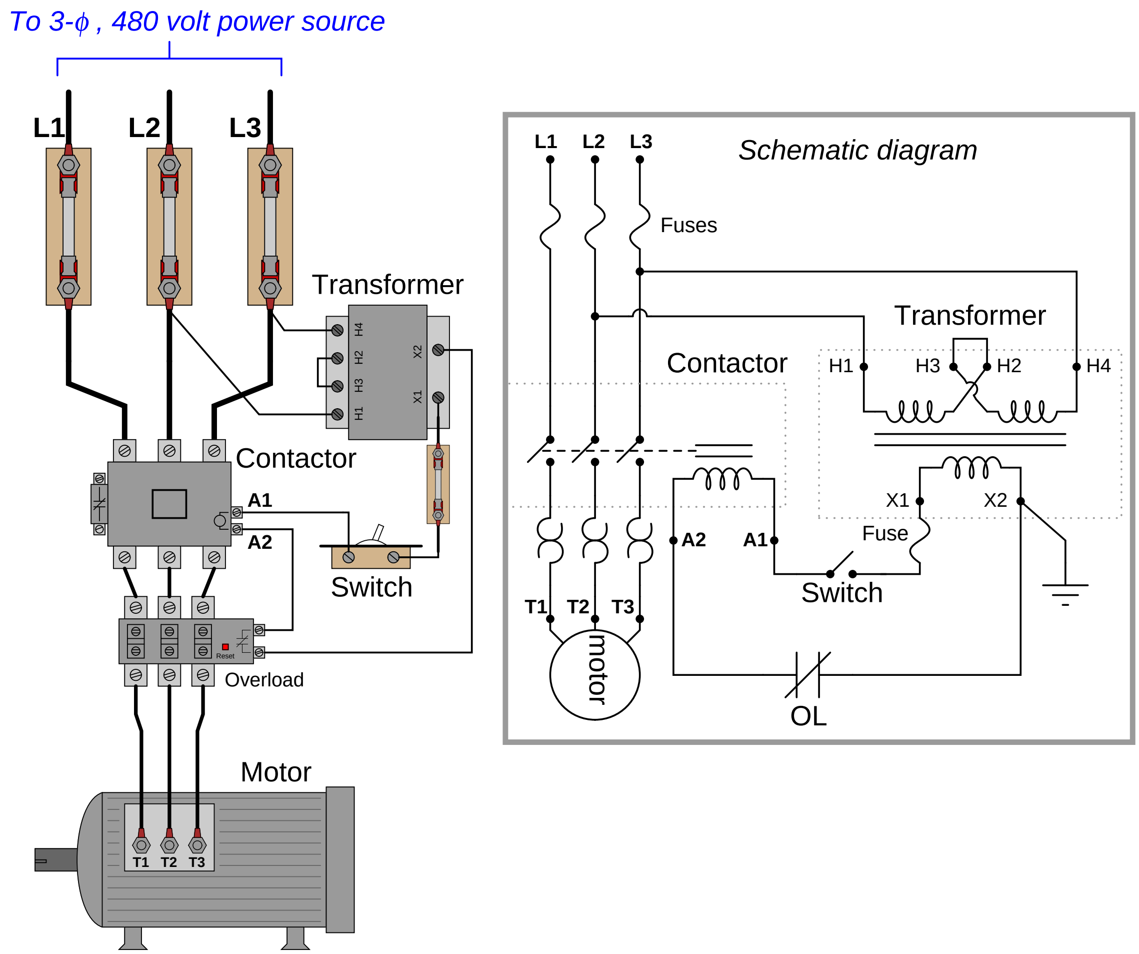
Why is there any time required to re-set an overload heater contact after a "trip?" Circuit breakers can be re-closed mere moments after a trip with no problem, and fuses (of course) can be replaced moments after blowing. Is this an intentional design feature of overload heaters, or just an idiosyncrasy?

Also, explain why the reset curve starts to decrease for currents above 300% of the motor's full-load rating. Why doesn't the reset time curve continue to increase with increasing fault current magnitudes?

file i02308

Question 77

Identify at least three independent faults that could cause this motor not to start:



For each of the proposed faults, explain *why* they would prevent the motor from starting.

file i02306

Question 78

Protective relays are special power-sensing devices whose job it is to automatically open or close circuit breakers in large electric power systems. Some protective relays are designed to be used directly with large electric motors to provide sophisticated monitoring, shut-down, and start-up control.

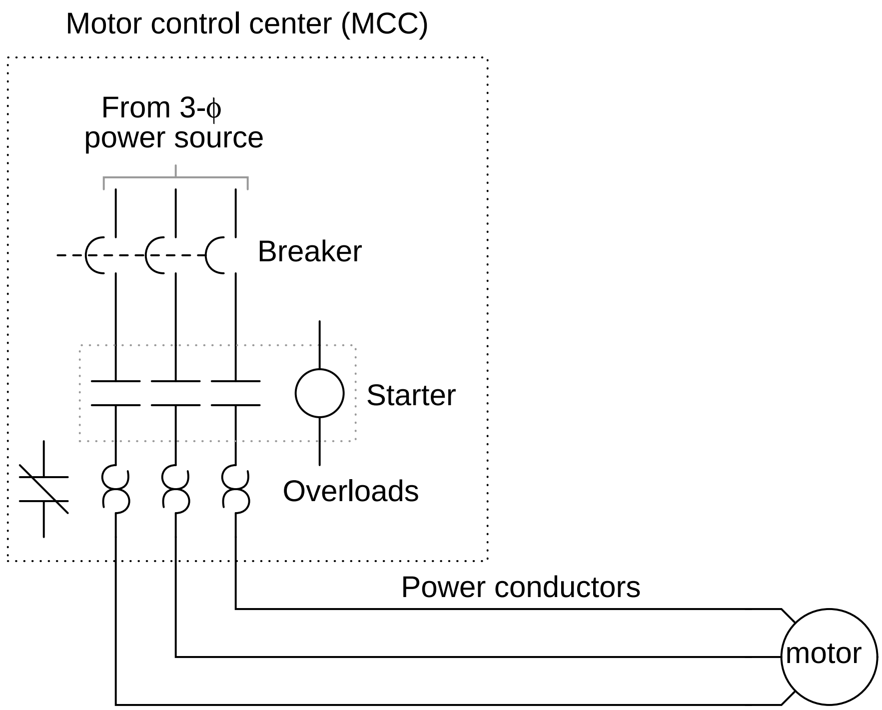
One of the features of these motor-oriented protective relays is *start-up lockout*. What this means is the relay will prevent someone from attempting too many successive re-starts of a large electric motor. If the motor is started and stopped several times over a short period of time, the relay will prevent the person from starting it again until a sufficient "rest" time has passed.

Explain why a large electric motor would need to "rest" after several successive start-up events. If electric motors are perfectly capable of running continuously at full load for years on end, why would a few start-ups be worthy of automatic lock-out?

file i02311

Question 79

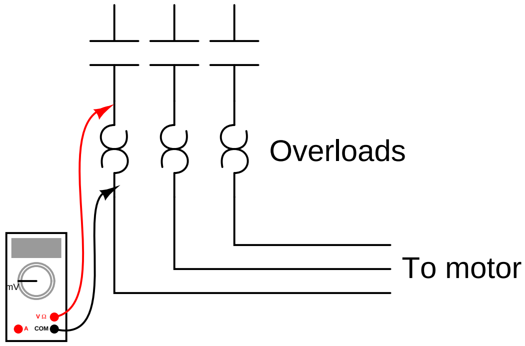
The starter and overload heater assembly for an industrial electric motor is often located quite a distance from the motor itself, inside a room referred to as a *motor control center*, or MCC:



Since it is impossible for a technician to be in two places at once, it is often necessary to perform diagnostic checks on a malfunctioning electric motor from the MCC where the technician has access to all the control circuitry.

One such diagnostic check is line current, to detect the presence of an open motor winding. If a three-phase motor winding fails open, or if one of the three-phase power conductors fails open along the way to the motor, the motor will not run as it should. This is called *single-phasing*. A good way to check for this condition is to use a clamp-on (inductive) ammeter to check line current on all three lines while the starter is energized. This may be done at any location where there is physical access to the motor power conductors.

Suppose, though, you are working on a job site where single-phasing is suspected and you do not have a clamp-on ammeter with you. All you have is a DMM (digital multimeter), which does not have the ability to safely measure the motor's current. You are about to head back to the shop to get a clamp-on ammeter when a more experienced technician suggests an alternate test. He takes your DMM, sets it to the AC *millivolt* range, then connects the test probes to either side of each overload heater element, one heater at a time like this:



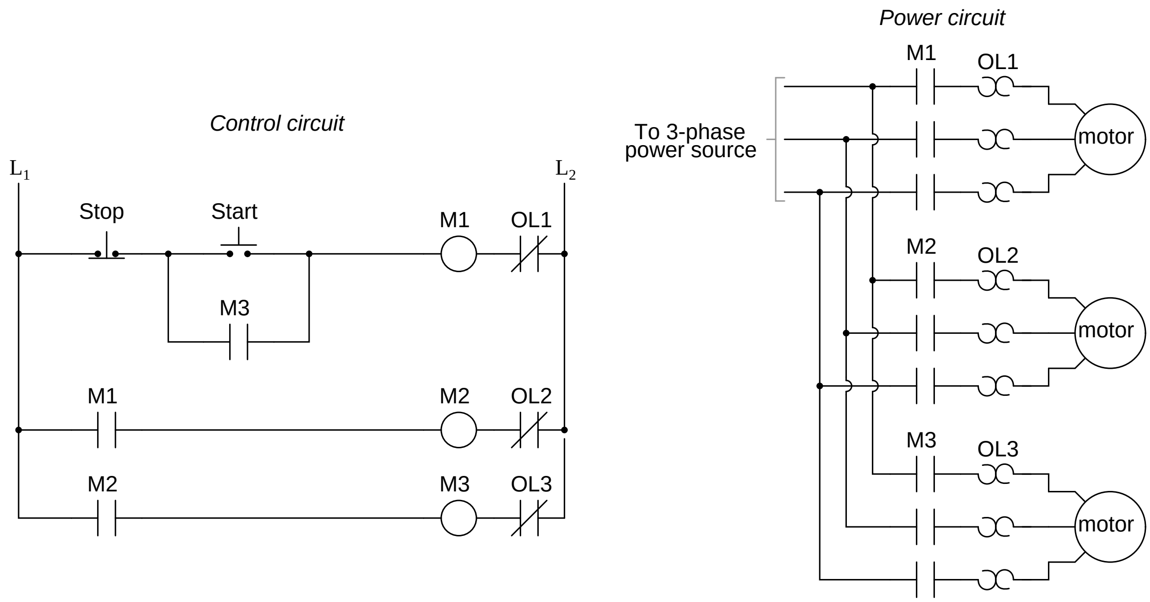
Across each overload heater element he measures about 20 mV AC with the starter engaged. From this he determines that the motor is *not* single-phasing, but is drawing approximately equal current on all three phases.

Explain how this diagnostic check works, and why this determination can be made. Also describe what limitations this diagnostic procedure has, and how a clamp-on ammeter really is the best way to measure motor line current.

file i02312

Question 80

This motor control circuit commands three motors to start and stop together:



Examine the control circuit and then explain how starting one motor starts up the others. Also, determine what will happen if motor #3 suffers an overload (i.e. OL3 warms up enough to trip).

Suggestions for Socratic discussion

- Explain why *inrush current* could be a problem in this three-motor control system, and identify at least one practical solution for it.
- If motor #2 were to become overloaded, would the system react any differently from an overloaded motor #3?

file i02399

Question 81

A delta-connected AC generator has a phase voltage of 13.8 kV, and is connected to a balanced wye-connected load consuming power at a rate of 0.75 MW. Assuming a power factor of 1 (unity), calculate the following parameters in this polyphase circuit, and draw a sketch of it:

- Line voltage = __________ volts
- Line current = __________ amps
- Equivalent phase resistance (of load) = ______ ohms
- Phase voltage (of load) = __________ volts
- Phase current (of load) = __________ amps

Be sure to show all your calculations!

file i02360

Question 82

A wye-connected AC generator has a phase voltage of 7.2 kV, and is connected to a balanced delta-connected load consuming power at a rate of 3.4 MW. Assuming a power factor of 1 (unity), calculate the following parameters in this polyphase circuit, and draw a sketch of it:

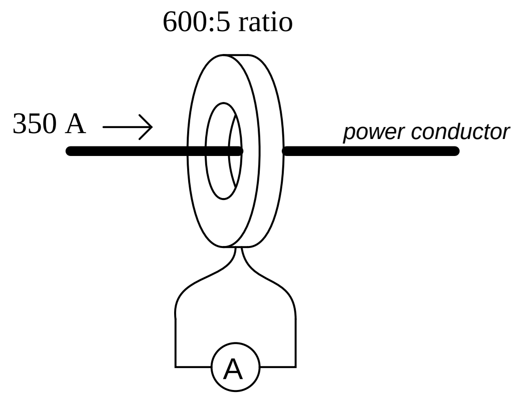
- Line voltage = __________ volts
- Line current = __________ amps
- Equivalent phase resistance (of load) = ______ ohms
- Phase voltage (of load) = __________ volts
- Phase current (of load) = __________ amps

Be sure to show all your calculations!

file i02517

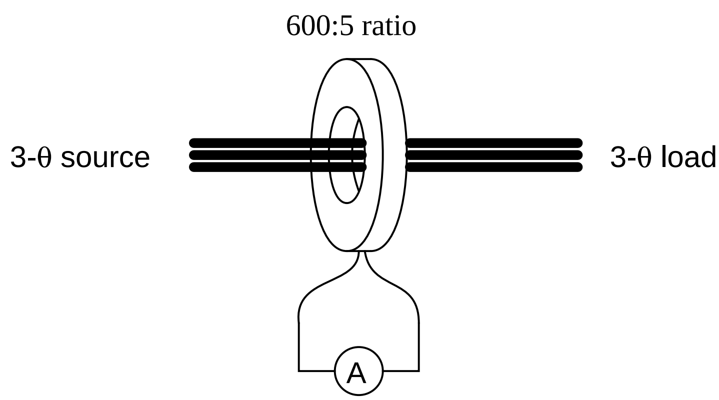
Question 83

A *current transformer* is a donut-shaped device used to measure the amount of AC current through a conductor, providing isolation between the power conductor and the instrument circuit. Their purpose is to serve as a permanent "clamp-on" ammeter for a high-current AC power conductor. The power conductor passes through the center of the "donut" while a stepped-down current is generated in the secondary winding to pass through an AC ammeter:



Calculate the amount of current through the ammeter in this example circuit, given the line current and ratio shown.

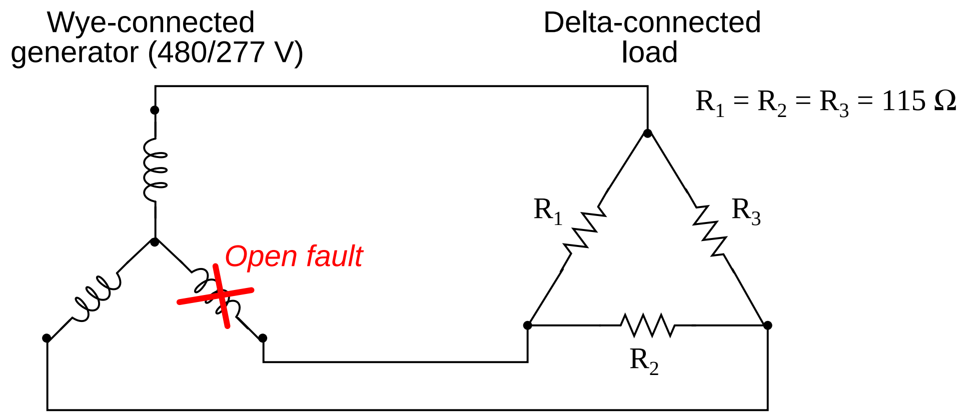
Next, calculate the amount of current registered by the same ratio CT for all three line conductors of a three-phase power system as shown here (still assuming 350 amps AC in each line), explaining your answer:



file i04760

Question 84

Calculate all phase voltages and currents in the load given an open fault in one of the source's (alternator's) coils:

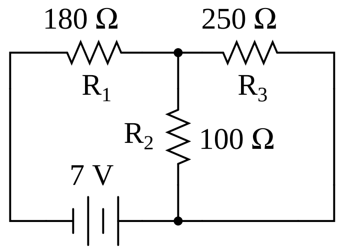


Phase quantity	**Value** (volts/amps)
V_{R1}	
V_{R2}	
V_{R3}	
I_{R1}	
I_{R2}	
I_{R3}	

file i02363

Question 85

Complete the table of values for this circuit:



	R_1	R_2	R_3	Total
V				
I				
R	180 Ω	100 Ω	250 Ω	
P				

As you solve this problem, be sure to store all intermediate calculations (i.e. answers given to you by your calculator which you will use later in the problem) in your calculator's memory locations, so as to avoid re-entering those values by hand. Re-entering calculated values unnecessarily introduces rounding errors into your work, as well as invites keystroke errors. *Avoiding the unnecessary introduction of error is a very important concept in Instrumentation!*

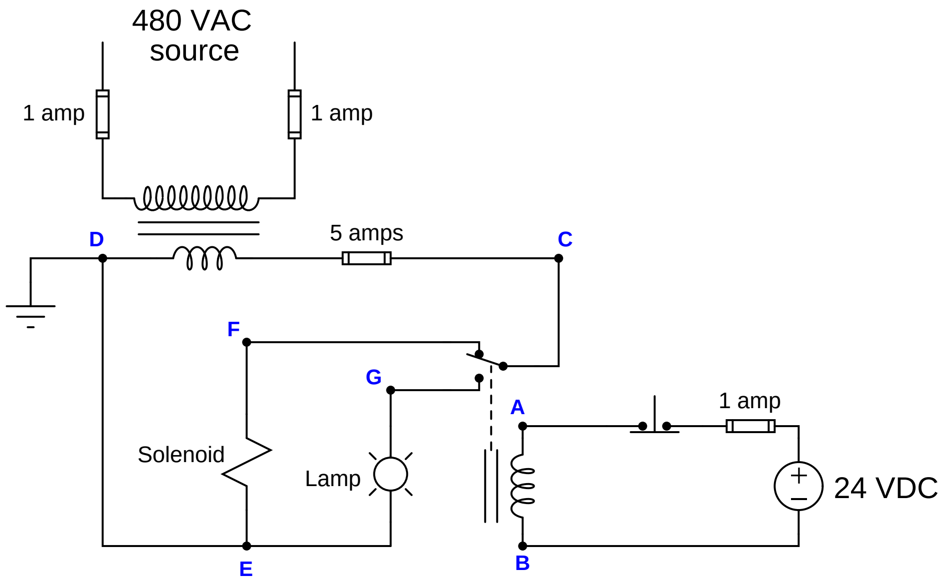
If your final answers are rounded as a result of not doing this, you will only receive half-credit for your work. This is a general policy for all your mathematical work in this program, not just this particular problem!

Note: the task of analyzing any series-parallel resistor network is greatly simplified by an approach outlined in the online textbook *Lessons In Electric Circuits*, in the "Series-Parallel Combination Circuits" chapter. There, a technique is demonstrated by which one may reduce a complex series-parallel network step-by-step into a single equivalent resistance. After this reduction, Ohm's Law and Kirchhoff's Laws of voltage and current are applied while "expanding" the circuit back into its original form. Even though the current notation in this textbook is electron flow rather than conventional flow, the series-parallel analysis technique works all the same.

file i01168

Question 86

Suppose the solenoid energizes when the pushbutton switch is pressed and de-energizes when the pushbutton is released just as it is supposed to, but the lamp never energizes regardless of the pushbutton switch's state:



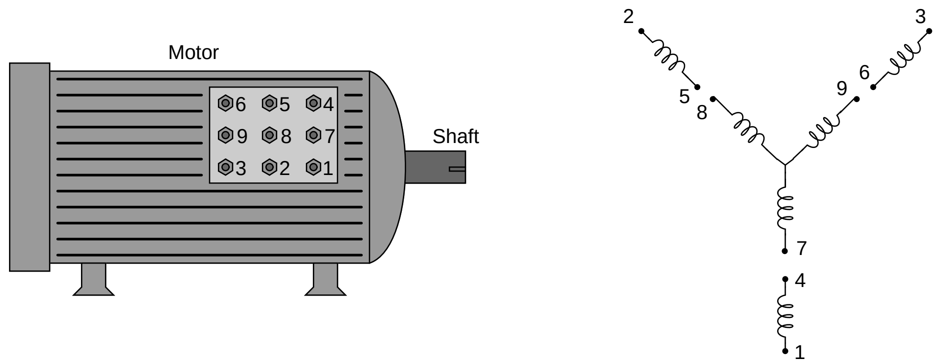
Identify the likelihood of each specified fault for this circuit. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this circuit.

Fault	Possible	Impossible
Pushbutton switch failed open		
NC relay contact failed open		
NO relay contact failed open		
Relay coil failed open		
480 volt fuse(s) blown		
Pushbutton switch failed shorted		
NC relay contact failed shorted		
NO relay contact failed shorted		
Relay coil failed shorted		
24 VDC source dead		

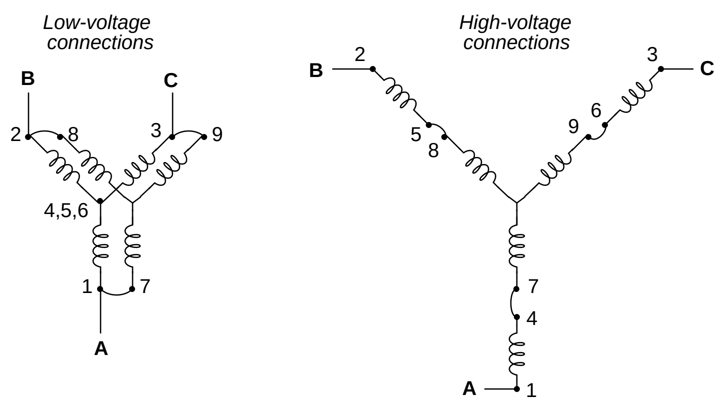
file i03136

Question 87

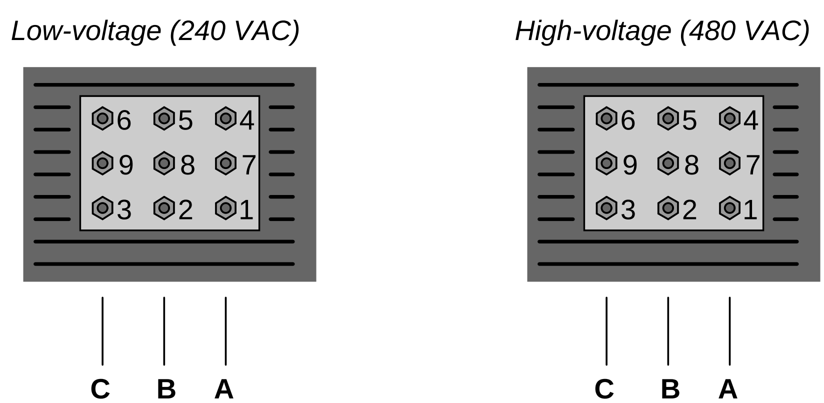
Three-phase electric motors are often equipped with a set of electrical terminals for configuring different voltage ranges and/or base speeds. Different configurations consist of different patterns of "jumper" wires connecting these terminals together. For example, here is an illustration of a three-phase electric motor with nine stud-and-nut terminals for connecting a set of six wire windings (coils) in two different configurations: one for low voltage (240 volts AC) and one for high voltage (480 volts AC):



The following schematics show how the six windings interconnect for each voltage configuration, and how the three AC power conductors (A, B, and C) connect to supply AC power to these windings:



Sketch the proper power conductor and jumper connections for low-voltage operation and for high-voltage operation:



file i03248

Question 88

Each of these statements is incorrect in some way. Correct the misconceptions in each:

"Thermal overloads protect against overcurrent conditions in case there is a short-circuit in the power conductors feeding a motor bucket."

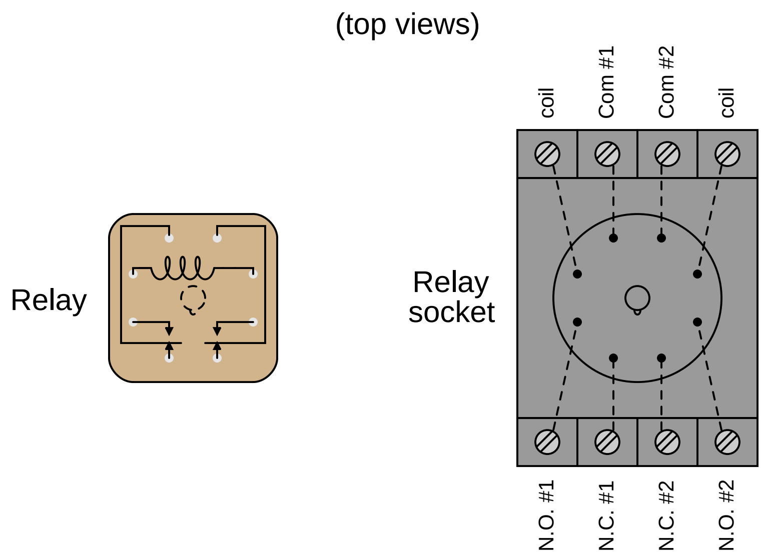
"Thermal overloads protect against motor overheating by sensing the temperature of the motor. They operate on temperature, rather than on motor current like a circuit breaker."

"When an overload heater senses an over-loaded condition, it opens up like a fuse to directly interrupt power to the motor."

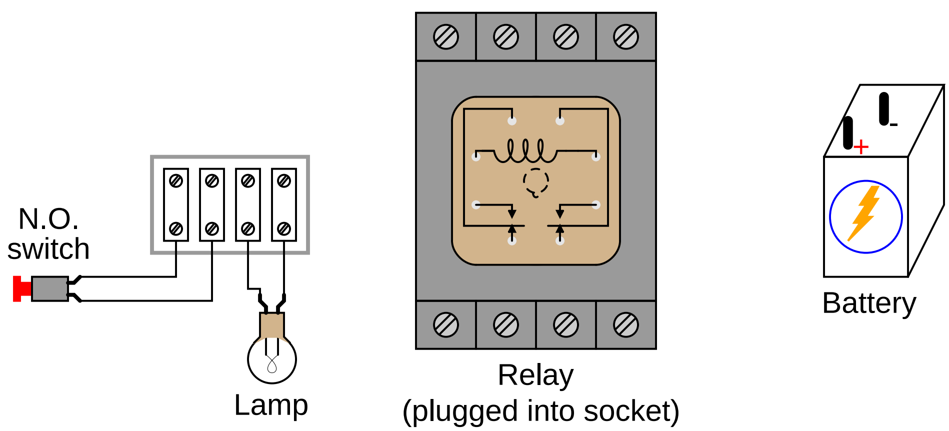
file i01283

Question 89

Small relays often come packaged in clear, rectangular, plastic cases. These so-called "ice cube" relays have either eight or eleven pins protruding from the bottom, allowing them to be plugged into a special socket for connection with wires in a circuit. Note the labels near terminals on the relay socket, showing the locations of the coil terminals and contact terminals:



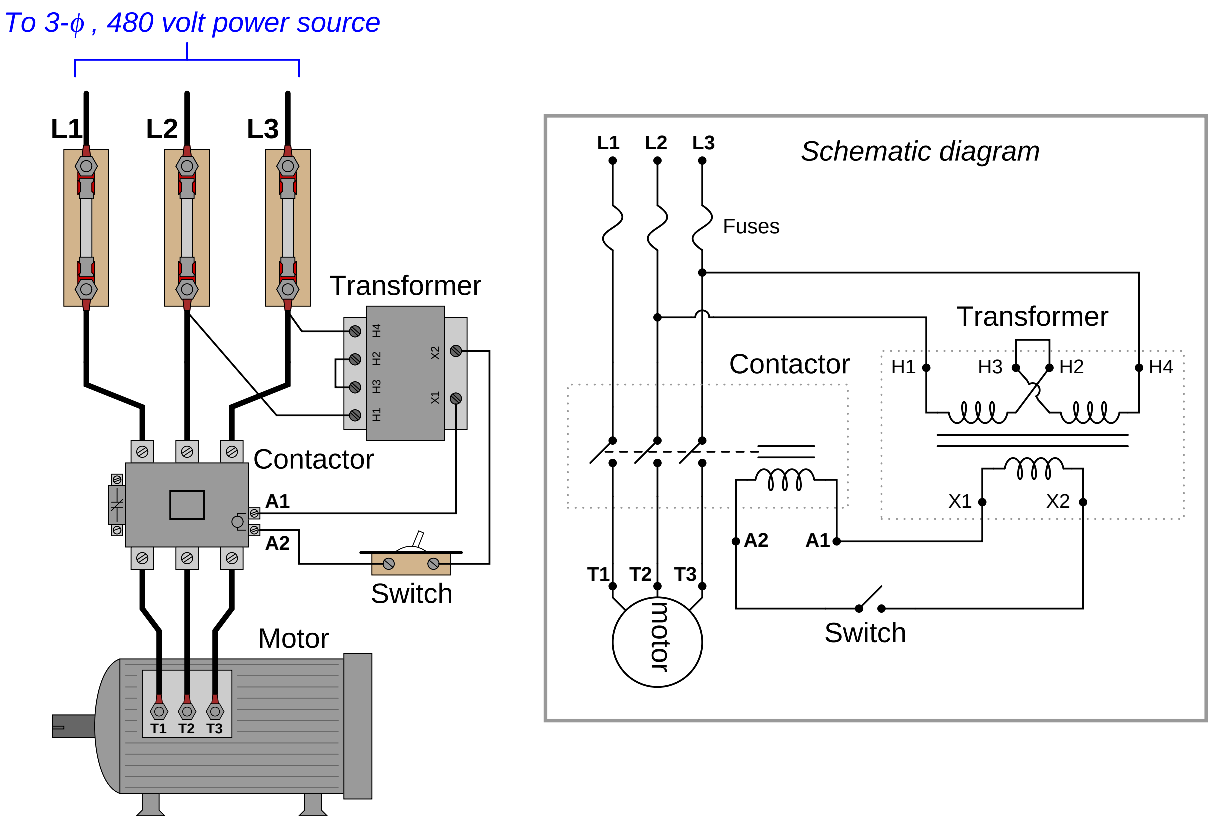
Draw the necessary connecting wires between terminals in this circuit, so that actuating the normally-open pushbutton switch sends power from the battery to the coil to energize the relay, with one of the relay's normally-open contacts turning the lamp on. The pushbutton switch should not carry any lamp current, just enough current to energize the relay coil:



file i03210

Question 90

In this 480 volt AC induction motor control circuit (sometimes referred to as a "bucket"), a three-pole relay (typically called a *contactor*) is used to switch power on and off to the motor. The contactor itself is controlled by a smaller switch, which receives 120 volts AC from a step-down transformer to energize the contactor's magnetic coil. Although this motor control circuit used to work just fine, today the motor refuses to start.



Using your AC voltmeter, you measure 478 volts AC between L1 and L2, 479 volts AC between L2 and L3, and 478 volts AC between L1 and L3. With the switch in the "on" position, you measure 117 volts AC between terminals X1 and X2 on the transformer. From this information, identify the following:

- Two components or wires in the circuit that you know cannot be failed either open or shorted, besides the 480 volt AC source which is obviously operational.

- Two different component or wire failures in the circuit, either one of which could account for the problem and all measured values, and the types of failures they would be (either open or shorted).

file i03175

Question 91

Lab Exercise – introduction

Your team's task is to construct a three-phase reversing motor starter circuit, complete with a three-phase transformer bank to step between different voltage levels. You will also demonstrate proper safety precautions appropriate for working with three-phase power circuitry, including lock-out-tag-out and verification of safe conditions using a multimeter.

The following table of objectives show what you and your team must complete within the scheduled time for this lab exercise. Note how some of these objectives are individual, while others are for the team as a whole:

Objective completion table:

Performance objective	**Grading**	**1**	**2**	**3**	**4**	**Team**
Team meeting and prototype sketch (do *first!*)	mastery	–	–	–	–	
Circuit design challenge	mastery					– – – –
Final schematic diagram and system inspection	mastery					– – – –
Proper use of insulation tester	mastery					– – – –
Safety demonstrations	mastery					– – – –
Energized Electrical Work Permit (NFPA 70E)	mastery	–	–	–	–	
Transformer bank wiring inspection	mastery	–	–	–	–	
Proper motor control function	mastery	–	–	–	–	
Troubleshooting	mastery					– – – –
Lab question: Wiring connections	proportional					– – – –
Lab question: Commissioning	proportional					– – – –
Lab question: Mental math	proportional					– – – –
Lab question: Diagnostics	proportional					– – – –
Decommission and lab clean-up	mastery	–	–	–	–	
Personal tool kit complete (show on last day)	mastery					– – – –
Reply to email message on BTC account	mastery					– – – –

The only "proportional" scoring in this activity are the lab questions, which are answered by each student individually. A listing of potential lab questions are shown at the end of this worksheet question. The lab questions are intended to guide your labwork as much as they are intended to measure your comprehension, and as such the instructor may ask these questions of your team day by day, rather than all at once (on a single day).

In addition to this motor control system, you must individually construct a *PLC trainer* for learning PLC programming. An example is documented in the next question of this worksheet.

PLC objective completion table:

Performance objective	**Grading**	**1**	**2**	**3**	**4**	**Team**
All components unwired before construction	mastery					– – – –
All inputs (switches) function properly	mastery					– – – –
All outputs (lights) function properly	mastery					– – – –

It is essential that your team plans ahead what to accomplish each day. A short (10 minute) team meeting at the beginning of each lab session is a good way to do this, reviewing what's already been done, what's left to do, and what assessments you should be ready for. There is a lot of work involved with building, documenting, and troubleshooting these working instrument systems!

As you and your team work on this system, you will invariably encounter problems. You should always attempt to solve these problems as a team before requesting instructor assistance. If you still require instructor assistance, write your team's color on the lab whiteboard with a brief description of what you need help on. The instructor will meet with each team in order they appear on the whiteboard to address these problems.

Lab Exercise – team meeting, prototype sketch, and instrument selection

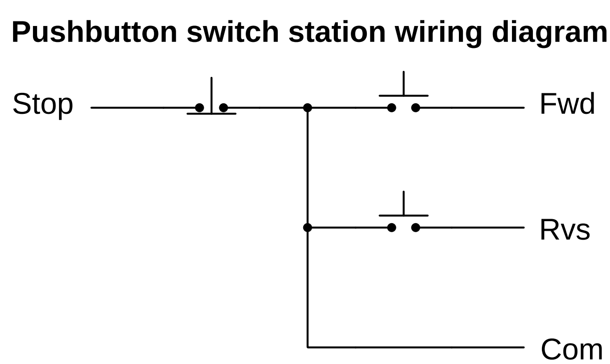
An important first step in completing this lab exercise is to **meet with your instructor** as a team to discuss safety concerns, team performance, and specific roles for team members. If you would like to emphasize exposure to certain equipment (e.g. use a particular type of control system, certain power tools), techniques (e.g. fabrication), or tasks to improve your skill set, this is the time to make requests of your team so that your learning during this project will be maximized.

An absolutely essential step in completing this lab exercise is to work together as a team to **sketch a prototype diagram** showing what you intend to build. This usually takes the form of a simple electrical schematic and/or loop diagram showing all electrical connections between components, as well as any tubing or piping for fluids. This prototype sketch need not be exhaustive in detail, but it does need to show enough detail for the instructor to determine if all components will be correctly connected for their safe function.

You should practice good problem-solving techniques when creating your prototype sketch, such as consulting equipment manuals for information on component functions and marking directions of electric current, voltage polarities, and identifying electrical sources/loads. Use this task as an opportunity to strengthen your analytical skills! Remember that you will be challenged in this program to do all of this on your own (during "capstone" assessments), so do not make the mistake of relying on your teammates to figure this out for you – instead, treat this as a problem *you* must solve and compare your results with those of your teammates.

Your team's prototype sketch is so important that the instructor will demand you provide this plan before any construction on your team's working system begins. *Any team found constructing their system without a verified plan will be ordered to cease construction and not resume until a prototype plan has been drafted and approved!* Similarly, you should not deviate from the prototype design without instructor approval, to ensure nothing will be done to harm equipment by way of incorrect connections. Each member on the team should have ready access to this plan (ideally possessing their own copy of the plan) throughout the construction process. Prototype design sketching is a skill and a habit you should cultivate in school and take with you in your new career.

When selecting components for this lab exercise, you will need to choose a step-down "control power" transformer, a pair of three-phase contactors (one for forward and one for reverse), and an overload "heater" assembly. A three-pushbutton Forward/Reverse/Stop control station has already been constructed for you, having four wires ready to connect to your motor starter assembly:



After locating suitable components, you should qualitatively test them prior to construction of your system. For an electric motor, this means checking continuity through all the windings. For switches, ohmmeter ("continuity") measurements will tell you if the switch contacts are actuating as they should. For the contactor, you may manually actuate the contacts and also check the contacts and coil for continuity using your ohmmeter. If any component fails to respond properly, notify the instructor and then tag it with a label explaining what it does (or what it fails to do).

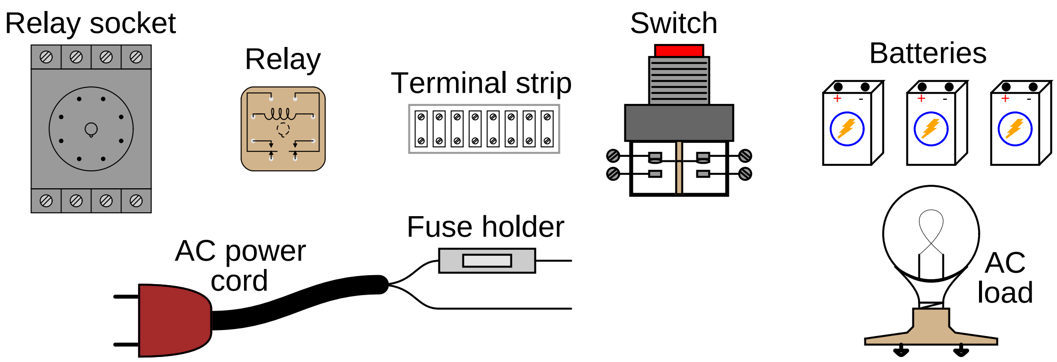
Another detail important to the planning of your system is identifying the necessary gauge (size) of the wires used. Consult article 310 of the National Electrical Code (the "NEC," also known as *NFPA 70*) book regarding "ampacity" ratings for different gauges of stranded copper wire. Your motor's nameplate will provide the information you will need on line current.

Planning a functioning system should take no more than an hour if the team is working efficiently, and will save you hours of frustration (and possible component destruction!).

Lab Exercise – circuit design challenge

Connect an "ice-cube" relay to a low-voltage DC source as well as 120 volts AC so that a hand-operated switch will control the energization of a 120 VAC load. All electrical connections must be made using a terminal strip (no twisted wires, crimp splices, wire nuts, spring clips, or "alligator" clips permitted), and the 120 VAC portion of the circuit must be fused for overcurrent protection.

This exercise tests your ability to properly interpret the "pinout" of an electromechanical relay, properly wire a switch to control a relay's coil, properly wire a load to the contacts of a relay, properly select NO/NC contacts on both the switch and the relay, and use a terminal strip to organize all electrical connections.



The following components and materials will be available to you: assorted "ice cube" **relays** with DC-rated coils and matching **sockets** ; assorted pushbutton **switches** ; **terminal strips** ; lengths of **hook-up wire** ; **battery clips** (holders) ; 120 VAC **power cord** with **fuse assembly** ; 120 VAC **lamp or other suitable load**.

You will be expected to supply your own screwdrivers and multimeter for assembling and testing the circuit at your desk, as well as a copy of this page for your instructor to mark conditions. The instructor will supply the battery(ies) to power your circuit when you are ready to see if it works. Until that time, your circuit will remain unpowered.

Load/switch status (instructor chooses): ____ On when pressed *or* ____ Off when pressed

Study reference: the "Control Relays" section of *Lessons In Industrial Instrumentation*.

Lab Exercise – documenting the system

Given the hazards associated with three-phase AC power circutry, it is essential that you carefully plan your circuit in its entirety prior to assembling it. For this reason, the instructor will require a complete, detailed schematic diagram of your motor starter circuit. These diagrams must be thoroughly checked for accuracy and electrical safety, to ensure no unnecessary hazards are present when power is applied.

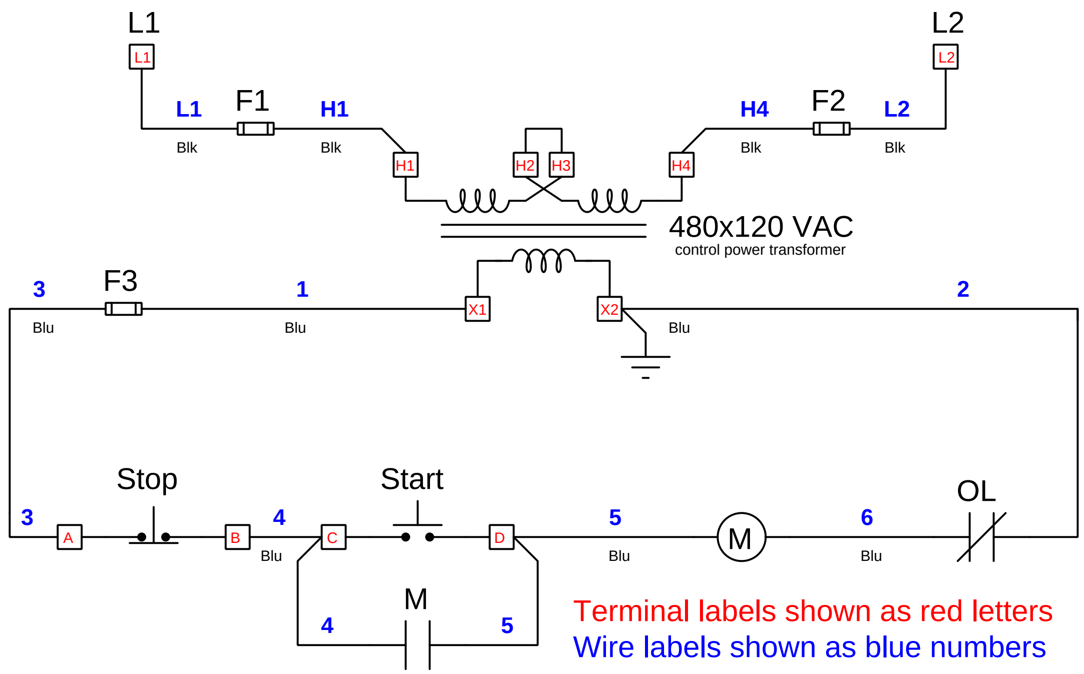
A sample schematic diagram for a one-direction motor starter circuit is shown on the next page. Your schematic diagram must be *comprehensive* and *detailed*, showing every wire connection, every cable, every terminal block, etc. The principle to keep in mind here is to make the schematic diagram so complete and unambiguous that anyone can follow it to see what connects to what, even someone unfamiliar with motor control circuits. In industry, systems are often constructed by contract personnel with limited understanding of how the system is supposed to function. The schematic diagrams they follow must be so complete that they will be able to connect everything properly without necessarily understanding how it is supposed to work.

Note that each and every wire in your system needs to be labeled with a number. Wires electrically common to each other at all times (i.e. connected at terminal blocks, not passing through any component) must bear the same label number. An easy way to label wires is to wrap a short piece of masking tape around each wire then writing on that masking tape with a permanent marker. Furthermore, each number or other label appearing on a device terminal (e.g. the screw terminals on an octal-base relay socket) must be shown on your schematic diagram in parentheses, to distinguish those labels from wire numbers used to identify wires. With each wire and each device terminal clearly labeled, one cannot go wrong in re-connecting wires that were undone. This is important when technicians remove components for repair and replacement, as the schematic diagram is their only guide to proper re-connection of the new or repaired components.

When your entire team is finished drafting your individual schematic diagrams, call the instructor to do an inspection of the system. Here, the instructor will have students take turns going through the entire system, with the other students checking their diagrams for errors and omissions along the way. During this time the instructor will also inspect the quality of the installation, identifying problems such as frayed wires, improperly crimped terminals, poor cable routing, missing labels, lack of wire duct covers, etc. The team must correct all identified errors in order to receive credit for their system.

After successfully passing the inspection, each team member needs to place their schematic diagram in the diagram holder located in the middle of the lab behind the main control panel. When it comes time to troubleshoot another team's system, this is where you will go to find a schematic diagram for that system!

Note that this sample diagram is shown only to illustrate the conventions you should use in documenting wire labels, terminal labels, etc. Your team's diagram will differ substantially from this one, most notably because it is a reversing motor control circuit whereas this example diagram shows a one-directional motor control circuit:



Reversing motor control circuits always contain normally-closed *interlocking* relay contacts to prevent simultaneous energization of both "Forward" and "Reverse" contactors. The one-direction motor control circuit shown above lacks interlock contacts, because there is only one direction it can turn.

Feel free to consult the "Typical Wiring Diagrams" booklet produced by Allen-Bradley for manual and magnetic full-voltage starter units, contained on your Instrumentation Reference. This booklet shows a wide variety of starter circuit configurations, including diagrams for reversing starter circuits.

Note that wiring diagrams for motor control circuits often take two forms: *schematic* and *pictorial*. Schematic diagrams are laid out in such a way as to minimize the number of wire crossings, in order to aid visual analysis of the circuit. Pictorial diagrams, on the other hand, are laid out in a manner resembling the physical orientation of circuit components, and therefore typically are more difficult to analyze because there are many more wires crossing over each other in order to reach their intended terminal points. It is highly recommended that you make your diagrams *schematic* rather than pictorial, especially for ease of interpretation when you do troubleshooting on motor control circuits and must use the diagram to determine your diagnostic tests.

Common mistakes:

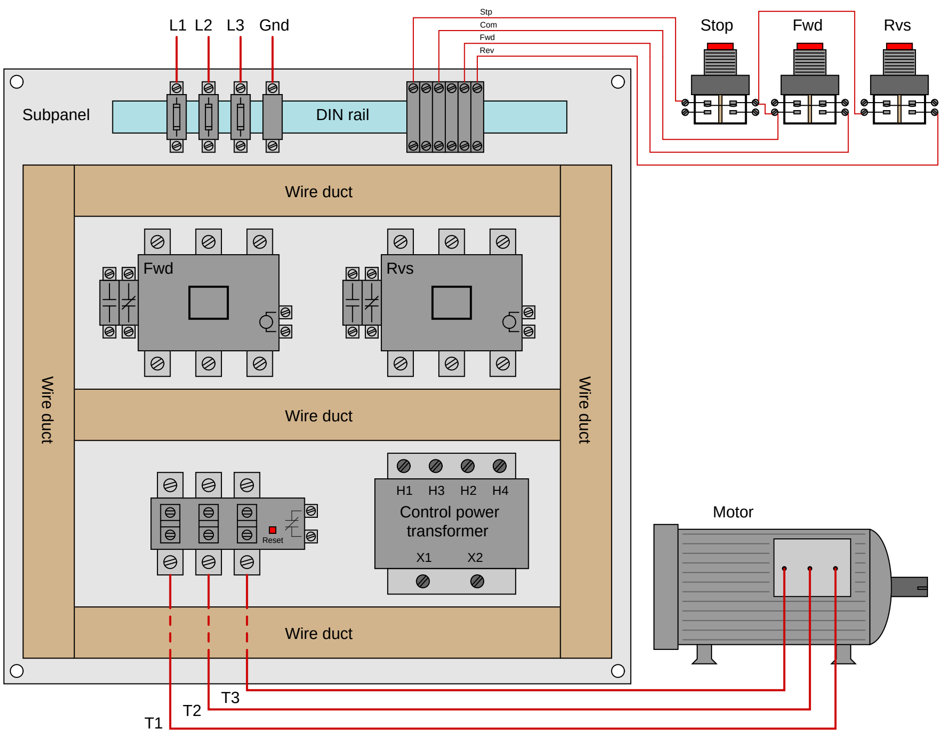
- Copying (verbatim) a sample diagram from a book, rather than customizing the diagram for the components at hand.
- Basing your diagram off of a team-mate's diagram, rather than closely inspecting the system for yourself.
- Forgetting to label all wires (see example diagram).
- Forgetting to label all terminals (see example diagram).
- Forgetting to note all wire colors.
- Forgetting to put your name on the schematic diagram!

Creating and inspecting accurate schematic diagrams should take no more than one full lab session (3 hours) if the team is working efficiently!

Lab Exercise – building the system

After getting your wiring diagram approved by the instructor, you are cleared to begin building your system. Mount all control components (control power transformer, contactors, overload unit, fuse holders) on a metal subpanel (plate) designed to insert into an electrical enclosure. Locate the pushbutton switched at some other location such as the main control panel for the lab. This ensures a long enough cable run for the switches to make the system realistic for testing and troubleshooting. Note: you must marshall all switch wiring through terminal blocks on the subpanel, so that the switches may be disconnected from the rest of the control circuit without disturbing any other wiring.

Power to your control circuit will come through four terminals located at one edge of the metal subpanel: three fused terminals for the three-phase power lines (L1, L2, and L3), and one unfused terminal for earth (safety) ground which will be bonded to the metal subpanel. Plastic "wire duct" will be used to route all wires between components. Here is a model layout (note that yours may look different):



All wires need to enter and exit the wire duct perpendicularly for a neat and professional appearance. All conductors must be stranded copper, of sufficient gauge for the full-load motor current according to the National Electrical Code (NEC). Each wire should bear its number label at each end where it terminates.

Before applying power to your motor control starter circuit, it must be inspected under instructor supervision. Testing will be performed using a high-voltage insulation tester (sometimes called a "Megger" in honor of a proper brand name for this type of instrument) to check for proper connections, proper fuse operation (i.e. when a fuse is pulled out of its socket, continuity to the protected device is interrupted), etc.

Common mistakes:

- Failing to tug on each and every wire where it terminates to ensure a mechanically sound connection.
- Students working on portions of the system in isolation, not sharing with their teammates what they did and how. It is important that the whole team learns all aspects of their system!

Building a functioning system should take no more than one full lab session (3 hours) if all components are readily available and the team is working efficiently!

Lab Exercise – insulation tester usage

An *insulation tester* is a special kind of ohmmeter designed to detect high-resistance paths for electric current (in the hundreds of megaohms). The purpose of using an insulation tester when checking the integrity of electric motors and motor control circuits is to reveal any breakdowns of electrical insulation that might not otherwise be detected using a regular low-range ohmmeter.

What makes an insulation tester different from a regular ohmmeter is its use of relatively high voltage to perform the test. Unlike a regular ohmmeter which only applies a few volts (or even just a few tenths of a volt for many modern DMM ohmmeter functions) to the circuit under test, an insulation tester contains within it a high-voltage generator capable of supplying hundreds or even thousands of volts to the test leads in order to "stress" the circuit under test and reveal any breakdown of insulation. This makes an insulation tester capable of delivering an electrical shock to the user if incorrectly operated!

Legacy insulation testers, especially the "Megger" brand whose name has become synonymous with insulation test instruments, used hand-crank electromechanical generators to create this high voltage. Early "Megger" testers actually had a small crank handle protruding from the side which the user would turn after having connected the test leads to the circuit. If something went wrong and the user became shocked by the tester's output voltage, they would naturally stop cranking the handle. Modern insulation testers have battery-powered high voltage generator circuits, and use a pushbutton to trigger the application of high voltage to the circuit under test. Again, the notion being that anyone shocked by the output of the instrument will naturally stop pressing the button.

All insulation testers have rather high output impedance, so that when connected across a short-circuit the high-voltage power source inside the tester will not be damaged by excessive current. This makes insulation testers perfectly valid for testing continuity in addition to testing for the presence of non-continuity (i.e. that conductors are insulated from each other).

Most insulation testers provide a way to vary the amount of voltage output by the tester, for different testing applications. When using an insulation tester, you want to use a test voltage greater than that normally experienced by the device or circuit under test, in order to adequately "stress" that device or circuit to ensure its proper operation when energized by its normal supply voltage. However, you do not want to use so much voltage that you actually cause damage to the device or circuit under test! This means the tester's output voltage should be configured to be *just one step above the circuit's normal operating voltage*.

Devices most susceptible to damage from mis-use of an insulation tester are *semiconducting* in nature. Diodes, transistors, SRCs, TRIACs, and associated devices may all be damaged rather easily by the mis-application of an insulation tester. This means one should not use an insulation tester on a circuit containing complex and expensive semiconductor components such as variable-speed motor drives (VSDs or VFDs).

Lab Exercise – safety demonstrations

This lab exercise, more than any other, harbors a significant level of personal danger due to the use of 480 VAC power. Exercising safe work habits is not just an objective of this lab, but it is essential for avoiding injury! This lab requires you to demonstrate the following procedures:

- The one-hand rule (working only with your right hand – keeping the left hand in a pocket or behind your back – when working on any energized circuit)
- Lock-out, Tag-out (properly documenting work to be done on a tag, then attaching both tag and lock to the disconnect device securing power)
- Attempt to start the motor (as a crude check to see that power has been disconnected)
- Proper use of meter to check for dangerous voltage (check for voltage between all possible pairs of points – including earth ground – and then verifying the meter's operation against a known voltage source)

Lab Exercise – complete an Energized Electrical Work Permit

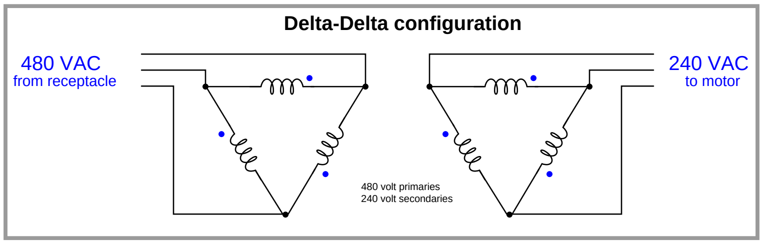
The NFPA 70E document provides a sample Energized Electrical Work Permit. Your team will print or photocopy this sample work permit and complete it for a specific job assignment selected by your instructor. Job examples include, but are not limited to:

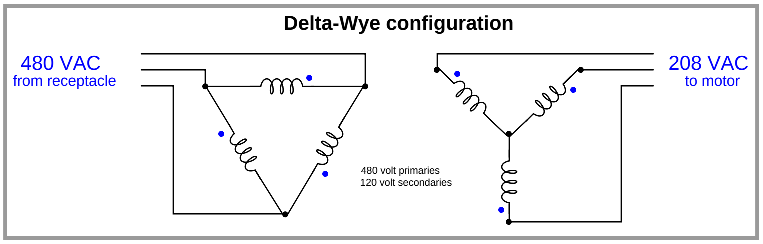
- Attaching 4-20 mA wires to the back of a panel-mounted loop controller while the controller is powered by 120 VAC.
- Using a multimeter to take voltage measurements on a 208 VAC motor starter circuit while it is powered through the step-down transformer bank in our lab.
- Using a multimeter to take voltage measurements on the 480 VAC lines feeding the step-down transformer bank in our lab.
- Using a multimeter to take voltage measurements on a live 480 VAC motor starter circuit fed directly from a three-phase transformer with a specified MVA rating.
- Using a multimeter to take voltage measurements on a VFD while it is powered through an isolation transformer of specified KVA rating (just like some of the VFDs in our lab).
- "Racking in" a 4160 VAC circuit breaker into a live panel.
- Using a clamp-on ammeter to measure current through a line feeding a 480 VAC motor.

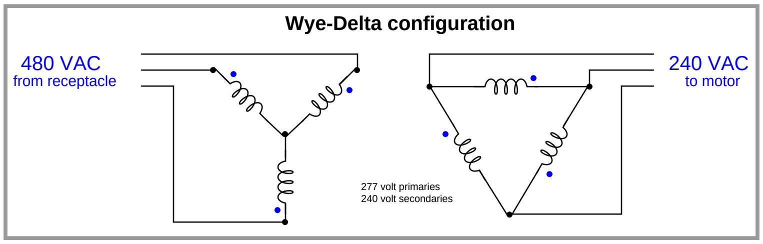
For every quantitative portion of the permit (e.g. calculating approach boundary distances) you must show the calculations used or tables referenced from the NFPA 70E standard.

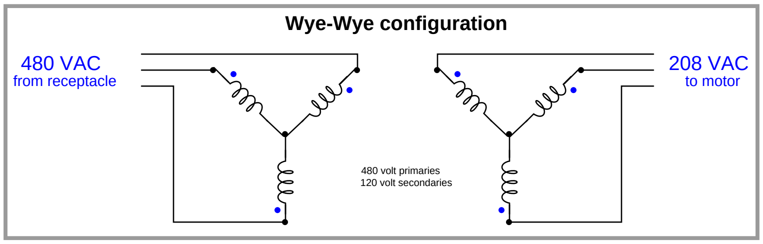
Lab Exercise – wiring the step-down transformer bank

In order to power your 240 VAC or 208 VAC motor from the 480 VAC receptacle in the lab, or to step up the 120 VAC three-phase power from our miniature AC power grid system to 208, 240, 416, or 480 volts to run the motor, you will need to wire three transformers together to create a three-phase transformer bank. Here are your configuration options, based on the different possible primary/secondary voltage ratings available for the transformers:





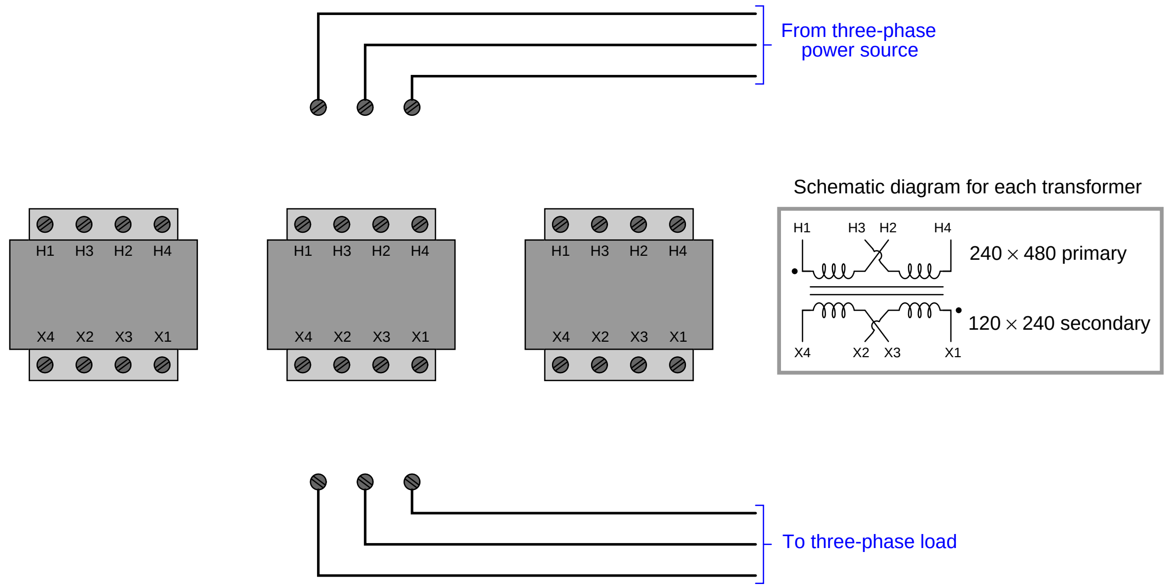




Multiple wiring options are possible depending on the rating of your motor, the power source used, and the particular transformers employed in this three-phase bank. Your instructor may prescribe one of these wiring configurations, or alternatively specify input and output line voltages and let you as a team choose the appropriate configuration.

After this, you must work as a team to determine the proper phasing ("polarity") for the transformers and then connect the necessary wires in order to build the desired circuit. You may find the section titled "Transformer Polarity" in your *Lessons In Industrial Instrumentation* textbook helpful in explaining this concept. The instructor must inspect your plan as well as the constructed circuit before you are allowed to apply power to the transformer bank.

The following pictorial diagram might be useful for you and your team to use for sketching the necessary Delta/Wye connections and transformer winding jumpers to achieve the necessary step-down ratios:



If you need to step voltage up from 120 VAC to something greater, it is permissible to run the transformers "backwards" by applying power to the lower-voltage "secondary" sides (using that side as the primary winding) and connecting the higher-voltage "primary" sides to your motor starter. The essential limitation is that no winding's voltage or current ratings be exceeded at any time.

Lab Exercise – troubleshooting

The most challenging aspect of this lab exercise is *troubleshooting*, where you demonstrate your ability to logically isolate a problem in the system. All troubleshooting is done on an individual basis (no team credit!), and must be done *on a system you did not help build*, so that you must rely on schematic diagrams to find your way around the system instead of from your own memory of building it.

Each student is given a limited amount of time to identify both the general location and nature of the fault, logically justifying all diagnostic steps taken. All troubleshooting activities will take place under direct instructor supervision to ensure students are working independently and efficiently.

Failure to correctly identify both the general location and nature of the fault within the allotted time, and/or failing to demonstrate rational diagnostic procedure to the supervising instructor will disqualify the effort, in which case the student must re-try with a different fault. Multiple re-tries are permitted with no reduction in grade.

A standard multimeter is the only test equipment allowed during the time limit. No diagnostic circuit breaks are allowed except by instructor permission, and then only after correctly explaining what trouble this could cause in a real system.

The instructor will review each troubleshooting effort after completion, highlighting good and bad points for the purpose of learning. Troubleshooting is a skill born of practice and failure, so do not be disappointed in yourself if you must make multiple attempts to pass! One of the important life-lessons embedded in this activity is how to deal with failure, because it *will* eventually happen to you on the job! There is no dishonor in failing to properly diagnose a fault after doing your level best. The only dishonor is in taking shortcuts or in giving up.

Common mistakes:

- Neglecting to take measurements with your multimeter.
- Neglecting to check other measurements in the system (e.g. pressure gauge readings).
- Incorrectly interpreting the wiring diagram (e.g. thinking you're at the wrong place in the system when taking measurements).
- Incorrect multimeter usage (e.g. AC rather than DC, wrong range, wrong test lead placement). This is especially true when a student comes to lab unprepared and must borrow someone else's meter that is different from theirs!

Remember that the purpose of the troubleshooting exercise is to foster and assess your ability to intelligently diagnose a complex system. Finding the fault by luck, or by trial-and-error inspection, is not a successful demonstration of skill. The only thing that counts as competence is your demonstrated ability to logically analyze and isolate the problem, correctly explaining all your steps!

Troubleshooting takes a lot of lab time, usually at least two 3-hour lab sessions for everyone in a full class to successfully pass. Be sure your team budgets for this amount of time as you plan your work, and also be sure to take advantage of your freedom to observe others as they troubleshoot, to better learn this art.

Lab questions

- **Wiring connections**
- Determine correct wire connections between components to create a working 3-phase motor control circuit, based on diagrams of components with terminals labeled

- **Commissioning and Documentation**
- Explain the meanings of the various ratings specified on a motor nameplate
- Explain the meanings of the coil and contact ratings specified on a contactor nameplate
- Explain how an *insulation tester* may be used to test the integrity of an electric motor's windings
- Explain how an *insulation tester* might cause damage to circuit components if improperly used
- Explain how to configure a multi-voltage induction motor for different operating voltages, given the information shown on a motor nameplate
- Explain what *arc flash* and *arc blast* are, and what causes these effects
- Explain how *overload heaters* in a motor control circuit perform a function fundamentally different from a fuse or a circuit breaker

- **Mental math** (no calculator allowed!)
- Convert horsepower rating of a three-phase AC electric motor into a current rating (at a specified line voltage)
- Convert current rating of a three-phase AC electric motor into a horsepower rating (at a specified line voltage)

- **Diagnostics**
- Determine whether or not a given diagnostic test will provide useful information, given a set of symptoms exhibited by a failed system
- Identify at least two plausible faults given the results of a diagnostic test and a set of symptoms exhibited by a failed system
- Propose a diagnostic test for troubleshooting a failed system and then explain the meanings of two different test results

Lab Exercise – decommissioning and clean-up

The final step of this lab exercise is to decommission your team's entire system and re-stock certain components back to their proper storage locations, the purpose of which being to prepare the lab for the next lab exercise. Remove your system documentation (e.g. wiring diagram) from the common holding area, either discarding it or keeping it for your own records. Also, remove all wire labels from wiring and cables.

Leave the following components in place, mounted on the racks:

- Large electric motors
- Large variable-frequency drive (VFD) units
- Cables inside conduit interconnecting junction boxes together
- Pipe and tube fittings (do not unscrew pipe threads)
- Supply air pressure regulators

Return the following components to their proper storage locations:

- Manual (e.g. pushbutton) switches
- "Jumper" cables used to connect terminal blocks within a single junction box
- Power cables and extension cords

Lab Exercise – tool kit and email usage

Two additional objectives that are not technically a part of making this lab project function, but are nevertheless very important to your continued success in the Instrumentation program, include assembling a personal tool kit and using your BTC email account (which is automatically created for every student at the college).

You will be using your tool kit throughout the remainder of this program, and so it is very important to have it complete and ready to use by the end of this lab exercise. Note that there are several optional items listed in addition to mandatory items. These optional tools are useful, but not 100% necessary for the work you will be doing in the lab. Also note that there are some consumable items in your tool list such as electrical compression terminals which you will need to keep stocked as you use them in your labwork.

Likewise, you will be relying on email to receive important messages from your instructor(s) throughout the remainder of the program. These messages include, but are not limited to, job announcements, guest speaker appearances, schedule changes, emergency notifications, scholarship announcements, and feedback on your personal performance in the program. The reason we use email as opposed to using learning management software is because it is imperative you learn how to appropriately use email for your chosen career. Email is simply the most common and most practical medium businesses use for day-to-day electronic communication.

Every BTC student is automatically given an email account upon registration, and this account remains active for some time after graduation. If you would rather not add one more email account to your electronic life, there is the option of having all messages received in your BTC email inbox automatically forwarded to the email platform of your choice (Yahoo, Hotmail, Gmail, Live, etc.) which may be selected as an option within your BTC email management webpage. *It is your responsibility to log in to your BTC email account, set up any forwarding features you would like, and to check your email account daily to receive these important messages.*

The library staff at BTC provide technical support for all school-related IT (Information Technology) needs. If you are experiencing trouble with your email account, with password management, or any other network-based technology necessary for your learning at BTC, the library staff are well-trained and helpful in this regard.

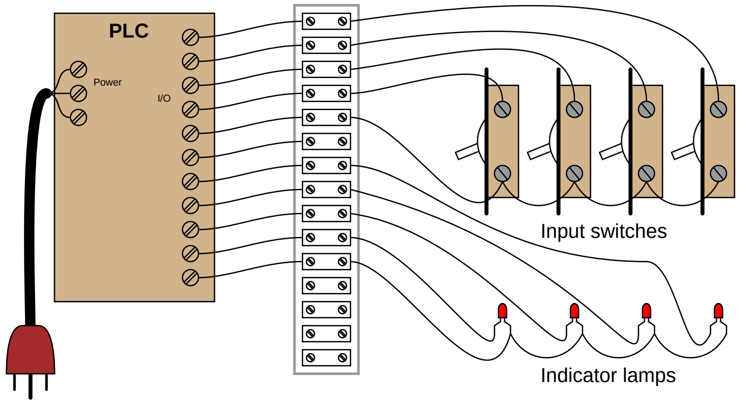
Your readiness for email use will be assessed by your reply to an email message sent to you by your instructor. Replying to this email message with an email message of your own is a mastery-level objective for every new student in this lab exercise.

When you graduate from this program and enter the workforce, your BTC email account will remain active for some time, but not in perpetuity. Therefore, you must inform your instructors of your preferred email account for post-graduation correspondence before you leave BTC. We use email to regularly communicate job announcements of interest to graduates, so it is in your best interest to remain connected.

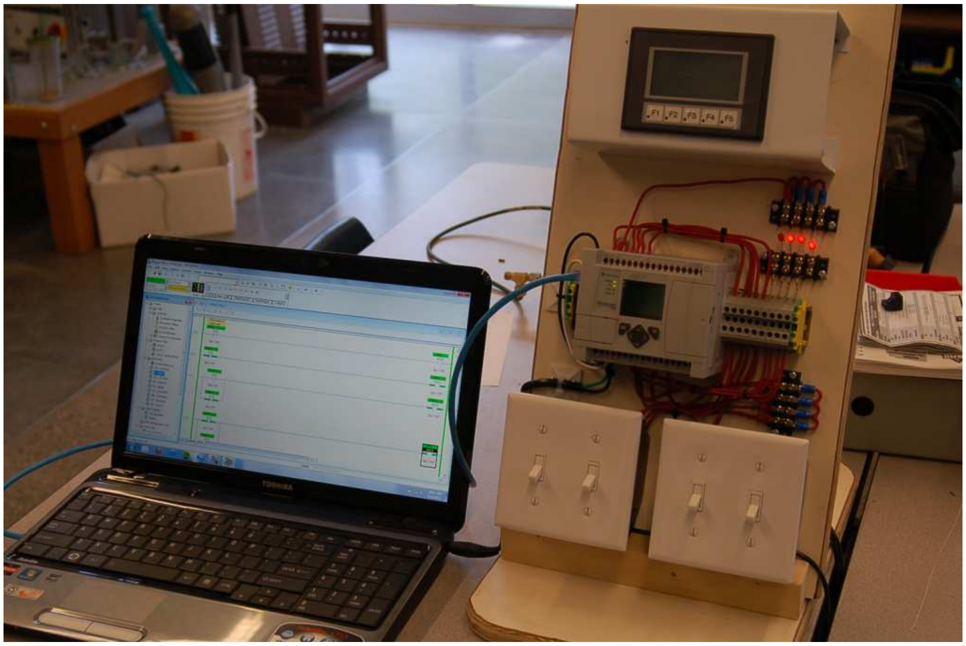
file i02132

Question 92

In order to learn PLC programming and perform the exercises necessary for exams in this course, you must have your own PLC *trainer* consisting of a working PLC and input switches all wired and ready to use.



All components should be securely mounted to a wood board or some other structure making it easy to transport and use. You *must* have a terminal block in between the switches, indicators, and PLC I/O terminals to allow for easy connection and disconnection of external devices to your PLC without wearing out the screws on the PLC's terminal block prematurely. Separate terminal blocks are easily replaced, whereas the terminal block on your PLC is likely much more expensive and inconvenient to replace! A photograph of a student-built PLC trainer is shown here as an example:



Note the use of terminal blocks for all wiring connections between the PLC and external devices, as well as the use of residential-style light switches for the PLC's inputs.

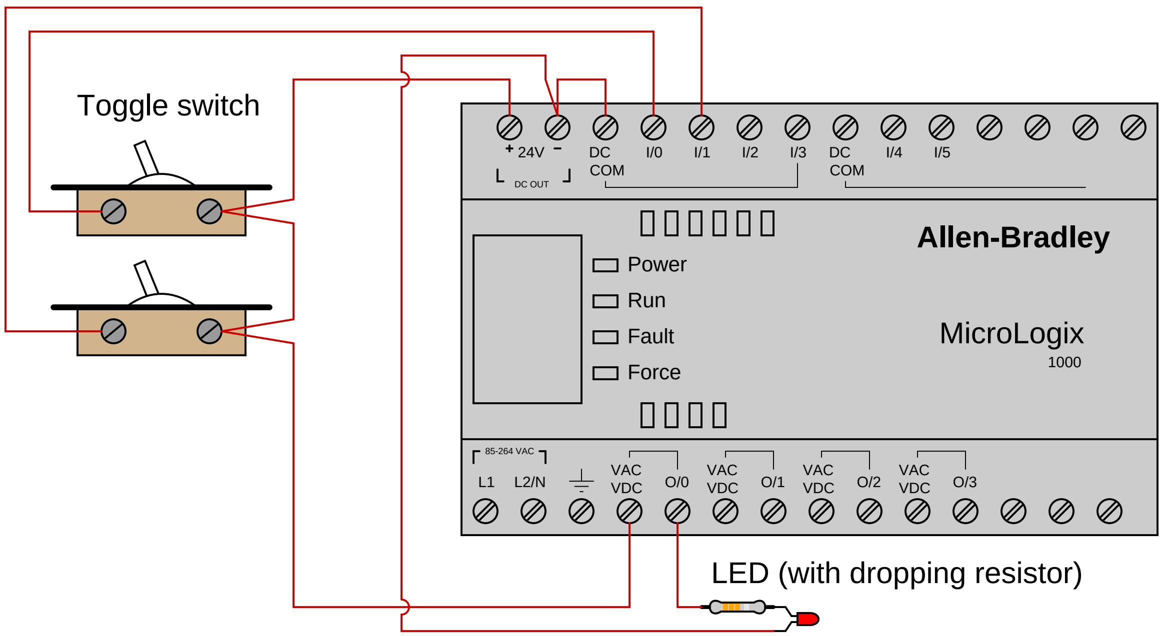
Consult the user's manual for your PLC in order to determine how all devices should be wired to the input and output (I/O) terminals. Note that often there are different types of I/O (AC, DC, sourcing, sinking) available for the same (or similar) model of PLC. Most PLC user's manuals give detailed diagrams showing how to connect devices to discrete I/O points, so be sure to follow the proper diagram for your specific PLC model!

Once you have your PLC wired, the next step is to install and run the software used to program your programmable logic controller (PLC), and try to get the two devices communicating with each other. This, of course, requires you have a special cable connecting your PC to your PLC, with any necessary "drivers" installed on your PC to allow it to communicate. Like all serial-based communications, the PC needs to be properly configured with regard to bit rate, number of data bits, number of stop bits, and parity in order to communicate with the PLC. The software you will be using should have an "auto detect" feature which will sequentially try various combinations of these parameters until it finds one combination that works. Note: on Allen-Bradley PLCs, you must first install and run software called *RSLinx* which manages communications between your PC and PLC, before you start up the programming software (*RSLogix*).

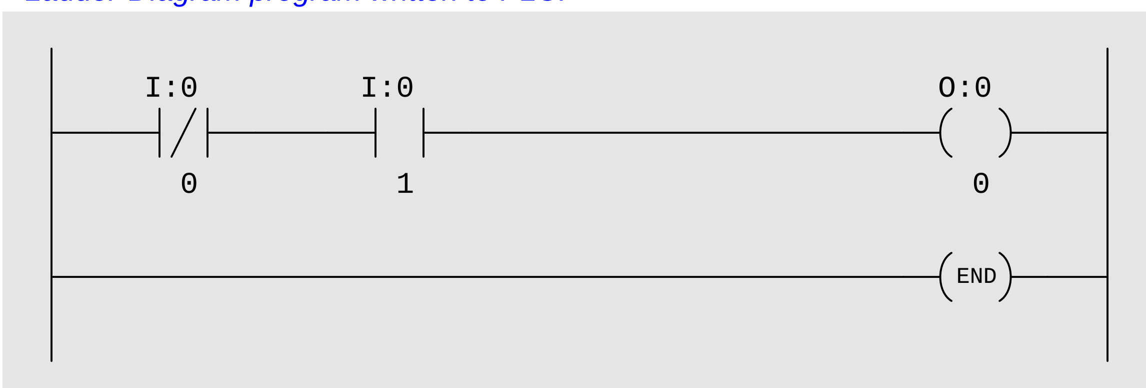
After that, your next step is to use programming software (installed in a personal computer) to program your PLC with some simple function consisting of "contact" and "coil" instructions. The purpose of a virtual contact in a PLC program is to *read* data bits from memory, while the purpose of a virtual coil in a PLC program is to *write* data bits to memory. Thus, you will create programs for the PLC using virtual contacts to read the states of real-world switches connected to inputs on the PLC, and using virtual coils to control real-world outputs on the PLC to energize loads such as lamps and solenoids. The interconnections and arrangements of these virtual contacts and coils determine the logic implemented by the PLC: specifying the conditions necessary to energize real-world devices based on input conditions.

You will find step-by-step instructional tutorials for both Allen-Bradley MicroLogix and Koyo CLICK PLCs in your Instrumentation Reference (provided by the instructor). Follow these tutorials to establish communication between your PC and your PLC, and to write a simple contact-and-coil ladder diagram program, before attempting the exercises that follow. You will also find much pertinent information for programming Allen-Bradley MicroLogix PLCs in the *RSLogix 500 Getting Results Guide*, since the SLC 500 line of Allen-Bradley PLCs program so similarly to the MicroLogix line.

This example shows an Allen-Bradley MicroLogix 1000 series PLC (model 1761-L10BWA) wired to two toggle switches and one LED indicator lamp, complete with a demonstration program. Note that line power (120 VAC) wire connections to power the PLC have been omitted, so the focus is solely on the I/O wiring:



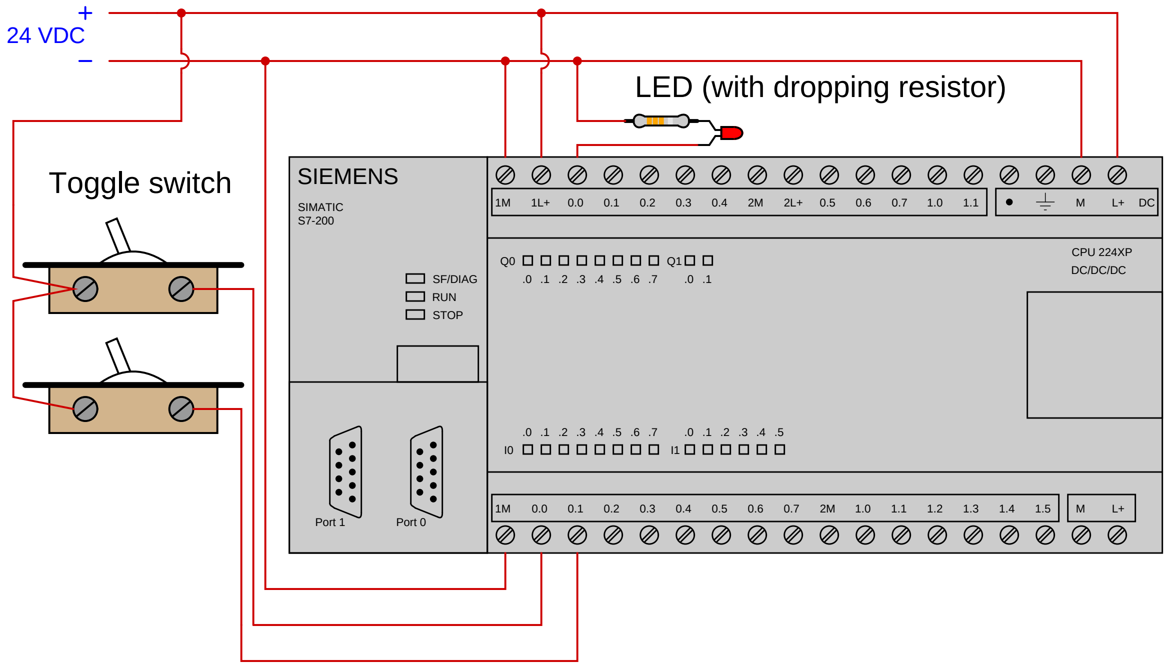
Ladder-Diagram program written to PLC:



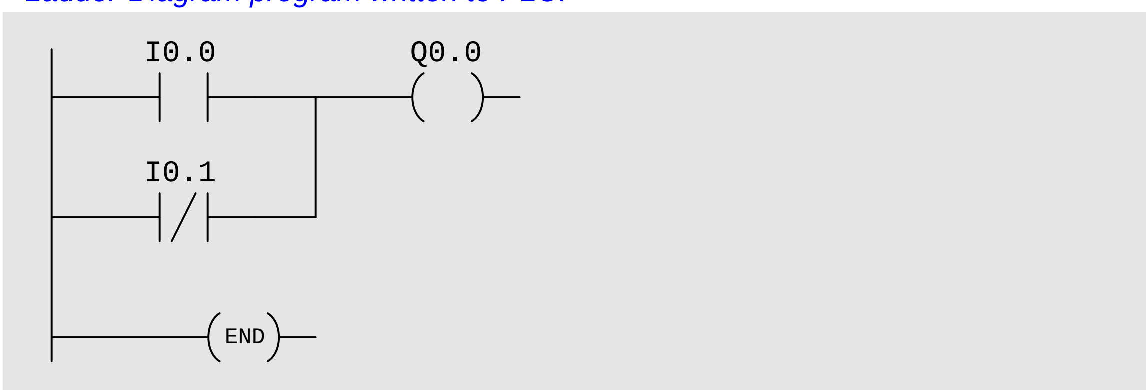
Note how Allen-Bradley I/O is labeled in the program: input bits designated by the letter `I` and output bits designated by the letter `O`.

Based on the wiring and program you see for this PLC, identify the switch state combinations resulting in an energized lamp. Try duplicating this program in your own PLC (even if it is a different brand or model) and see how it functions. Be sure to activate the *color highlighting* feature of your programming editor so you may see the "live" status of the program's virtual contacts and coil!

This example shows a Siemens S7-200 series PLC (model 224XP) wired to two toggle switches and one LED indicator lamp, complete with a demonstration program:



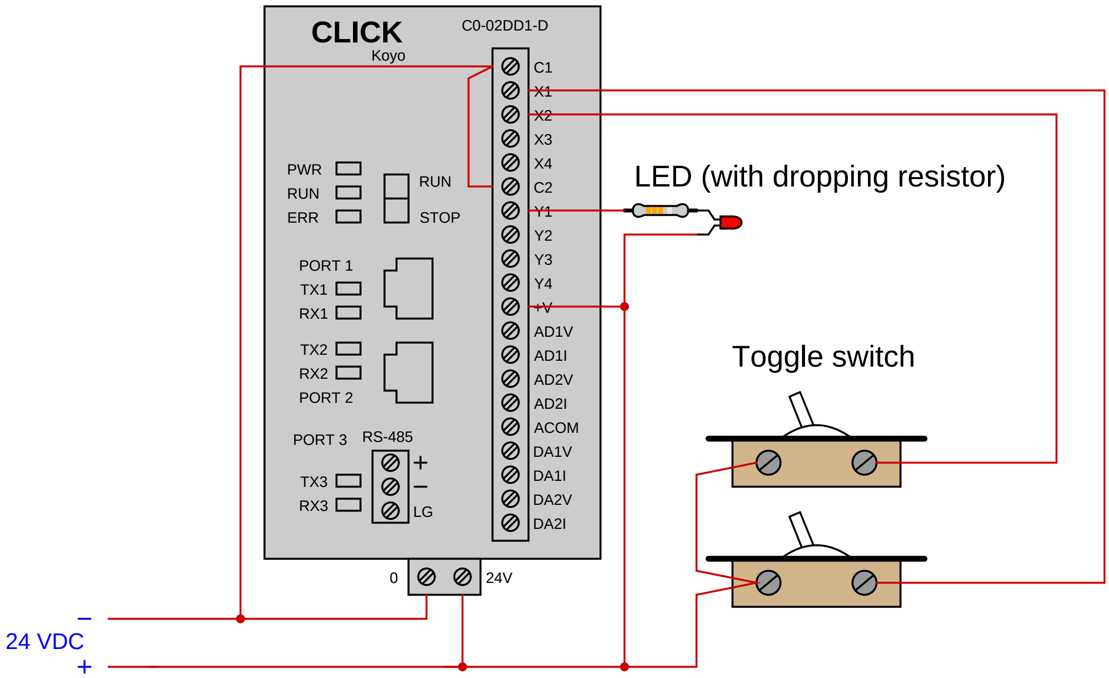
Ladder-Diagram program written to PLC:

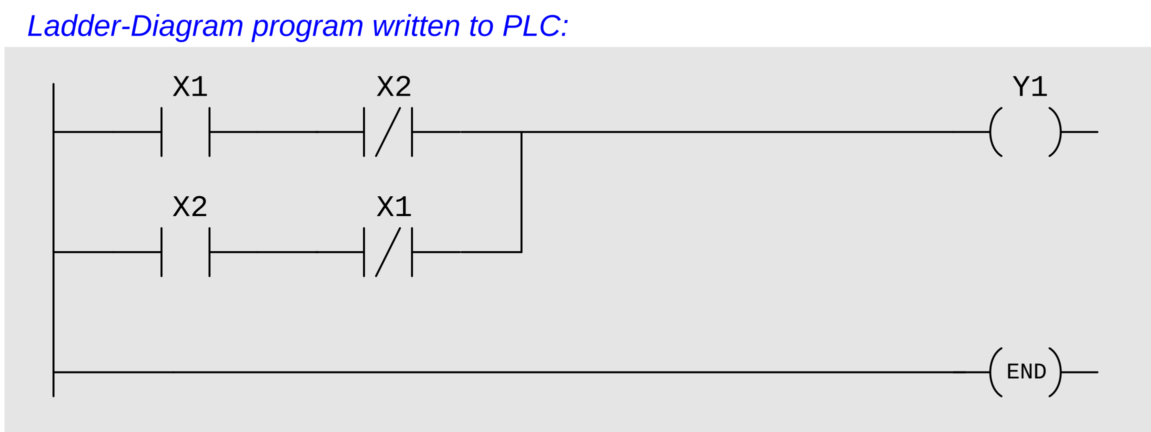


Note how Siemens I/O is labeled in the program: input bits designated by the letter `I` and output bits designated by the letter `Q`.

Based on the wiring and program you see for this PLC, identify the switch state combinations resulting in an energized lamp. Try duplicating this program in your own PLC (even if it is a different brand or model) and see how it functions. Be sure to activate the *color highlighting* feature of your programming editor so you may see the "live" status of the program's virtual contacts and coil!

This example shows a Koyo "CLICK" PLC (model C0-02DD1-D) wired to two toggle switches and one LED indicator lamp, complete with a demonstration program:





Note how Koyo I/O is labeled in the program: input bits designated by the letter `X` and output bits designated by the letter `Y`.

Based on the wiring and program you see for this PLC, identify the switch state combinations resulting in an energized lamp. Try duplicating this program in your own PLC (even if it is a different brand or model) and see how it functions. Be sure to activate the *color highlighting* feature of your programming editor so you may see the "live" status of the program's virtual contacts and coil!

file i04513

Answer 1

Here is a collection of typical answers from previous students addressing question #1 (goals of enrolling in Instrumentation):

- To achieve job security
- To gain a sense of doing something important in life
- To have respect on the job
- To be financially stable
- To provide for family
- To use your mind instead of doing menial work

Here is a collection of employer data addressing question #3 (important knowledge/skills):

In 2009, the *Industrial Instrumentation and Control Technology Alliance* (IICTA) conducted a survey of 23 industrial instrumentation experts from across the United States to rank the relative importance of knowledge and skill areas listed on the *Texas Skill Standards Board* (TSSB) skill standard for "Industrial Instrumentation and Controls Technician." The following is a list of knowledge/skill areas from this skill standard where "critically important" (the absolute highest importance) was the most popular vote of the experts surveyed, along with the percentage of experts voting the knowledge/skill area as "critical", and also my own qualitative judgment of how difficult it is for someone to first acquire that knowledge or skill:

Knowledge / Skill area	**% vote**	**Difficulty**
Ability to learn new technology	65%	Hard
Interpret and use instrument loop diagrams	65%	Moderate
Configure and calibrate instruments	65%	Moderate
Knowledge of test equipment	61%	Hard
Interpret and use process and instrument diagrams	57%	Moderate
Interpret and use instrument specification sheets	52%	Easy
Knowledge of basic AC/DC electrical theory	52%	Hard
Knowledge of basic mathematics	48%	Moderate
Interpret and use electrical diagrams	48%	Moderate
Interpret and use motor control logic diagrams	43%	Moderate
Knowledge of system interactions (e.g. interlocks & trips)	43%	Hard
Knowledge of permits and area classifications	43%	Easy
Understanding consequences of changes	43%	Hard
Proper use of hand tools	43%	Moderate
Knowledge of control schemes (e.g. ratio, cascade)	39%	Hard
Proper tubing and wiring installation	35%	Moderate
Motor control circuit knowledge	30%	Moderate
Electrical wiring knowledge	30%	Moderate

Which of these knowledge/skill areas would you consider yourself proficient in right now?

On January 24, 2013 the Washington State Workforce Training and Education Coordinating Board presented results of a survey gathering input from over 2800 employers state-wide. One of the questions on this survey asked employers if they had experienced difficulty with entry-level employees demonstrating the following skills. A partial listing of results is shown here:

Knowledge / Skill area	Percentage experiencing difficulty
Solve problems and make decisions	50%
Take responsibility for learning	43%
Listen actively	40%
Observe critically	38%
Read with understanding	32%
Use math to solve problems and communicate	31%

In July and August of 2011, the Manufacturing Institute and Deloitte Development LLC collaborated to adminster a "Skills Gap study" across a range of manufacturing industries in the United States. Survey results were collected from 1123 respondents, with one of the survey questions asking *"What are the most serious skill deficiencies in your current employees?"*. The responses to this question are tabulated here:

Knowledge / Skill area	Percentage experiencing difficulty
Inadequate problem-solving skills	52%
Lack of basic technical training	43%
Inadequate "soft skills" (attendance, work ethic)	40%
Inadequate computer skills	36%
Inadequate math skills	30%
Inadequate reading/writing/communication skills	29%

In December of 2001, the question "What qualities should an Instrumentation graduate possess in order to excel in their profession?" was posed to representatives on the Advisory Committee for BTC's Instrumentation program. In addition to a firm knowledge of fundamentals (electronics, physics, mathematics, process control), one advisor in particular noted that "self-direction and the ability to learn on your own" was even more important than these.

Do you see a pattern emerging from a comparison of these feedback results? As any economist can tell you, the highest-valued commodity is one with the greatest demand *and* the least supply. Which knowledge/skill area do you see in these survey results meeting *both* criteria? Are there other (lesser-valued) knowledge/skill areas of high value as defined by the same criteria of low supply and high demand?

Here is a collection of images addressing question #2 (career options):

Electric power generation:

Photos taken at the Satsop nuclear generating station in Washington.

Combined-cycle (gas turbine plus steam turbine) power plant, fueled by natural gas, in Ferndale, Washington.

Antelope Valley coal-fired power plant in Beulah, North Dakota.

Hydroelectric turbine generators at Grand Coulee Dam in Washington.

Oil and natural gas exploration/production:

BP Exploration's "Atlantis" offshore rig while under construction.

BTC Instrumentation grad Paige repairing flare ignitors on an offshore rig in the Gulf of Mexico.

Oil well drilling rig in the Bakken oil play (Stanley, North Dakota). These rigs drill approximately 2 miles down, then drill horizontally and fracture the shale rock to allow oil to seep out and be collected.

Oil wellhead and pump in Stanley, North Dakota.

Oil refining:

The Phillips66 refinery in Ferndale, Washington.

Coal gasification:

Dakota Gasification plant in Beulah, North Dakota. Produces synthetic natural gas, ammonia, and a variety of other high-value chemical products from coal. A majority of the carbon dioxide produced in this process is captured and piped to oil fields in Canada for enhanced recovery operations, where the CO_2 *gas ends up sequestered in underground wells.*

Chemical processing:

Chemtrade Solutions sulfuric acid reprocessing plant in Anacortes, Washington. This plant receives "spent" sulfuric acid from two oil refineries (alkylation units, where sulfuric acid is used as a liquid catalyst) and reprocesses this contaminated acid into nearly pure acid for re-sale and re-use in the refineries.

Wood pulping and paper production:

This is the "blend chest" at a small pulping operation, where different grades of wood pulp are mixed together to achieve the correct blend for paper production.

Pharmaceutical manufacturing:

Photos taken at Zymogenetics in Seattle. Sorry – they wouldn't let me snap any pictures of the really cool stuff!

Natural gas compression and distribution:

Williams Northwest Pipeline's gas compression facility in Sumas, Washington.

Large reciprocating (piston) engine used to compress natural gas.

Food processing and packaging:

Plant floor at Nature's Path Foods in Blaine, Washington.

Automated boxing machine for cereal.

Alcohol production and bottling:

Mash tuns and bottling line at RedHook Brewery in Woodinville, Washington.

Municipal water and wastewater treatment:

Potable water filtering at the city of Arlington, Washington.

Wastewater clarification at West Point treatment facility in King County (Seattle), Washington.

Electrical power distribution:

Bonneville Power Administration's Custer, Washington substation switchyard (500,000 volts).

Lumber milling and treatment:

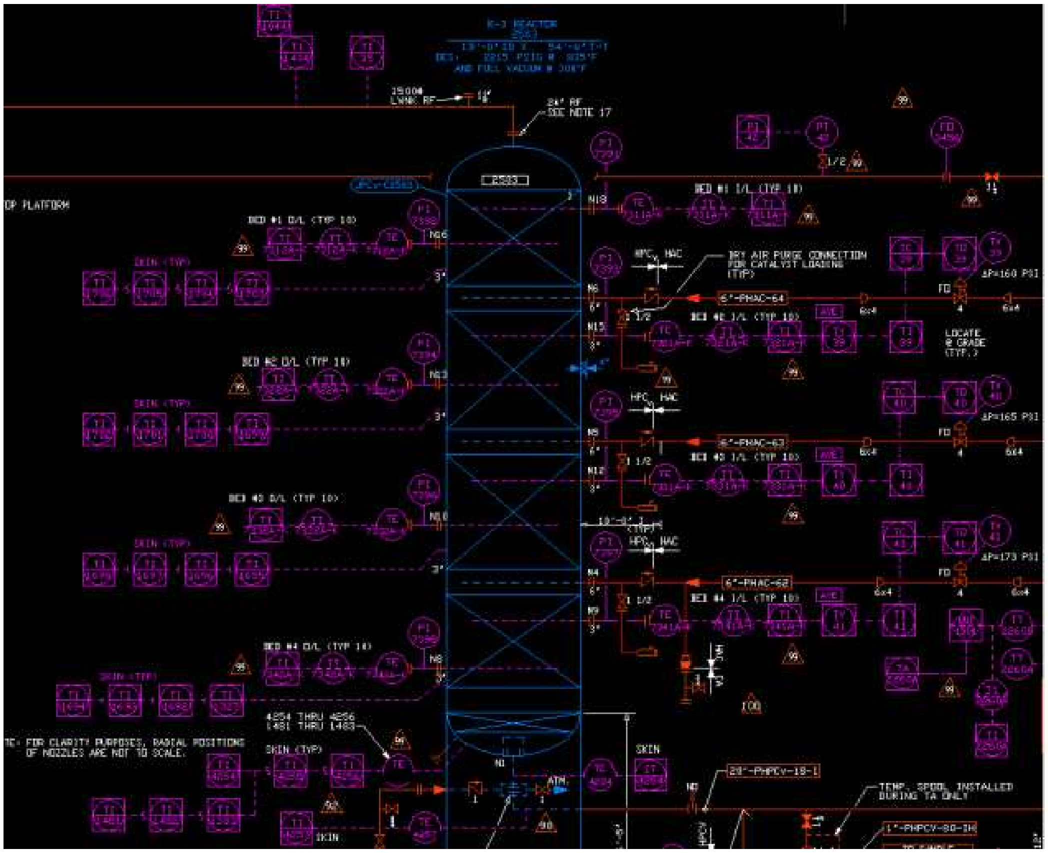
A computer-controlled drilling machine places holes into a wooden power line crossarm.

A retort used to pressure-treat lumber.

Aerospace:

Photos taken at NASA's rocket engine test facility in Stennis, Mississippi.

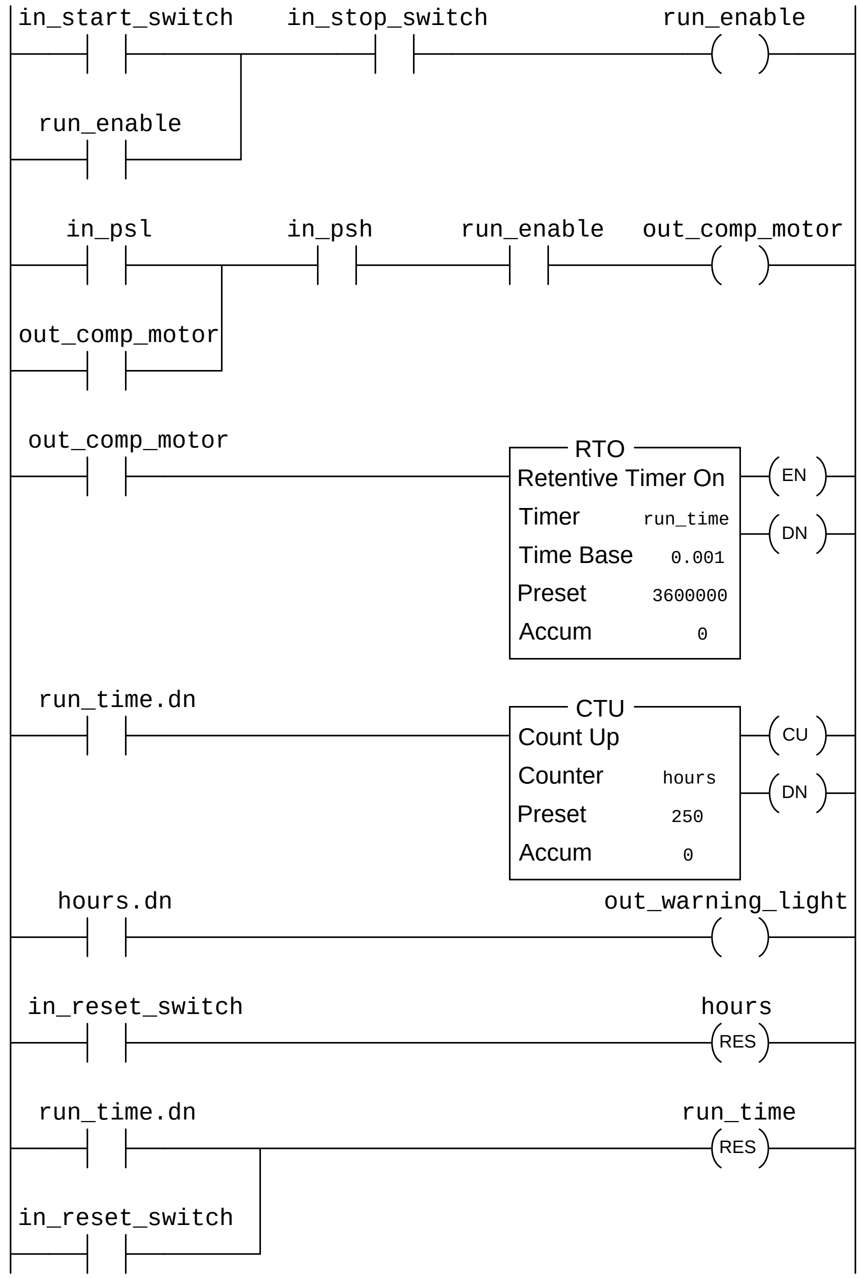
Instrument control circuit layout and design:



A typical screenshot of AutoCAD being used to draft a P&ID for an oil refinery unit.

"Potline" buildings at the Alcoa/Intalco aluminum smelter in Ferndale, Washington.

PLC programming (control system design engineering):

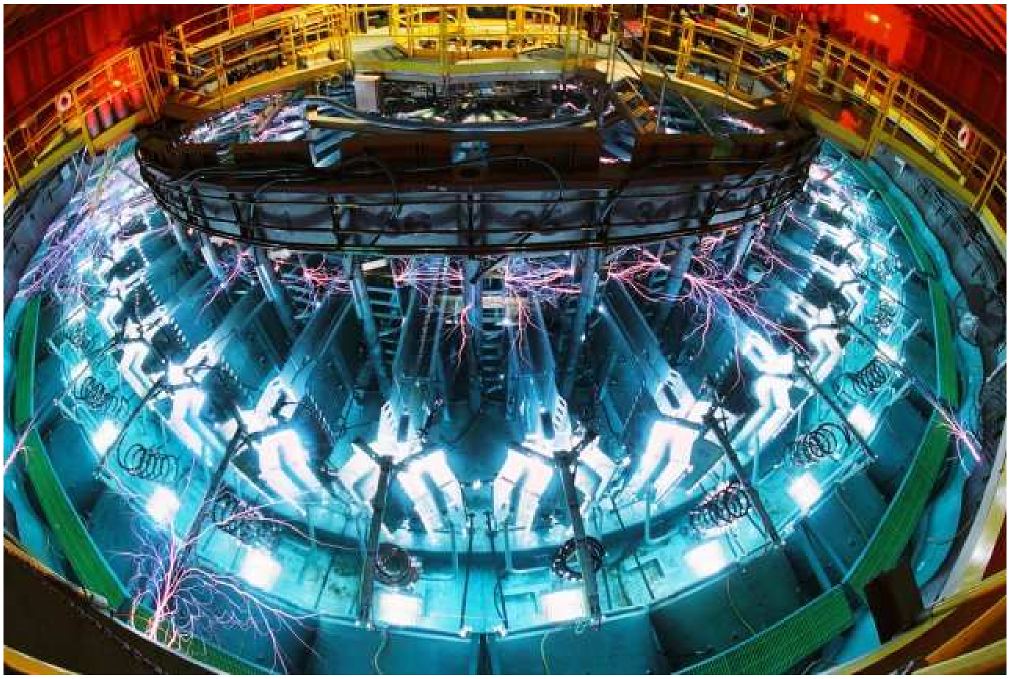


A typical PLC "ladder logic" program for an air compressor controlled by a Rockwell ControlLogix 5000 PLC is shown here.

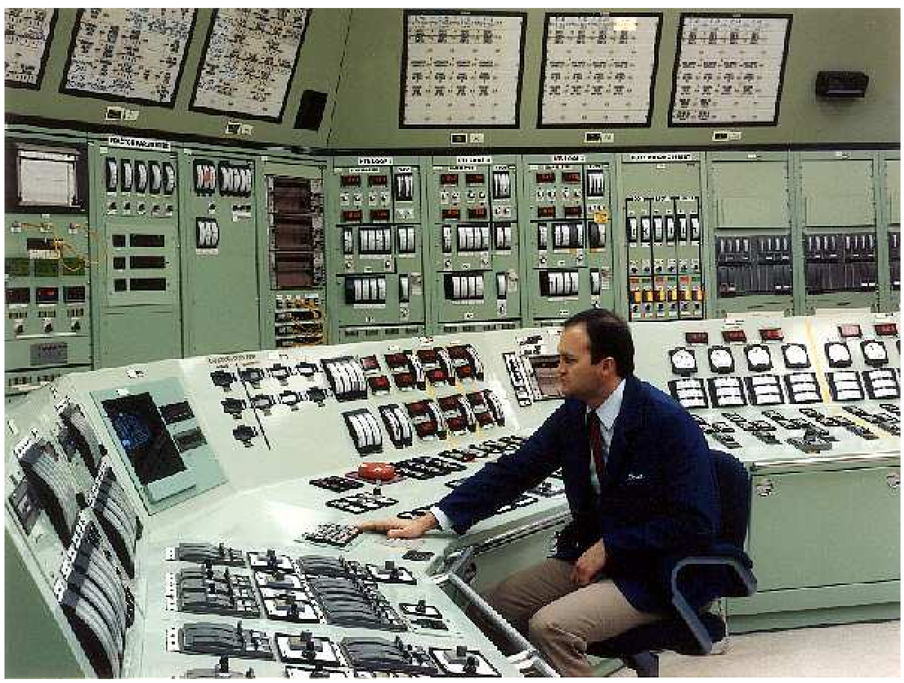
Environmental monitoring:

A Sutro weir used to measure the flow of water out of lake Padden in Bellingham, Washington.

Energy research and development:

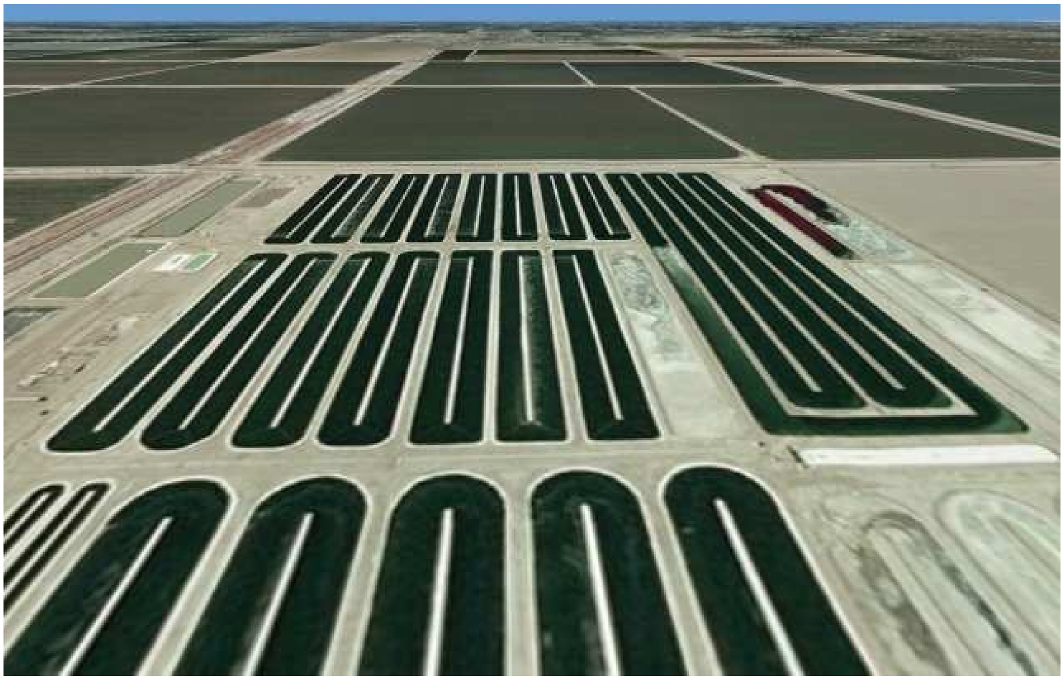


Sandia National Laboratory's pulsed power device used to conduct experiments in nuclear fusion, and also to test the effects of electromagnetic pulse energy on military hardware. Photo courtesy Department of Energy.



The control room of Pacific Northwest National Laboratory's Fast Flux Test facility, used to conduct research on nuclear fission "breeder" reactor technology. Photo courtesy Department of Energy.

Renewable energy:



Pacific Northwest National Laboratory's experimental algae ponds for solar-to-biomass conversion. Photo courtesy Department of Energy.

Wind turbines at the Wild Horse wind farm near Ellensburg, Washington, operated by Puget Sound Energy.

Photovoltaic array at the Wild Horse wind farm near Ellensburg, Washington, operated by Puget Sound Energy.

Mining:

BTC Instrumentation grads Micah and Mark working on a control valve near an ore crushing mill in Alaska.

Control valve service:

Customer Repair Report

EMERSON Process Management

Page 3 of 3

Customer Order Number		Fisher/Agent Order Number	Ship Date	Serial Number
			3/7/2007	

Job Number	Line Number	Description	Customer Equipment Tag
	0001	2" EZ	18-PV-22A

PICTURES INFORMATION

AS FOUND

CR72374
AS FOUND

CR72374
AS FOUND

CR72374
AS FOUND

AS LEFT

CR72374
AS LEFT

CR72374
AS LEFT

Typical "As-Found" and "As-Left" page of a control valve rebuild report.

Contract instrumentation work:

BTC Instrumentation grad Corey services a control valve at a Wyoming oil refinery during a winter shutdown.

Other career sectors not shown in this photo collection include (but are not limited to):

- Manufacturing assembly lines
- Automotive research and development
- Weight scale and weighfeeder service
- Calibration standard laboratories
- University campus utility work
- Geological monitoring (volcano monitoring)
- Robotics
- CNC machine tool maintenance
- Remotely piloted vehicles
- Instrumentation sales

Answer 2

Answer 3

Answer 4

Answer 5

Answer 6

Answer 7

The general philosophy of education in these courses may be summed up in a proverb:

"Give a man a fish and you feed him for a day. Give a man a fishing pole and you feed him for life."

Instrumentation is a highly complex, fast-changing career field. You will not survive, much less thrive, in this field if all you can ever learn is what someone directly teaches you. In order to stay up-to-date with new technology, figure out solutions to novel problems, and adapt to a changing profession, you absolutely *must* possess independent learning ability. You must be able to "fish" for new knowledge and understanding on your own. These courses are designed to foster this higher-level skill.

Answer 8

A *mastery* assessment is one that must be passed with a 100% score (no errors). Mastery assessments are usually given with multiple opportunities to pass. The basic idea is, you try and try until you get it perfect. This ensures mastery of the concept, hence the name.

By contrast, a *proportional-graded* assessment is one where you do not have to achieve perfection to pass. Most of the tests and assignments you have completed in your life are of this type. A grade (percentage, ranking, and/or letter) is given based on how well you answer the question(s).

In all the Instrumentation courses, all exams have both mastery and proportional sections. Lab exercises likewise have both mastery and proportional sections as well. Preparation and feedback grades are strictly proportional, with no mastery component.

Follow-up question: what happens if you fail to fulfill a mastery assessment within the allotted time?

Answer 9

Each student is allowed a certain number of hours absence time per quarter (refer to the syllabus for the exact number!), to be used for absences of any reason. Absences exceeding this number of hours will result in grade deductions (refer to the syllabus to see how severe!). Unused absence hours may be donated by students to their classmates at the end of each quarter to help out fellow students in need.

Answer 10

Contacting your instructor and team-mates allows you to keep abreast of any new developments, and find out how you can participate (if possible) during your absence. For instance, there may be something your lab team could have you research while you're out, to bring back to school the next day.

Answer 11

If you find yourself completely lost on a question or on a portion of the assigned reading despite having exhausted all available study time before class, you should highlight these specific points in your notes and seek help immediately at the beginning of class time. Chances are, you won't be the only person with that same question, and your query at the beginning of class will help others too!

Answer 12

Answer 13

An anecdote to relate regarding active reading on challenging subjects is when I had to study policy statements at BTC in preparation for an accreditation audit. The texts were long, boring, and I had little interest in their particulars. I found myself nodding off as I tried to read the policy statements, and unable to explain the meaning of what I had just read. Finally, I forced myself to outline each section of these policy papers in my own words, paragraph by paragraph, until I could articulate their meaning. To be sure, this technique took longer than simply reading the text, but it was *far* more effective than plain reading (even with underlining and highlighting!).

I've successfully applied similar strategies studying labor contracts for my work with the union at BTC. Several times I've been called upon to research policies in other college contracts, and I have done so (again) by summarizing their statements in my own words to ensure I am comprehending them as I read.

Answer 14

The ammeter shows R_2 carrying all the current, therefore either R_2 must be shorted or R_1 must be open.

Fault	**Possible**	**Impossible**
R_1 failed open	$\surd$	
R_2 failed open		$\surd$
R_3 failed open		$\surd$
R_1 failed shorted		$\surd$
R_2 failed shorted	$\surd$	
R_3 failed shorted		$\surd$
Current source dead		$\surd$

Answer 15

Answer 16

This is most definitely a synchronous motor and not an induction motor. It it were an induction motor, the speed would be less than synchronous.

The number of poles in this motor is 4.

Slip speed = 0 RPM (because it is synchronous).

Answer 17

Answer 18

Answer 19

Answer 20

Answer 21

Partial answer:

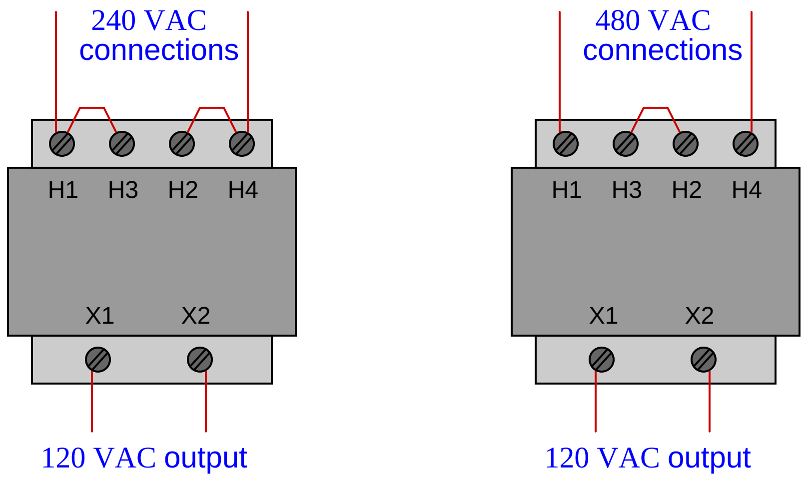
- The fact that this is a **step-down** transformer, is clearly evident from its primary/secondary turns ratio: the winding having more turns will exhibit greater voltage (and less current) than the winding having fewer turns

- Fuse current = 1.528 amps

Answer 22

$I_{source} = 187.5$ mA $\qquad\qquad I_{load} = 72.73$ mA

Answer 23



I'll let you determine ways to use a multimeter for winding tests in a control power transformer.

A *megger* is a special high-resistance ohmmeter using a test voltage of several hundred or thousand volts. It is able to detect faults in the insulation of transformer windings in the multiple-megaohm range!

Answer 24

Answer 25

Partial answer:

$V_{phase(source)} = 7.967$ kV
$I_{phase(source)} = 5.312$ A
$V_{phase(load)} = 7.967$ kV
$P_{total} = 126.96$ kW

Answer 26

Partial answer:

$E_{line} = 2400$ V
$I_{phase(source)} = 2.667$ A
$I_{phase(load)} = 4.619$ A

Answer 27

Partial answer:

$I_{line} = 26.93$ A
$E_{phase(source)} = 277$ V
$E_{phase(load)} = 479.8$ V

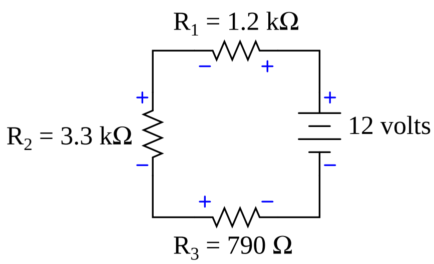
Answer 28

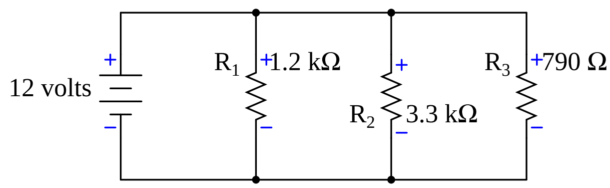
Partial answer:

$I_{line} = 25.88$ A
$I_{phase(source)} = 14.94$ A
$E_{phase(load)} = 2402$ V

Answer 29

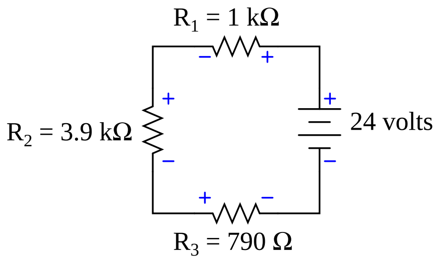
Answer 30

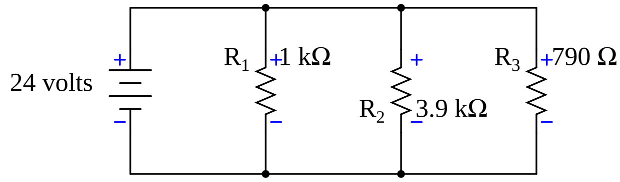




Quantity	Series circuit	Parallel circuit
V_{R1}	2.722 V	12 V
V_{R2}	7.486 V	12 V
V_{R3}	1.792 V	12 V
I_{R1}	2.268 mA	10 mA
I_{R2}	2.268 mA	3.636 mA
I_{R3}	2.268 mA	15.190 mA

Answer 31





Quantity	Series circuit	Parallel circuit
V_{R1}	4.218 V	24 V
V_{R2}	16.450 V	24 V
V_{R3}	3.332 V	24 V
I_{R1}	4.218 mA	24 mA
I_{R2}	4.218 mA	6.154 mA
I_{R3}	4.218 mA	30.380 mA

Answer 32

- $V_{primary} = 48$ volts
- $V_{secondary} = 14.77$ volts
- $I_{primary} = 30.3$ mA
- $I_{secondary} = 98.5$ mA

This is a *step-down* transformer.

Answer 33

$I_{load} = 23.77$ mA $\qquad$ $V_{load} = 8.318$ V

Answer 34

$E_{line} = 220$ V
$I_{line} = 0.482$ A
$E_{phase(source)} = 220$ V
$I_{phase(source)} = 0.278$ A
$E_{phase(load)} = 220$ V
$I_{phase(load)} = 0.278$ A
$P_{total} = 183.8$ W

Answer 35

Fault	**Possible**	**Impossible**
Circuit breaker tripped		$\surd$
Transformer primary winding failed open	$\surd$	
Transformer secondary winding failed open	$\surd$	
Resistor failed open		$\surd$
Resistor failed shorted		$\surd$
Open wire between K and P	$\surd$	
Doorbell unit failed open	$\surd$	
Doorbell unit failed shorted		$\surd$

Answer 36

A good way to convert horsepower into watts using the 746 conversion factor is to set up the equality in the form of a "unity fraction" to cancel units:

"Unity fraction"

$$\frac{2.5 \cancel{\text{HP}}}{1} \times \frac{746 \text{ watts}}{1 \cancel{\text{HP}}} = 1865 \text{ watts}$$

This cancellation technique ensures the multiplication and/or division is done properly, with the units showing you exactly how the fraction *must* be set up to properly cancel the undesired unit (horsepower) and replace it with the desired unit (watts).

I = 7.77 amps of current (assuming 100% efficiency).

I = 8.63 amps of current (assuming 90% efficiency).

Here is a sample spreadsheet page, showing one possible layout for the values:

	1	2	3	4	5
1	HP =	2.5		Current (ideal) =	
2	Voltage =	240		Current (actual) =	
3	Efficiency =	90%			
4					
5					

- **Cell R1C5 formula:** `= R1C2 * 746 / R2C2`
- **Cell R2C5 formula:** `= R1C5 / R3C2`

Note that the use of "R1C1" spreadsheet row/column labeling is arbitrary; one may use the more customary "A1" letter/number labeling if desired. There are some advantages to numbered row/column labels in more advanced spreadsheet programming, however, and so I recommend this style over the letter/number style.

Answer 37

$P_{load} = 3.59$ MW

Line current in the three-phase system is given as 150 amps. According to the 2008 edition of the National Electrical Code, this would require a #4 AWG copper wire (from table 310.21 in NFPA 70).

Line current in the single-phase system is calculated to be 260 amps. This would require 1/0 copper wire according to the same table in the NEC.

The ratio of three-phase current to single-phase current is $\frac{1}{\sqrt{3}}$, which tells us how much smaller the cross-sectional area of the three-phase conductors may be compared to the cross-sectional area of the single-phase conductors. However, we know the three-phase system requires 3 conductors whereas the single-phase system requires only 2 conductors: an increase in conductor count of $\frac{3}{2}$. The overall savings in copper realized by three-phase distribution may therefore be calculated by multiplying these two ratios:

$$\left(\frac{1}{\sqrt{3}}\right)\left(\frac{3}{2}\right) = 0.866$$

Therefore, a three-phase power system requires just 86.6% of the copper required by a single-phase power system to convey the same amount of electrical power!

Answer 38

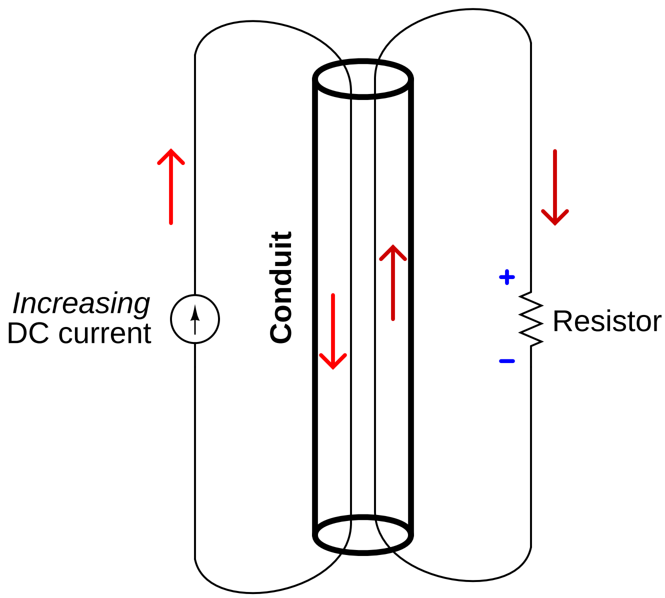
DC line current at 110 volts (@ 18 kW load) = 163.6 amps

AC line current at 13.8 kilovolts (@ 18 kW load) = 1.304 amps

The advantage of AC should be clear from this example: the freedom to use transformers to step voltage up and down at will allows us to use high voltage for low-current transmission of power (using conductors only large enough to handle these low currents) while still being able to use low voltages at the points of use for safety.

Thomas Edison's DC power distribution was horribly inefficient by modern standards, requiring buried copper bus bars to conduct the very large currents necessary to power many loads. Even then, the maximum distances were short (only a few miles before voltage drops became excessive) owing to the resistive losses of the copper bars.

Answer 39



The induced current runs opposite the incident current in accordance with Lenz's Law, in an attempt to oppose the change in magnetic flux near the wires.

Answer 40

Answer 41

Answer 42

Terminal-to-terminal resistance should be very low, since you are merely measuring the DC resistance of the stator windings. Terminal-to-frame resistance, however, should be infinite because the insulation of the stator windings should prevent any electrical contact with the motor frame.

Answer 43

Current = 3.39 amps AC

This is most definitely an induction motor and not a synchronous motor!

Answer 44

I_{line} = 67.30 amps of current (assuming 100% efficiency).

I_{line} = 73.15 amps of current (assuming 92% efficiency).

Answer 45

Answer 46

Answer 47

Answer 48

The bolted-fault MVA rating of the 3 kVA transformer bank feeding a 208 volt motor starter will be its base MVA rating (0.003 MVA) divided by its impedance (5%, or 0.05 per-unit):

$$\mathrm{MVA}_{bf} = \frac{\mathrm{MVA}_{base}}{Z}$$

$$\mathrm{MVA}_{bf} = \frac{0.003}{0.05} = 0.060$$

Arc flash boundary distance may be calculated one of two different ways:

$$D_c = \sqrt{2.65 \times \mathrm{MVA}_{bf} \times t} \qquad \text{NFPA 70E Equation D.2.1(d)}$$

$$D_c = \sqrt{53 \times 1.25 \times \mathrm{MVA}_{base} \times t} \qquad \text{NFPA 70E Equation D.2.1(e)}$$

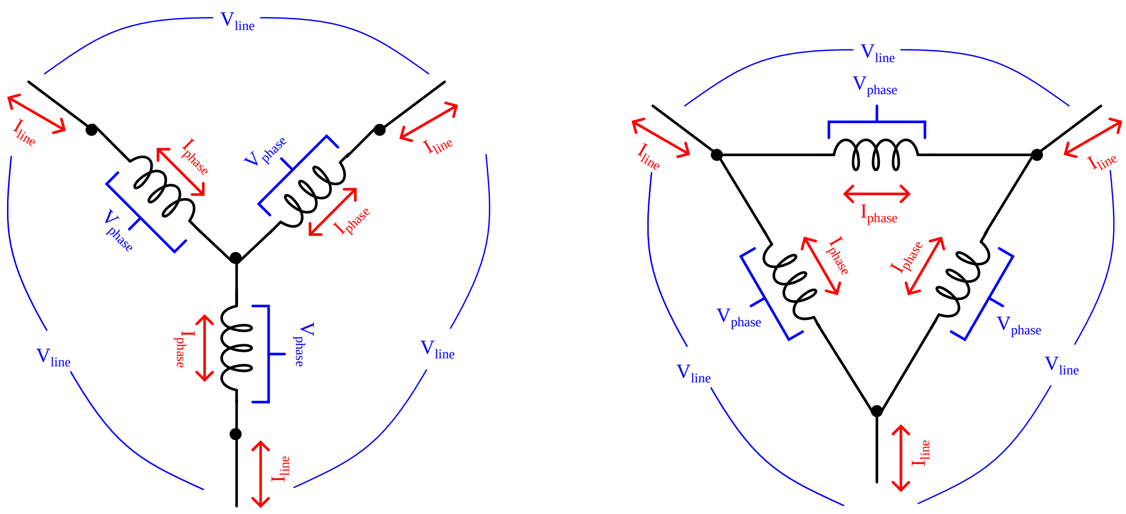
The time to clear a fault was specified as half of one cycle, which is 8.333 milliseconds at 60 Hz. Calculating both ways:

$$D_c = \sqrt{2.65 \times 0.060 \times 0.008333} = 0.036 \text{ ft} = 0.44 \text{ in}$$

$$D_c = \sqrt{53 \times 1.25 \times 0.003 \times 0.008333} = 0.041 \text{ ft} = 0.49 \text{ in}$$

In either case, the arc flash boundary is *less than half an inch* which effectively means no arc flash protection is necessary. This is why we use such a small transformer bank to supply three-phase power to our motor control circuits: the low kVA rating of this transformer bank acts as a safety feature to limit arc flash hazard to a negligible level.

Answer 49



Wye configuration

- $I_{phase} = I_{line}$
- $V_{phase} < V_{line}$

Delta configuration

- $V_{phase} = V_{line}$
- $I_{phase} < I_{line}$

Answer 50

It is helpful to recall how three-phase power is *generated* when trying to answer this question: we generate three-phase power by rotating a magnet at the center of three sets of coils, spaced 120^o apart from each other around the circle.

The magnetic field appears to rotate because the stator windings are energized out-of-step in a 1-2-3 sequence. This is not unlike a string of blinking "Christmas lights" which appear to move because the lights blink in a sequence that has a definite direction.

The compass needle's rotational speed would be 3600 RPM (60 revolutions per second) as a power supply frequency of 60 Hz. To halve this speed, we would either need to add twice as many poles to the motor, or else halve the frequency (30 Hz).

To reverse the needle's direction, reverse the phase sequence of the power. This may be accomplished by swapping any two of the three power conductors to the stator.

Answer 51

As the rotor spins clockwise, the lamps will blink from left to right (**C-B-A-C-B-A**). To reverse the sequence, simply swap any two wires ($A \leftrightarrow B$, $B \leftrightarrow$ C, or $A \leftrightarrow C$). Swapping any two phases will change a C-B-A sequence into an A-B-C sequence.

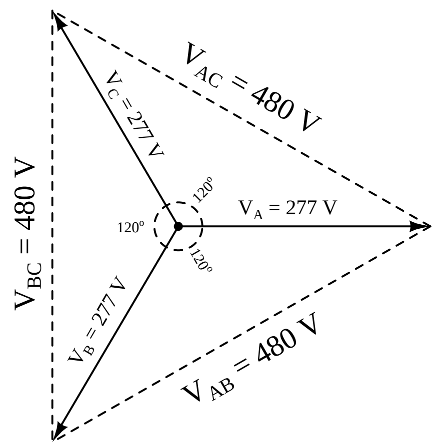
Answer 52

29.3 Hz is 29.3 flashes per second, which when matching the shaft's speed equates to 29.3 revolutions per second. This is equivalent to 1758 RPM.

This must be a 4-pole, induction AC motor operating on a 60 Hz power supply, since 1800 RPM is the synchronous speed of a 4-pole machine at 60 Hz. The slip speed of this induction motor is $1800 - 1758 =$ 42 RPM.

Answer 53

Phase voltage = 277 volts AC (given)
Line voltage = $V_{AB} = V_{BC} = V_{AC} = V_{phase}\sqrt{3}$ = 480 volts AC



Phase current = 17 amps AC (given)
Line current = $I_A = I_B = I_A = I_{phase}$ = 17 amps AC

Total load power = total source power = $3I_{phase}V_{phase} = I_{line}V_{line}\sqrt{3}$ = 14.13 kW

Answer 54

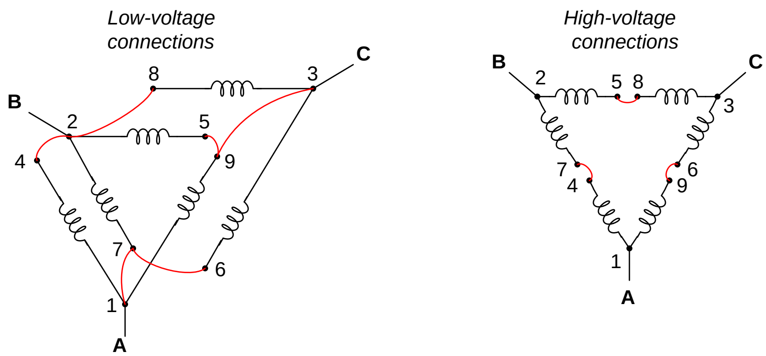
Phase current = 17 amps AC (given)
Line current = $I_A = I_B = I_C = I_{phase}\sqrt{3}$ = 29.4 amps AC

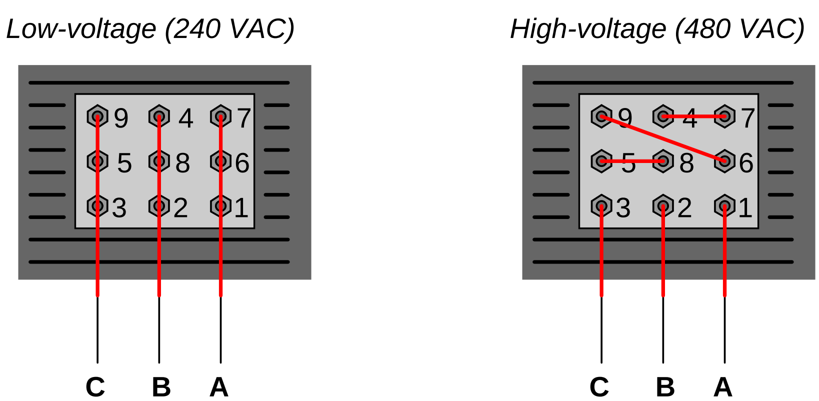
Phase voltage = 240 volts AC (given)
Line voltage = $V_{AB} = V_{BC} = V_{AC} = V_{phase}$ = 240 volts AC

Total load power = total source power = $3I_{phase}V_{phase} = I_{line}V_{line}\sqrt{3}$ =12.24 kW

Answer 55

This is just an exercise in connecting the dots! A helpful problem-solving technique to apply to such problems is *tracing all connections made* in the schematic diagram after making those connections in the pictorial diagram. This helps you keep track of which connections have been made, and which connections still need to be made.





Answer 56

A measurement of 0 volts *may* imply electrical continuity, but it may not. There are other reasons why one might obtain a 0 volt measurement, such as an open fault isolating the measurement points from power. If some *other* part of the AC line is open (e.g. the contactor being de-energized), even an open fuse will drop 0 volts because it is not the only open in the circuit.

Answer 57

The left-hand motor always operates in a "wye" configuration. The right-hand motor operates as a "delta" in the low-speed mode and as a "wye" in the high-speed mode.

These motors achieve half-speed operation by doubling the number of active poles in their stators. Note that in each of the high-speed configurations, pairs of stator coils are connected in parallel so that they act as one coil. In each of the low-speed configurations, stator coils are connected in series with opposing polarities, so that they will have opposite magnetic poles and therefore function differently.

The doubling of poles is not unlike a doubling of light bulbs in a "chaser" light display, where the sequential blinking of light bulbs gives them an appearance of motion. Adding more light bulbs in between the existing bulbs of a chaser array (i.e. doubling the number of lights without changing the length of the array) makes it appear as though the lights' "motion" moves along at a slower pace for the same blinking frequency.

Answer 58

A *megger* is a special high-resistance ohmmeter using a test voltage of several hundred or thousand volts. It is able to detect faults in the insulation of motor windings in the multiple-megaohm range!

If one stator winding partially shorts in a wye-connected motor, the two line-to-line resistance measurements that are lower than the third indicate the shorted winding by commonality (e.g. if R_{AB} and R_{BC} are both less than R_{BC}, it must be winding B that is shorted.

If one stator winding partially shorts in a delta-connected motor, the one line-to-line resistance measurement that is lower than the other two indicates the shorted winding (e.g. if R_{AB} and R_{BC} are both greater than R_{BC}, it must be winding BC that is shorted.

Answer 59

$P = 202.3$ hp

If you calculated 181.5 amps for line current, you're close – you have assumed 100% efficiency for the motor! The actual line current is 197.2 amps if you take the motor's 92% efficiency into account.

Here is a formula you can use to convert torque (lb-ft) and speed (RPM) values into horsepower:

$$P = \frac{S\tau}{5252.113}$$

I don't expect anyone to memorize a formula like this, but one may derive it from a "thought experiment." It should be intuitively obvious that power (P) must be directly proportional to both torque (τ) and speed (S), with some constant of proportionality (k) included to account for units:

$$P \propto S\tau$$

$$P = kS\tau$$

If we were to imagine a 1-foot radius drum hoisting a 550 pound rate vertically at 1 foot per second as an example of a machine exerting exactly 1 horsepower, we may solve for τ and S, then calculate the necessary constant to make P equal to 1. The drum's torque would be 550 lb-ft, of course (550 lb of force exerted over a moment arm of 1 foot). With a circumferential speed of 1 foot per second, it would rotate at $\frac{1}{2\pi}$ revolutions per second, or $\frac{30}{\pi}$ RPM. If $\tau = 550$ and $S = \frac{30}{\pi}$ and $P = 1$ horsepower, then:

$$P = \frac{\pi S\tau}{30 \times 550}$$

In answer to the Socratic discussion question, the 92% efficiency works to diminish output current, rather than increase input current as in the case of the motor. Thus, the diesel-powered generator will output a line current of 167 amps.

Answer 60

Answer 61

Answer 62

Answer 63

- Pushbutton switch A fails open: *Lamp 1 always energized, lamp 2 simply becomes inverse status of pushbutton switch B.*
- Relay coil CR2 fails open: *Both lamp 1 and lamp 2 simply become inverse status of pushbutton switch A.*
- Relay contact CR1-1 fails open: *Lamp 1 simply becomes same status as pushbutton switch B.*
- Relay contact CR2-1 fails shorted: *Lamp 1 always energized.*
- Relay contact CR2-2 fails shorted: *Lamp 2 simply becomes inverse status of pushbutton switch A.*

Answer 64

This is a problem worthy of a good in-class discussion with your peers! Of course, several things could be wrong in this circuit to cause lamp 1 to never energize. When you explain what measurements you would take in isolating the problem, be sure to describe whether or not you are actuating either of the pushbutton switches when you take those measurements.

Jumpering across lamp 1 creates a *short-circuit* condition by removing the only load in that "rung" of the circuit!

Answer 65

Answer 66

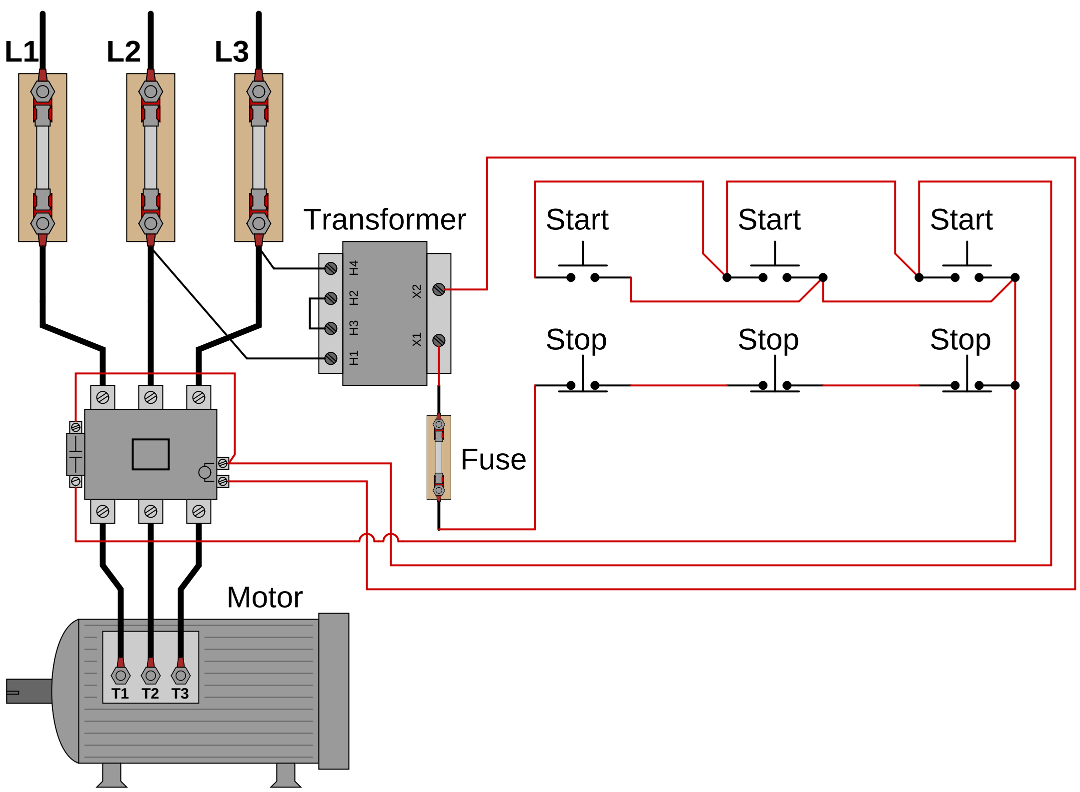
Answer 67

Answer 68

Answer 69

The normally-closed contacts are referred to as *interlock* contacts, and they prevent simultaneous *forward* and *reverse* actuation of the motor.

Answer 70



Answer 71

Step 1 should ensure zero energy at the motor. Step 2 alerts others not to re-energize the motor. Step 3 is a check to see that the correct motor has been locked out. Step 4 checks for voltage at all possible 2-point combinations on the power conductors. Step 5 verifies that the voltmeter is properly functioning.

Pulling a fuse on a control circuit forces the motor contactor to be a safety device, which it was never intended to be. Furthermore, it makes re-energizing the motor as simple as replacing a low-voltage fuse, which is far too easy (and therefore likely) for someone to do.

Answer 72

Fault	**Possible**	**Impossible**
Fuse F1 blown		√
Fuse F2 blown		√
Start switch failed open	√	
Stop switch failed open	√	
M1 coil failed open		√
M1 auxiliary contact failed open		√
M1 power contact(s) failed open	√	
OL contact failed open		√
Start switch failed shorted		√
Stop switch failed shorted		√
Transformer secondary failed shorted		√

Answer 73

Truth table (good circuit)

A	B	Output
0	0	0
0	1	0
1	0	1
1	1	0

Truth table (with fault)

A	B	Output
0	0	0
0	1	0
1	0	1
1	1	1

If you thought that the "faulted" truth table would be all 0's, you probably thought I said relay *contact* CR2 failed open. The fault I proposed was relay CR2 **coil** failed open.

Answer 74

Never, ever connect load devices in series in a control circuit such as this!

Answer 75

The blue lamp will be energized whenever the pressure switch senses a pressure that is less than 45 PSI.

The red and green lamps will both be de-energized whenever the level senses a level less than 1 foot 3 inches. If that switch senses a level greater than 1 foot 3 inches, either the red lamp or the green lamp will energize (not both simultaneously!) based on the pressure switch's state: a pressure less than 45 PSI energizes the relay coil and energizes the green lamp, while a pressure greater than 45 PSI de-energizes the relay coil and energizes the red lamp.

Answer 76

The reset time for an overcurrent heater is an intentional design feature. If the heater is too hot to re-set, then the motor is too hot to re-start.

Remember that the purpose of an overload heater is to provide a *thermal analogue* of the electric motor itself. Ideally, the heater heats up and cools down at the exact same rate as the motor. This explains why there is a necessary reset time after an overload heater causes the motor control circuit to "trip."

The reason for the reset time curve decreasing after about 300% full-load current is a bit more complex to answer. This, as well, is not an idiosyncrasy, but rather a design feature of the overload heater. Since greater levels of current will trip the heater in a shorter time, they actually heat up the motor less during that brief "on" time than a sustained overcurrent of lesser magnitude. Therefore the motor does not need to cool down as long prior to the next re-start.

Answer 77

Here are some possible faults (not an exhaustive list by any means!):

- Any fuse blown
- Contactor coil failed open
- Overload heater tripped (needs to be reset)
- Any transformer winding failed open
- Broken jumper between H3 and H2 on the transformer
- Corroded wire connection at terminal A1 or A2
- Motor winding failed shorted

Follow-up question: there will be a difference in operation between the L1 fuse blowing and either the L2 or L3 fuse blowing. Explain what this difference is, and why it might serve as a clue to what was wrong.

Answer 78

Inrush current is a factor with *every* motor type, AC or DC. It is easy to forget just how substantially larger a typical motor's inrush current is compared to its normal full-load current. When students consider the magnitude of the currents involved, and also the fact that most electric motors are fan-cooled and therefore lacking in cooling during the initial moments of a start-up, the reason for automatic lock-out after several successive start-up events becomes obvious.

Answer 79

Each overload heater element possesses a small amount of electrical resistance, which is the key to this diagnostic procedure. Of course, the measurement obtained is strictly qualitative, not quantitative as a clamp-on ammeter would give.

Follow-up question #1: what sort of result might occur with this diagnostic check if the motor were indeed single-phasing due to one of the overload heaters failing open?

Follow-up question #2: what other causes could there be for a three-phase motor "single-phasing" other than a motor winding failed open?

Answer 80

These three motors are all interlocked so that each one depends on the other. If any of them them trips, all three shut off!

In the specific case of motor #3, its tripping causes all three motors to shut off automatically. However, motors #1 and #2 may still be "jogged" by pressing and holding the "Start" pushbutton.

Answer 81

This is a graded question – no answers or hints given!

Answer 82

This is a graded question – no answers or hints given!

Answer 83

This is a graded question – no answers or hints given!

Answer 84

This is a graded question – no answers or hints given!

Answer 85

This is a graded question – no answers or hints given!

Answer 86

This is a graded question – no answers or hints given!

Answer 87

This is a graded question – no answers or hints given!

Answer 88

This is a graded question – no answers or hints given!

Answer 89

This is a graded question – no answers or hints given!

Answer 90

This is a graded question – no answers or hints given!

Answer 91

Answer 92

For the Allen-Bradley MicroLogix example, the lamp will energize only when switch 0 is turned off and switch 1 is turned on.

For the Siemens S7-200 example, the lamp will energize when switch 0 is turned on or if switch 1 is turned off, or both conditions occur simultaneously.

For the Koyo example, the lamp will energize according to the *Exclusive-OR* function with switch 1 and switch 2. The lamp energizes when switch 1 is on and switch 2 is off, or when switch 1 is off and switch 2 is on.