

Lab

HMI configuration for PLC control system: *Question 51, completed objectives due by the end of day 2*

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Exam

*Day 2* – 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 an ideal AC transformer circuit
  - Sketch proper wire connections for sourcing or sinking PLC I/O points and specified process switch trip conditions
  - Determine status of discrete PLC outputs given process switch stimuli and a RLL program
  - Calculate voltages and currents within balanced three-phase AC electrical circuits
  - Solve for a specified variable in an algebraic formula
  - Determine the possibility of suggested faults in a simple PLC circuit given a wiring diagram, RLL program listing, meter measurements, and/or reported symptoms
  - INST240 Review: Determine suitability of different level-measuring technologies for a given process fluid type
  - INST251 Review: Identify the graphed response of a controller as being either P, I, or D
  - INST263 Review: Determine effect of a fault in a selector or override control system
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**Recommended daily schedule**

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Day 1

**Theory session topic:** Review for exam

Questions 1 through 20; answer questions 1-9 in preparation for discussion (remainder for practice)

**Team tool locker inspection:** have students inventory their team tool lockers, posting lists to the outside of the locker doors documenting what’s missing.

Feedback questions (*41 through 50*) are optional and may be submitted for review at the end of the day

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Day 2

**Exam**

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Day 3

**Theory session topic:** Analog I/O

Questions 21 through 40; answer questions 21-23 in preparation for discussion (remainder for practice)

*The last day of the quarter is a full day, where all students are expected to attend as usual. Together, we will spend the lab session completing any remaining lab objectives, as well as doing general clean-up, reorganization, equipment repair, and other tasks necessary for the maintenance of our lab facility. See question 52 for a list of necessary tasks to complete.*

## 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-out/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.

## General Values, Expectations, and Standards (continued)

**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.

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## 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

## Course Syllabus

### INSTRUCTOR CONTACT INFORMATION:

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**DEPT/COURSE #:** INST 232

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

**COURSE TITLE:** PLC Systems

**COURSE DESCRIPTION:** In this course you will learn how to program data-handling functions in programmable logic controllers (PLCs) including comparison, arithmetic, and data transfer instructions. You will also learn to connect and program human-machine interface (HMI) panels to PLCs. **Pre/Corequisite course:** INST 231 (PLC Programming) **Prerequisite course:** MATH&141 (Precalculus 1) with a minimum grade of “C”

**COURSE OUTCOMES:** Program, analyze, and efficiently diagnose control systems incorporating programmable logic controllers (PLCs) and human-machine interface panels (HMIs).

**COURSE OUTCOME ASSESSMENT:** PLC/HMI programming, 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 an ideal AC transformer circuit, with 100% accuracy (mastery)
  - Sketch proper wire connections for sourcing or sinking PLC I/O points and specified process switch trip conditions, with 100% accuracy (mastery)
  - Determine status of discrete PLC outputs given process switch stimuli and a RLL program, with 100% accuracy (mastery)
  - Calculate voltages and currents within balanced three-phase electrical circuits, with 100% accuracy (mastery)
  - Solve for specified variables in algebraic formulae, with 100% accuracy (mastery)
  - Determine the possibility of suggested faults in a simple PLC circuit given a wiring diagram, RLL program listing, meter measurements, and/or reported symptoms, with 100% accuracy (mastery)
  - Program an HMI panel to fulfill a specified control system function
- 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
  - Augment a PLC-controlled motor start/stop system with an HMI panel providing operator access to operating parameters
  - Generate an accurate wiring diagram compliant with industry standards documenting your team's motor control system
- Independently perform the following tasks with 100% accuracy (mastery). Multiple re-tries are allowed with different specifications/conditions each time:
  - Research equipment manuals to sketch a complete circuit connecting a PLC to either a discrete sensing device or a discrete control element (e.g. VFD), with all components randomly selected by the instructor
  - Diagnose a random fault placed in another team's PLC motor control system by the instructor within a limited time using no test equipment except a multimeter and ladder logic editing software, 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>

- INST232 Section 1 (HMI programming, PLC comparison and arithmetic programming, PLC data transfer programming): 4 days theory and labwork
- INST232 Section 2 (PLC analog programming and project completion): 1 day theory and labwork + 1 day for mastery/proportional exams + 1 day for lab clean-up



**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.
- **Hands-on PLC programming challenges:** daily worksheet questions specify realistic scenarios requiring students to develop real PLC and HMI programs on their PLC trainers to implement the desired control function(s).
- **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 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>

- INST232\_sec1.pdf
- INST232\_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% ≥ <b>A</b> ≥ 95%	95% > <b>A-</b> ≥ 90%	
90% > <b>B+</b> ≥ 86%	86% > <b>B</b> ≥ 83%	83% > <b>B-</b> ≥ 80%
80% > <b>C+</b> ≥ 76%	76% > <b>C</b> ≥ 73%	73% > <b>C-</b> ≥ 70% (minimum passing course grade)
70% > <b>D+</b> ≥ 66%	66% > <b>D</b> ≥ 63%	63% > <b>D-</b> ≥ 60%      60% > <b>F</b>

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.

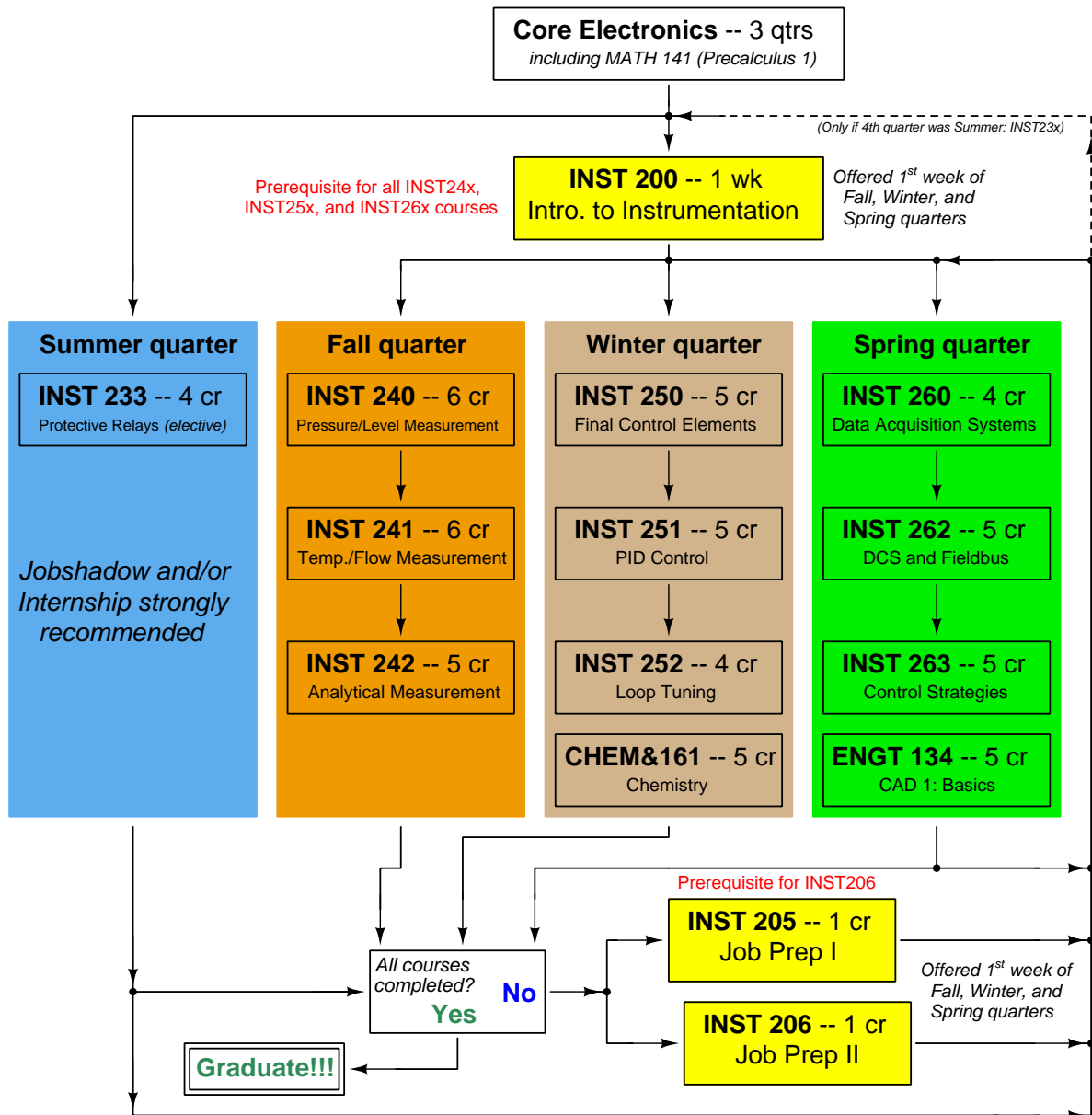
Individual preparation for Socratic dialogue sessions is measured by a “prep quiz” and/or personal inspection of your work by the instructor. A second (“summary”) quiz score for every Socratic session marks your participatory dialogue and ability to give reasoned answers to challenge questions on that 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>
- 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.
- Small “brick” PLC and HMI panel (*Automation Direct option*):
  - Automation Direct CLICK PLC model C0-00DD1-D (price  $\approx$  \$70) 8 discrete (DC) inputs, 6 discrete (DC) outputs
  - Automation Direct CLICK PLC model C0-02DD1-D (price  $\approx$  \$130) 4 discrete (DC) inputs, 4 discrete (DC) outputs, 2 analog inputs, 2 analog outputs, RS-485 Modbus communications port, real-time clock and calendar
  - Automation Direct CLICK 24 VDC power supply model C0-00AC (price  $\approx$  \$30) 24 VDC at 0.5 amp maximum output
  - Automation Direct C-More Micro HMI panel 3 inch EA1-S3ML-N (price  $\approx$  \$150)
  - *optional* Automation Direct C-More Micro touch-screen HMI panel 3 inch EA1-S3ML (price  $\approx$  \$190)
  - Automation Direct USB/serial adapter and cable part EA-MG-PGM-CBL (price  $\approx$  \$40) necessary for programming the C-More Micro HMI panel (also useful for programming the PLC)
  - **Note:** We have found the Automation Direct software works equally well through a 9-pin serial port as through a USB port (with converter), and is very “friendly” to use.
- Small “brick” PLC and HMI panel (*Allen-Bradley option*):
  - Rockwell (Allen-Bradley) MicroLogix 1000 model 1761-L10BWA (price  $\approx$  \$85 with BTC student discount at North Coast Electric) 6 discrete (DC) inputs, 4 discrete (relay) outputs
  - *or* Rockwell (Allen-Bradley) MicroLogix 1100 model 1763-L16BWA (price  $\approx$  \$240 with BTC student discount at North Coast Electric) 10 discrete (DC) inputs, 6 discrete (DC) outputs, 2 analog inputs, RS-485 communication port, 10 Mbit/s Ethernet communication port, embedded web server for remote monitoring of data points (series A or B programmable using free MicroLogix Lite software)
  - Rockwell (Allen-Bradley) cable part 1761-CBL-PM02 (price  $\approx$  \$30 with BTC student discount at North Coast Electric)
  - Automation Direct C-More Micro HMI panel 3 inch EA1-S3ML-N (price  $\approx$  \$150)
  - *optional* Automation Direct C-More Micro touch-screen HMI panel 3 inch EA1-S3ML (price  $\approx$  \$190)
  - Automation Direct cable part EA-MLOGIX-CBL (price  $\approx$  \$30) and adapter part EA-MG-SP1 (price  $\approx$  \$50) necessary for connecting the C-More Micro HMI panel to an Allen-Bradley MicroLogix 1000 PLC
  - Automation Direct USB/serial adapter and cable part EA-MG-PGM-CBL (price  $\approx$  \$40) necessary for programming the C-More Micro HMI panel
  - **Note:** Programming Allen-Bradley PLCs is best done using a PC with a 9-pin serial port. We have found trying to use a USB-to-serial adapter very troublesome with Allen-Bradley software!

## Sequence of second-year Instrumentation courses



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



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.

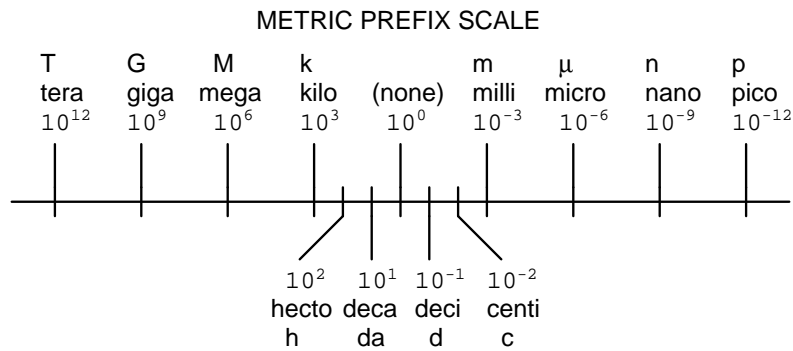
Labwork is perhaps the most difficult portion of the curriculum for a “distance” student to complete, since the equipment used in Instrumentation is typically too large and expensive to leave the school lab facility. “Distance” students must find a way to complete the required lab activities, either 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.

## 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:  $\mu$
- 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**

- $^{\circ}\text{F} = (^{\circ}\text{C})(9/5) + 32$
- $^{\circ}\text{C} = (^{\circ}\text{F} - 32)(5/9)$
- $^{\circ}\text{R} = ^{\circ}\text{F} + 459.67$
- $\text{K} = ^{\circ}\text{C} + 273.15$

### 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<sup>3</sup>) = 4 quarts (qt) = 8 pints (pt) = 128 fluid ounces (fl. oz.)  
= 3.7854 liters (l)

1 milliliter (ml) = 1 cubic centimeter (cm<sup>3</sup>)

**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<sup>2</sup>) = 4840 square yards (yd<sup>2</sup>) = 4046.86 square meters (m<sup>2</sup>)

**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<sup>10</sup>  
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<sup>2</sup>) = 32.1740 feet per second per second (ft/s<sup>2</sup>)

### Physical constants

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

Avogadro's number ( $N_A$ ) =  $6.022 \times 10^{23}$  per mole ( $\text{mol}^{-1}$ )

Electronic charge ( $e$ ) =  $1.602 \times 10^{-19}$  Coulomb (C)

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

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

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

### Properties of Water

Freezing point at sea level =  $32^\circ\text{F} = 0^\circ\text{C}$

Boiling point at sea level =  $212^\circ\text{F} = 100^\circ\text{C}$

Density of water at  $4^\circ\text{C}$  =  $1000 \text{ kg}/\text{m}^3 = 1 \text{ g}/\text{cm}^3 = 1 \text{ kg}/\text{liter} = 62.428 \text{ lb}/\text{ft}^3 = 1.94 \text{ slugs}/\text{ft}^3$

Specific heat of water at  $14^\circ\text{C}$  =  $1.00002 \text{ calories}/\text{g} \cdot ^\circ\text{C} = 1 \text{ BTU}/\text{lb} \cdot ^\circ\text{F} = 4.1869 \text{ Joules}/\text{g} \cdot ^\circ\text{C}$

Specific heat of ice  $\approx 0.5 \text{ calories}/\text{g} \cdot ^\circ\text{C}$

Specific heat of steam  $\approx 0.48 \text{ calories}/\text{g} \cdot ^\circ\text{C}$

Absolute viscosity of water at  $20^\circ\text{C}$  = 1.0019 centipoise (cp) = 0.0010019 Pascal-seconds (Pa·s)

Surface tension of water (in contact with air) at  $18^\circ\text{C}$  = 73.05 dynes/cm

pH of pure water at  $25^\circ\text{C}$  = 7.0 (*pH scale = 0 to 14*)

### Properties of Dry Air at sea level

Density of dry air at  $20^\circ\text{C}$  and 760 torr =  $1.204 \text{ mg}/\text{cm}^3 = 1.204 \text{ kg}/\text{m}^3 = 0.075 \text{ lb}/\text{ft}^3 = 0.00235 \text{ slugs}/\text{ft}^3$

Absolute viscosity of dry air at  $20^\circ\text{C}$  and 760 torr = 0.018 centipoise (cp) =  $1.8 \times 10^{-5}$  Pascal-seconds (Pa·s)

file conversion\_constants

**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

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### Question 1

Identify any area(s) of your study in which you would like to become stronger. Examples include technical reading, electrical circuit analysis, solving particular types of problems, time management, and/or skills applied in the lab. Cite specific examples if possible, and bring these to your instructor's attention so that together you may target them for improvement. As a starting point, try consulting the list of topics on the first page of the worksheet for the upcoming mastery exam, as well as the "General Values and Responsibilities" list near the beginning of the worksheet identifying the habits and qualities necessary for success in this career.

Next, identify practical strategies you will use to strengthen these areas. Examples include focusing on specific types of problem-solving whenever those types appear in the homework, working through practice problems for a particular subject, and/or coordinating with your lab team to give you more practice on specific skills.

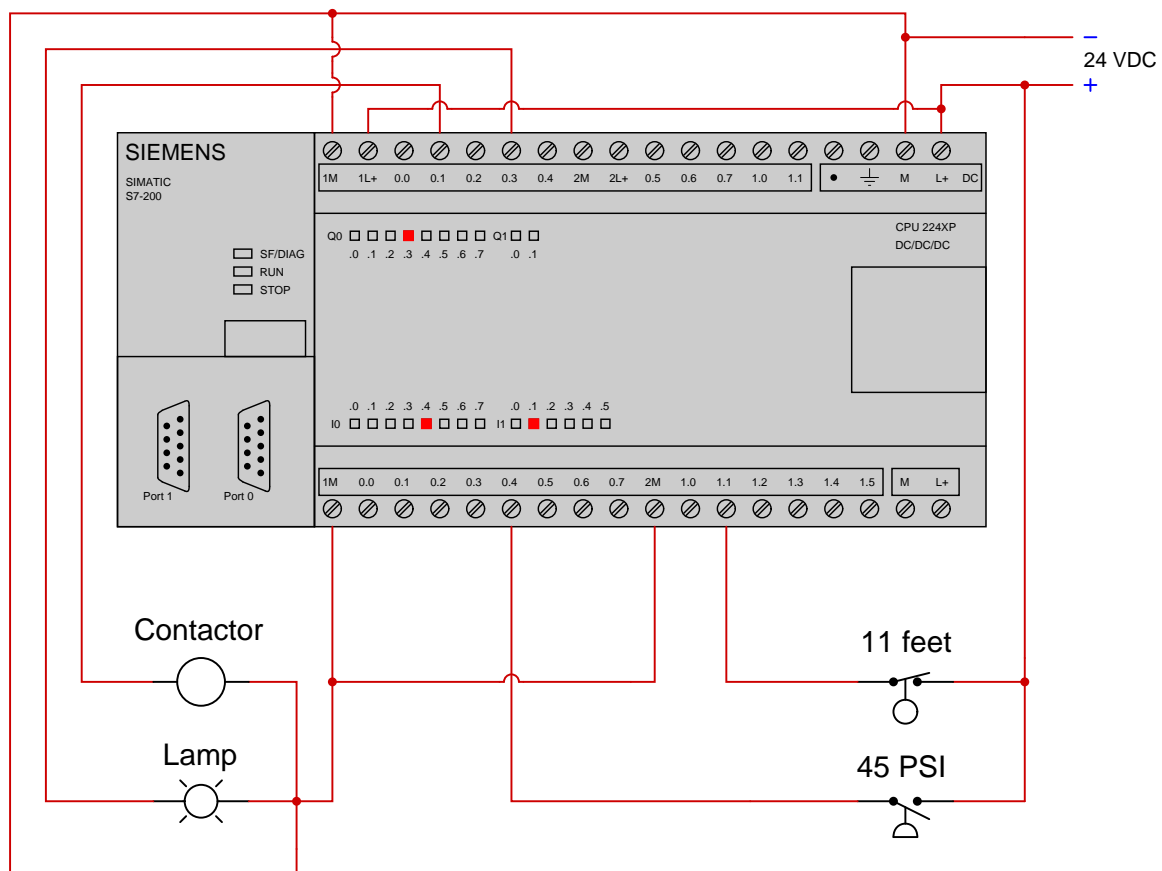
### Suggestions for Socratic discussion

- One useful strategy is to maintain a *journal* of all you've learned in a course of study. Explore ways you could take the work you're already doing to prepare for homework (daily discussions with your instructor) and turn this into a journal or even a weblog ("blog") for your own reflection and eventual use as a portfolio to showcase your capabilities to employers.
- Where exactly are the practice problem worksheets located on the *Socratic Instrumentation* website?
- Peruse the "feedback questions" for this (and/or past) course sections to identify any questions related to areas you would like to strengthen.

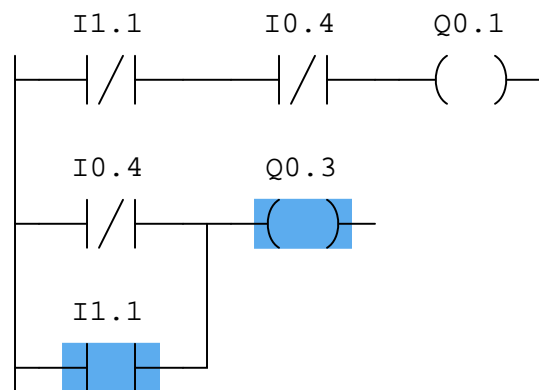
[file i00999](#)

## Question 2

This Siemens S7-200 PLC controls a motor contactor and a lamp from two process switches:



Examine this “live” program display for the PLC (showing colored status highlighting), determining what process condition(s) account for the lamp being energized and the motor not running:

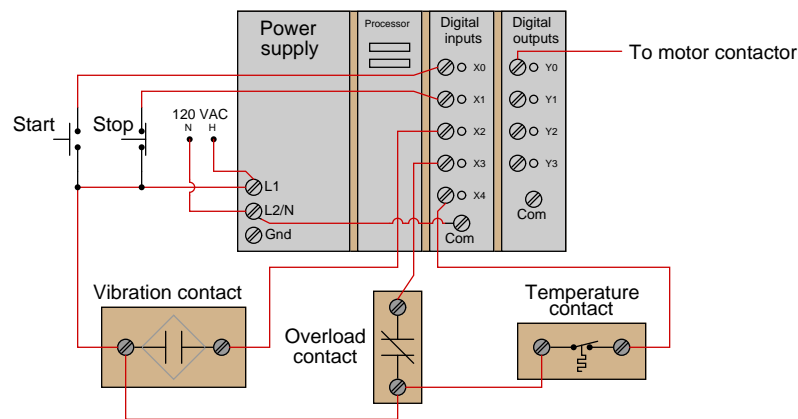


file i04539



### Question 3

This PLC is being used to start and stop an electric motor, and also to shut it down automatically in the event of excessive vibration, overcurrent, or high motor winding temperature:



The status of each shutdown contact is as follows:

- Vibration contact: *open* when good, *closes* when vibration becomes excessive
- Overload contact: *closed* when good, *opens* when overloaded
- Temperature contact: *closed* when good, *opens* when hot

Draw a PLC ladder-logic program to start and stop this motor. Be sure to make the program latching so that the operator does not have to hold the Start button to keep the motor running.

**PLC program**

#### Suggestions for Socratic discussion

- A powerful problem-solving technique is to simplify the problem so that it is easier to solve, then use that solution as a starting point for the final solution of the given (complex) problem. Show how you would first simplify the given problem here, and what that simple(r) solution would look like.
- Explain how you could fool the PLC into “thinking” there was a high-temperature condition when in fact there was not.
- Explain how you could fool the PLC into “thinking” there was a high-vibration condition when in fact there was not.

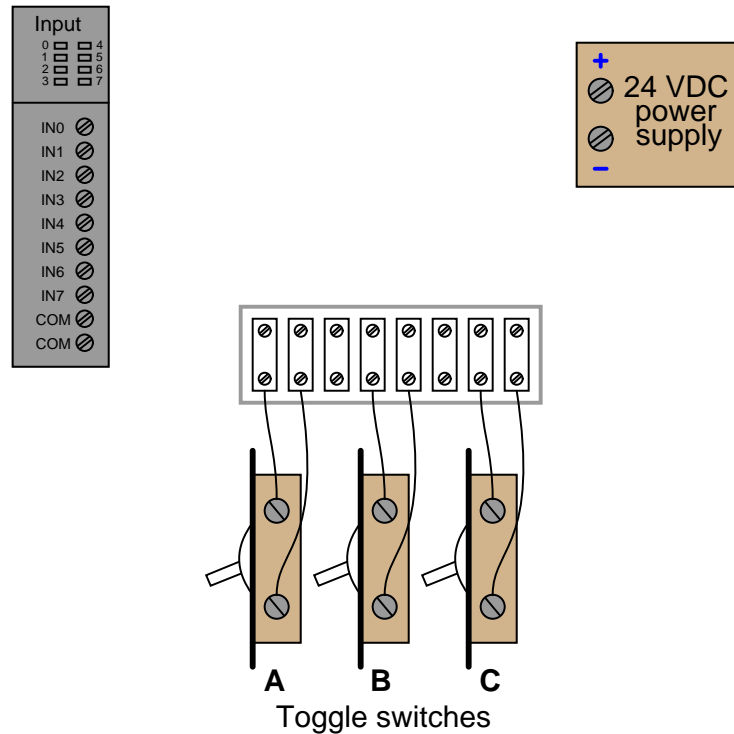
- Explain how you could fool the PLC into “thinking” there was an overload condition at the motor when in fact there was not.

[file i02662](#)

#### Question 4

The Allen-Bradley model 1746-IB8 is an eight-channel discrete (on/off) input module designed for their “SLC” line of programmable logic controllers (PLCs). This particular input module is designed to *sink* DC current originating from a 24 volt power supply (through discrete sensing devices such as pushbutton switches, toggle switches, proximity switches, and process switches). This means the current, traced using conventional flow notation, will be seen to *enter* each respective channel terminal on the input module.

#### Allen-Bradley 1746-IB8 24 VDC "sinking" input module

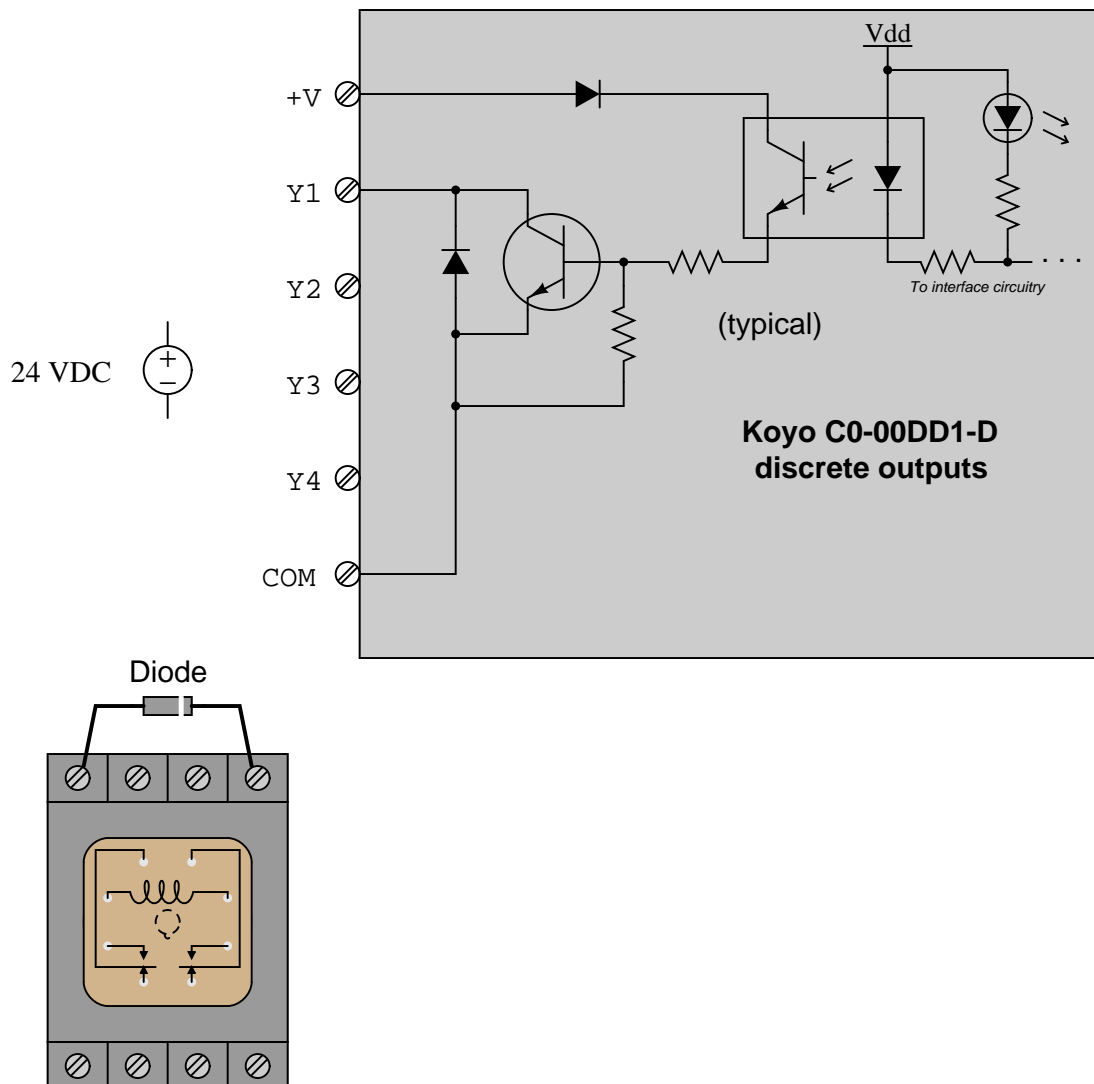


Sketch connecting wires such that the three toggle switches (A, B, and C) connect to input channels IN2, IN5, and IN7, respectively:

[file i03828](#)

### Question 5

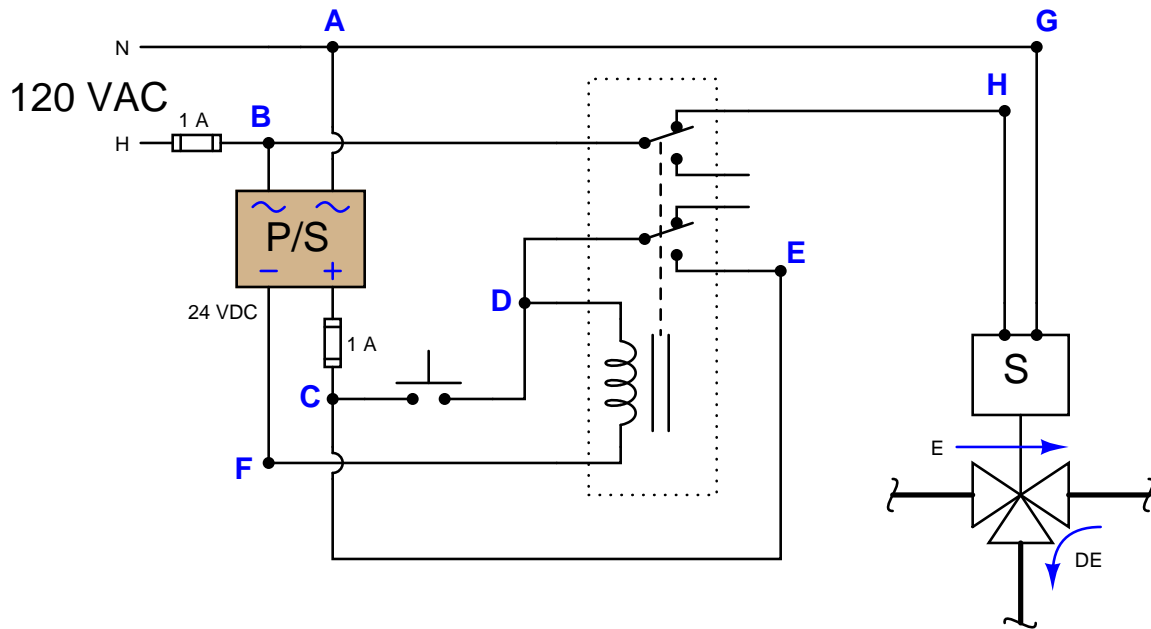
Sketch the wires necessary to connect a relay coil to discrete output channel Y3 of a Koyo “CLICK” PLC model C0-00DD1-D. The internal schematic diagram of the first channel (Y1) is shown as “typical” for channels Y2 through Y4 as well:



Also, identify whether this is a *sinking* or a *sourcing* output PLC.  
[file i04537](#)

# Question 6

Suppose this solenoid control circuit is not working as it should. When the pushbutton is pressed, the solenoid de-energizes as it should. However, the solenoid does not *remain* de-energized as it should when the pushbutton is released – instead, it energizes as soon as the switch is released:



A technician has already taken a DC voltage measurement between points C and E with the pushbutton released and the solenoid energized, and measured 0 volts.

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
Dead power supply		
Relay coil failed open		
Pushbutton switch failed open		
NO contact failed open		
NC contact failed open		
Relay coil failed shorted		
Pushbutton switch failed shorted		
Break in wire between points A and G		
Break in wire between points C and E		
Break in wire between point F and relay coil		

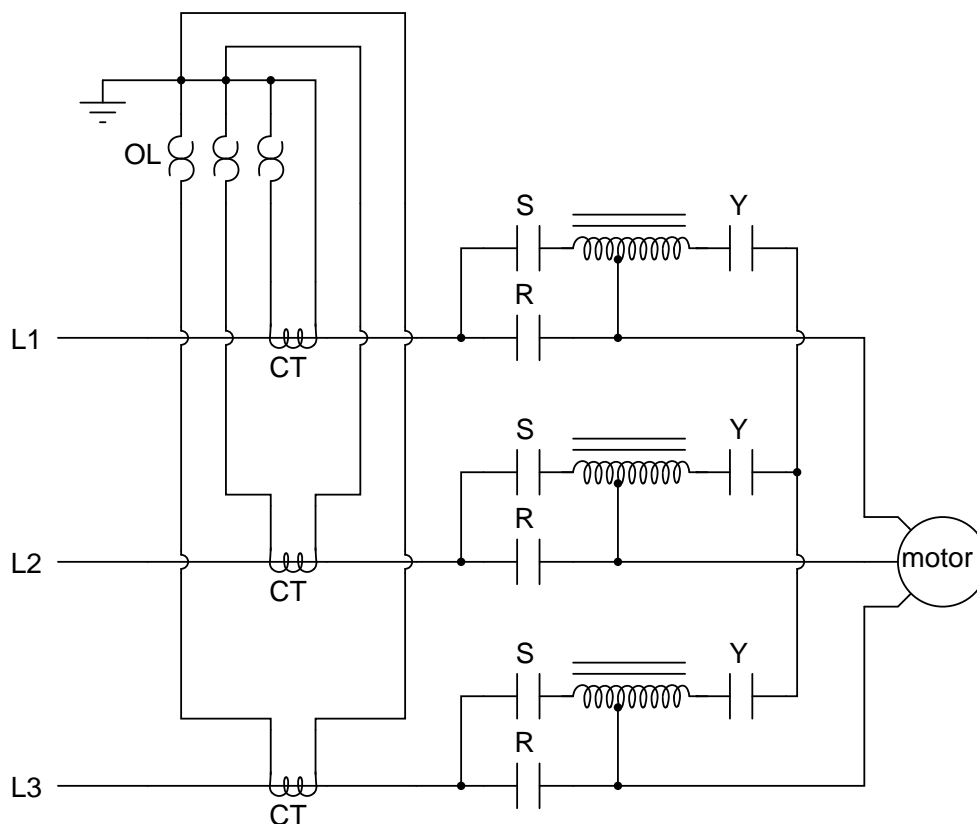
## Suggestions for Socratic discussion

- Identify where to place a *commutating diode* to prevent switch contacts from excessive arcing when de-energizing an inductive load.

[file i04690](#)

### Question 7

There are several different methods of providing *reduced-voltage starting* for electric motors. One of them is the *autotransformer* method. Here is a diagram showing how this works:



“L1,” “L2,” and “L3” represent the three phase power supply conductors. Three sets of contacts (R, S, and Y) serve to connect power to the motor at different times. The starting sequence for the motor is as follows:

1. Motor off (R open, S open, Y open)
2. Start button pressed (S and Y contacts all close)
3. Time delay (depending on the size of the motor)
4. Y contacts open
5. Time delay (depending on the size of the motor)
6. R contacts close, S contacts open

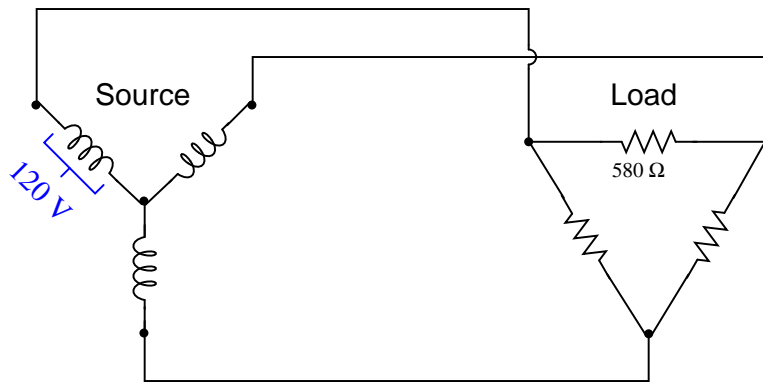
Explain the operation of this system. How do the autotransformers serve to reduce voltage to the electric motor during start-up?

#### Suggestions for Socratic discussion

- A problem-solving technique useful for analyzing circuits is to *re-draw the circuit* in a form that is easier to follow than what is shown to you on the given diagram. Discuss and compare different renderings of this circuit, and how these simplified sketches help you with the analysis.
- Explain the purpose of the devices labeled “CT” in this diagram, and also how the overload heaters adequately function even though they are not in series with the motor conductors.
- Explain how the start-up sequence for this electric motor could be controlled by a PLC.

## Question 8

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



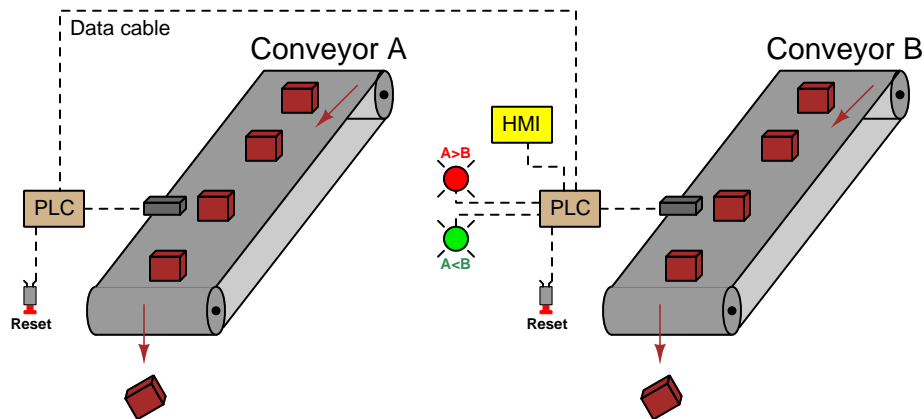
- $E_{line} =$
- $I_{line} =$
- $E_{phase(source)} =$
- $I_{phase(source)} =$
- $E_{phase(load)} =$
- $I_{phase(load)} =$
- $P_{total} =$

<b>Suggestions for Socratic discussion</b>
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- 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 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.

### Programming Challenge and Comparison – Remote object counting/comparison

Suppose we have an application where two PLCs are connected via a network cable. Both PLCs count objects passing by on two separate conveyor belts using their own proximity switches. One of the PLCs needs to energize one of two lamps depending on which conveyor belt passes the most objects, and that same PLC displays both belts' counts on an HMI:



Work individually or in teams to write a PLC program comparing the two conveyor belts' parts counts using network communication instructions. Each PLC needs to have its own dedicated "reset" switch to reset that conveyor's part counter individually. *Note: some PLC models do not support the network communication ability required in this programming challenge. The Allen-Bradley MicroLogix 1000 series A and B PLCs fall into this category, being able to only respond to message queries from other PLCs, not initiate their own queries of other PLCs.*

When your system is complete and tested, capture a screen-shot of the PLC program as it appears on your computer, and prepare to present your program solution to the class in a review session for everyone to see and critique. The purpose of this review session is to see multiple solutions to one problem, explore different programming techniques, and gain experience interpreting PLC programs others have written. When presenting your program (either individually or as a team), prepare to discuss the following points:

- Show how the communication command(s) is set up, including all the relevant parameters such as baud rate, parity bits, stop bits (which must be set identically in the PLC and the other device).
- Identify which Modbus codes were used to read and/or write information with the other device.
- If multiple communication instructions were used in the PLC program, show how you programmed the PLC so these instructions would not interfere with each other (because they are each using the same communications port on the PLC).
- How you designed the program (i.e. what steps you took to go from a concept to a working program)

#### Suggestions for Socratic discussion

- Would you recommend one PLC in this system execute two counter functions (one for each conveyor), or would you recommend each PLC does its own counting? Explain your reasoning!
- If you program your system for duplex communication (i.e. the "master" PLC both reading from and writing to the "slave" PLC), how do you coordinate the communication instructions so that the "read" and "write" instructions happen at different times and never simultaneously?

[file i02493](#)

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## Question 10

Configure a personal computer to act as an ASCII data terminal, receiving ASCII-coded data through a serial port and displaying the alphanumeric characters on the screen. Several “terminal emulator” programs exist for this purpose, perhaps the most common Microsoft Windows-based variant being *Hyperterminal* (this used to be one of the “stock” accessory programs included with Windows installations). Another popular terminal emulator program is *Kermit*. Locate a terminal emulator program, install it on your computer, and create a simple serial-port cable which you may connect between your computer and your PLC for data communications (using the *transmit*, *receive*, and *ground* pins only).

You may wish to test the terminal software and cable by connecting two personal computers together and exchanging messages back and forth using the same software.

<b>Suggestions for Socratic discussion</b>
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- Identify how communication parameters for your terminal emulator program are set (including bit rate, number of data bits, number of stop bits, parity, etc.)
- Which pins on the 9-pin or 25-pin serial connector will you use for transmit, receive, and ground?
- Why is it important to have the computer’s *transmit* pin connected to the PLC’s *receive* pin, and visa versa?



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### Question 11

Write a relay ladder-logic (RLL) program in your PLC that *repeatedly* sends a short ASCII-encoded message to a data terminal (e.g. a personal computer running a terminal emulator program) at 10-second intervals as long as a discrete input channel is energized.

<b>Suggestions for Socratic discussion</b>
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- What is the easiest way to send messages on repeating intervals? If using a timer function, how do you get the timing sequence to repeat itself?

PLC comparison:

- Allen-Bradley Logix 5000: the “ASCII Write” instructions **AWT** and **AWA** may be used to do this. The “ASCII Write Append” instruction (**AWA**) is convenient to use because it may be programmed to automatically insert linefeed and carriage-return commands at the end of a message string.
  - Allen-Bradley SLC 500: the “ASCII Write” instructions **AWT** and **AWA** may be used to do this. The “ASCII Write Append” instruction (**AWA**) is convenient to use because it may be programmed to automatically insert linefeed and carriage-return commands at the end of a message string.
  - Siemens S7-200: the “Transmit” instruction (**XMT**) is useful for this task when used in Freeport mode.
  - Koyo (Automation Direct) DirectLogic: the “Print Message” instruction (**PRINT**) is useful for this task.
- file i03742

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### Question 12

Write a relay ladder-logic (RLL) program in your PLC that increments a counter whenever a discrete input channel is energized, sending an ASCII message to a data terminal showing the counter's current value appended to the end of a text string, like this:

The counter value is:  $X$

(Where  $X$  is the current value of the counter)

#### Suggestions for Socratic discussion

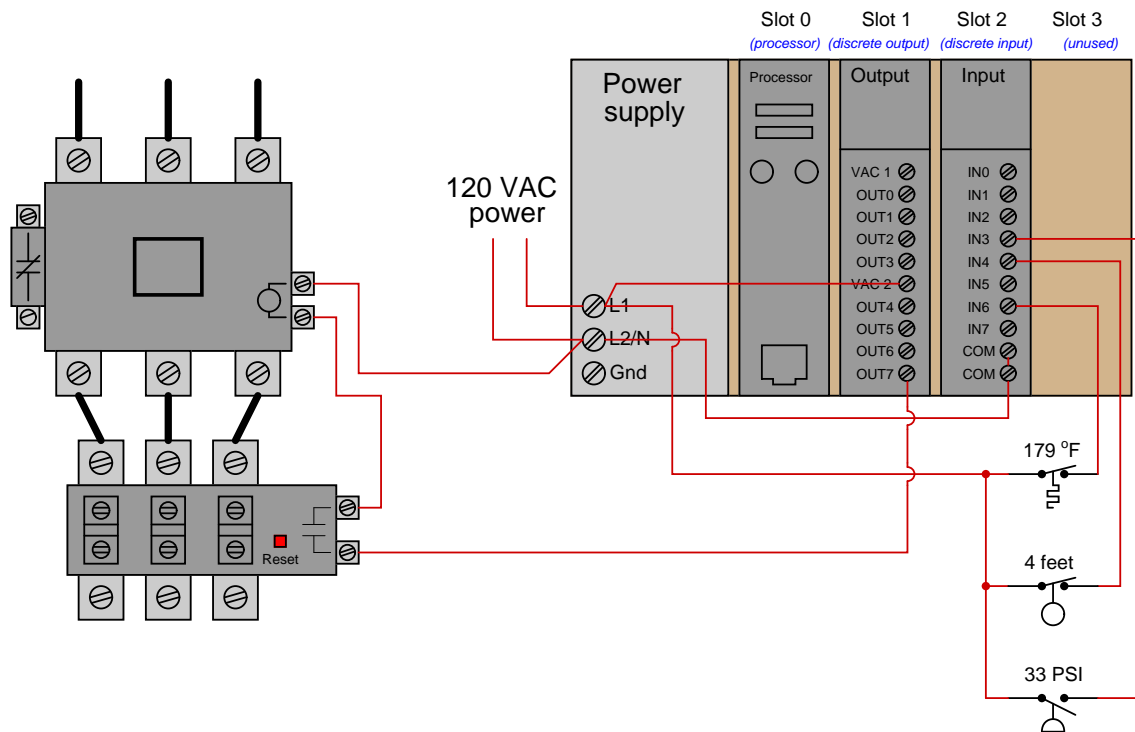
- How do you distinguish the counter's integer count value from the text string when sending the entire ASCII message to the terminal?

PLC comparison:

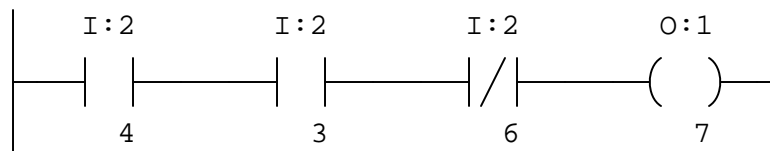
- Allen-Bradley Logix 5000: the “ASCII Write” instructions **AWT** and **AWA** may be used to do this. The “ASCII Write Append” instruction (**AWA**) is convenient to use because it may be programmed to automatically insert linefeed and carriage-return commands at the end of a message string.
  - Allen-Bradley SLC 500: the “ASCII Write” instructions **AWT** and **AWA** may be used to do this. The “ASCII Write Append” instruction (**AWA**) is convenient to use because it may be programmed to automatically insert linefeed and carriage-return commands at the end of a message string.
  - Siemens S7-200: the “Transmit” instruction (**XMT**) is useful for this task when used in Freeport mode.
  - Koyo (Automation Direct) DirectLogic: the “Print Message” instruction (**PRINT**) is useful for this task.
- [file i03745](#)

### Question 13

Suppose we have an Allen-Bradley model “SLC 500” PLC connected to a three process switches and a motor contactor as shown in this illustration:



Suppose the process temperature is 190 °F, the liquid level is 3.2 feet, and the pressure is 40 PSI. An offline view (no status color highlighting shown) of the PLC's program is as follows:



Instead of the motor starting, it remains de-energized. Determine at least three electrical faults that could prevent the motor from starting.

#### Suggestions for Socratic discussion

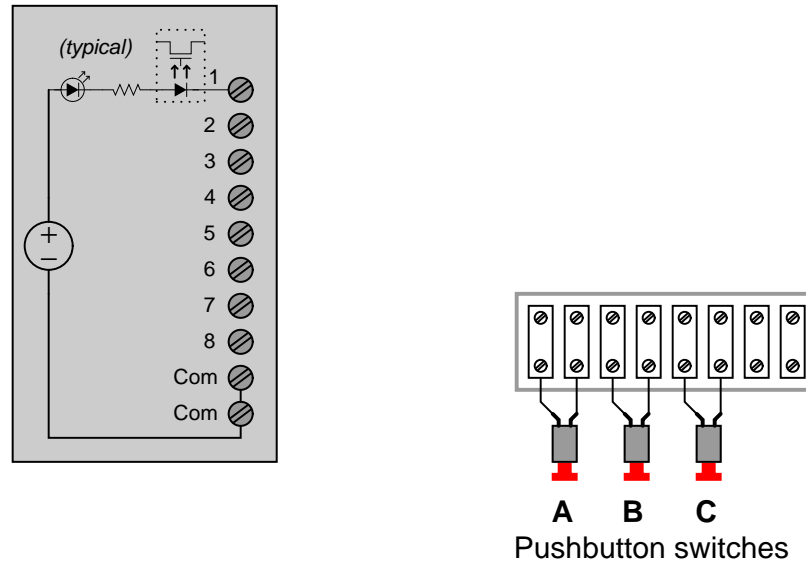
- What diagnostic indications might a technician look for to identify the nature of the problem?

[file i04542](#)

# Question 14

The Emerson “Remote Operations Controller” (ROC) model 809 is a device very similar to a PLC. Its standard discrete input module is shown in the diagram below, with the internal circuitry for channel 1 shown (typical of the other seven discrete input channels on this module):

ROC 809 discrete input module

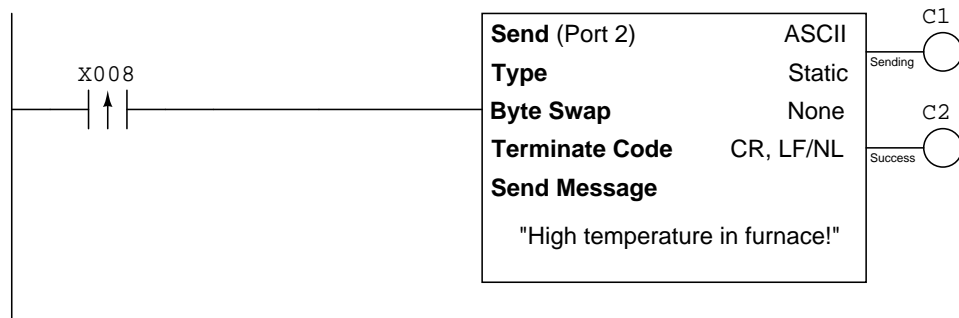


Sketch connecting wires such that the three pushbutton switches (A, B, and C) connect to input channels IN3, IN6, and IN8, respectively.

Also, identify whether this input module *sources* or *sinks* current.  
file i03834

### Question 15

Analyze this relay ladder-logic (RLL) program written for a Koyo CLICK PLC, designed to send an ASCII-encoded text message to a data terminal (e.g. a personal computer running a terminal emulator program, ready to display any text sent to it by the PLC over a serial data cable) whenever an alarm switch detects a high-temperature condition in a furnace:



Answer the following questions about this PLC program:

- Based on what you see here, is the high-temperature alarm switch sending the signal to the PLC electrically *NO* or is it *NC*? Is it even possible to tell, or do we need more information?
- Why is an edge-transition contact instruction used on the **X8** input bit, rather than a normal contact instruction?
- Modify the program so that it will work well without having to use an edge transition contact instruction.
- Modify the program so that it will only send no more than one message per 10 minutes, even if the high-temperature switch keeps tripping and resetting at a frequency faster than that.

[file i03743](#)

**Programming Challenge and Comparison – Modbus communication with a non-PLC device**

Write a PLC program that digitally communicates with a non-PLC device (e.g. a VFD). You will find that Koyo CLICK PLCs with built-in RS-485 communication ports and easy-to-configure Modbus send/receive instructions work exceptionally well for this task, especially when the Modbus register addresses are specified in hexadecimal (rather than decimal). If the device you choose is a variable-frequency motor drive (VFD), recommended functions to perform via the network include starting the motor, stopping the motor, and changing its speed. Your system must incorporate an HMI for user interface (e.g. entering the desired motor speed via the HMI panel).

Note: an essential step of this exercise is properly identifying all electrical connections for the network communication between the PLC and the non-PLC device. Improper network connections will not only fail to work, but they might even damage one or both of the devices! **For this reason, your instructor will inspect all proposed wiring before you make any connections!**

When your system is complete and tested, capture a screen-shot of the PLC program as it appears on your computer, and prepare to present your program solution to the class in a review session for everyone to see and critique. The purpose of this review session is to see multiple solutions to one problem, explore different programming techniques, and gain experience interpreting PLC programs others have written. When presenting your program (either individually or as a team), prepare to discuss the following points:

- Show how the communication command(s) is set up, including all the relevant parameters such as baud rate, parity bits, stop bits (which must be set identically in the PLC and the other device).
- Identify which Modbus codes were used to read and/or write information with the other device.
- If multiple communication instructions were used in the PLC program, show how you programmed the PLC so these instructions would not interfere with each other (because they are each using the same communications port on the PLC).
- How you designed the program (i.e. what steps you took to go from a concept to a working program)

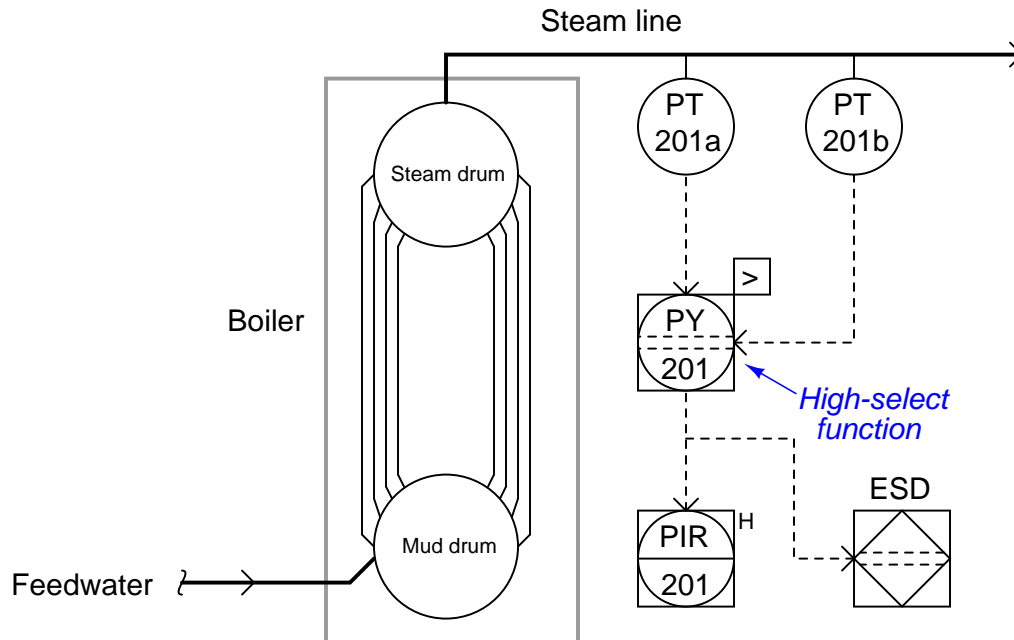
<b>Suggestions for Socratic discussion</b>
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- A powerful problem-solving technique is to simplify the problem so that it is easier to solve, then use that solution as a starting point for the final solution of the given (complex) problem. Show how you would first simplify the given problem here, and what that simple(r) solution would look like.
- Identify the advantages of using digital communications to allow a PLC to read and/or write data with other devices, as opposed to discrete I/O wire connections.

### Programming Challenge – High-select function

A very useful type of function in instrument control systems is a *signal selector*, selecting either the highest or the lowest value among multiple input signals. These signal selector functions are particularly useful in safety control systems for “voting” between the signals of redundant transmitters.

Suppose we had an application where two pressure sensors measured the pressure of steam coming from a boiler, and we wished to know the *greatest* of these two measured pressures in case one of the transmitters were to fail with a low output signal:

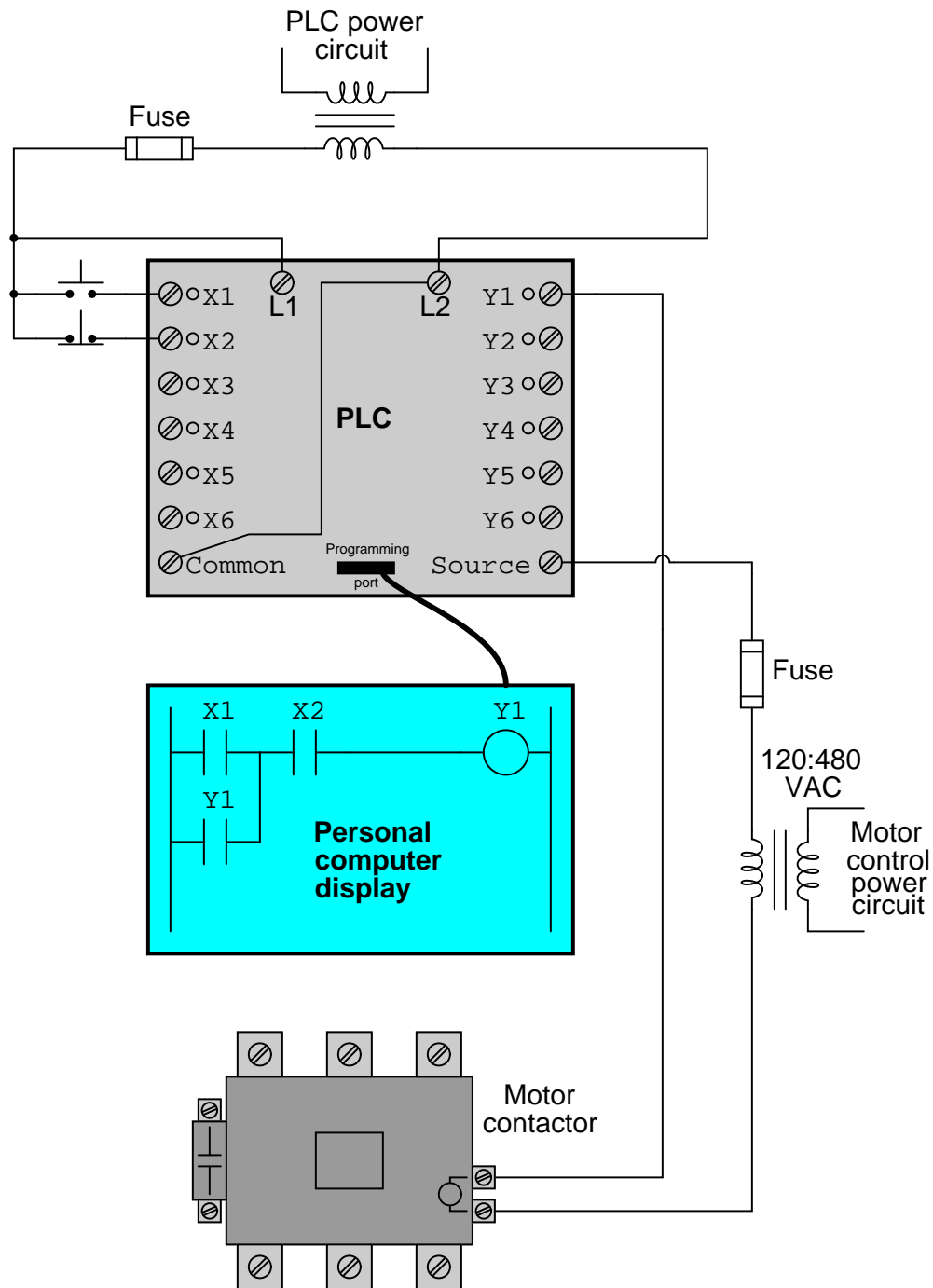


Write a PLC program and corresponding HMI project for a *high-select* function, the HMI displays only one pressure readout, and the PLC selects between the greater of two input values for the HMI to read. Feel free to use a pair of up/down counters to simulate the two analog signals received by redundant transmitters (unless your PLC has two analog input channels, in which case you may input variable voltage signals to simulate the transmitters' readings!).

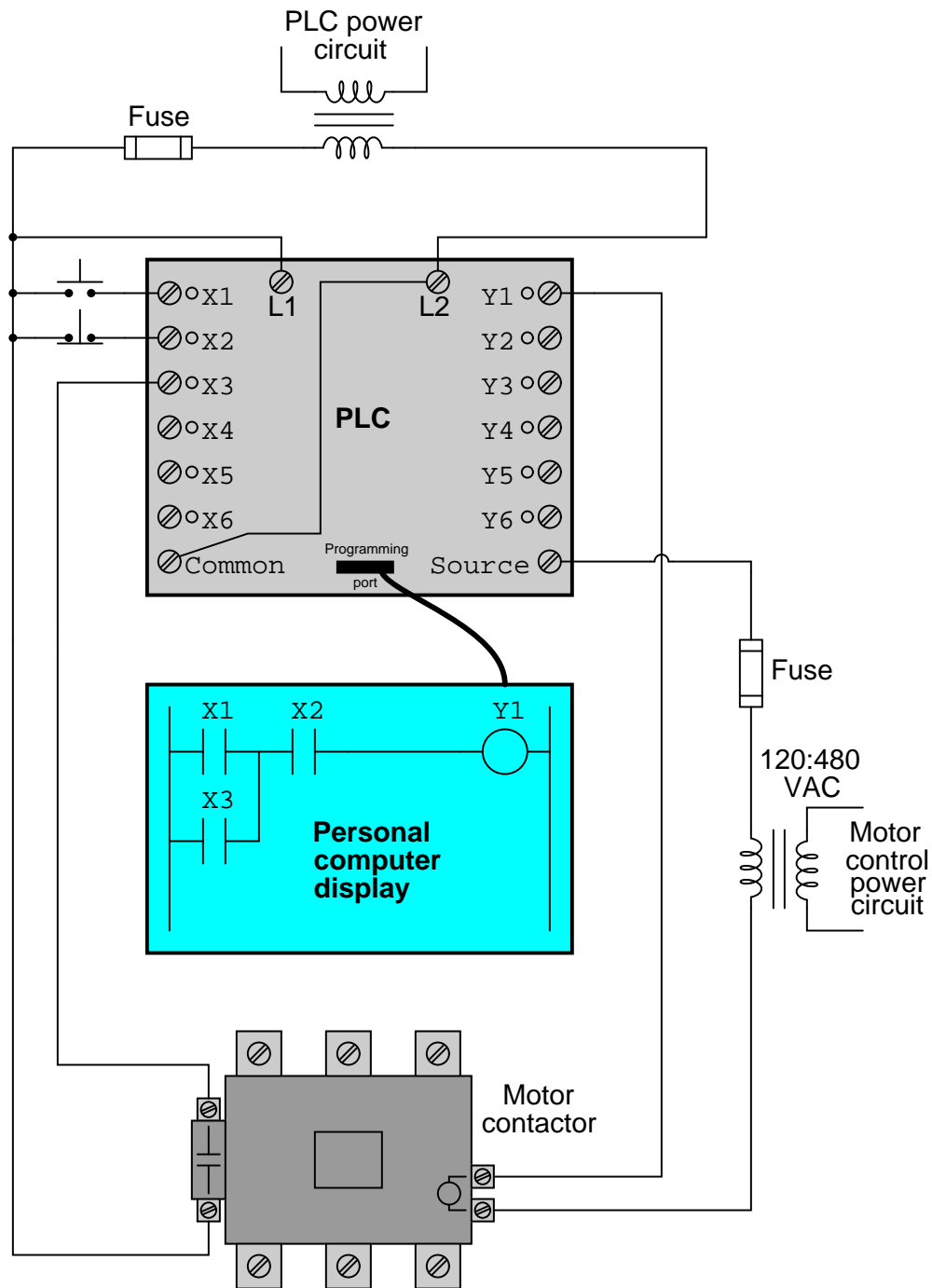
[file i02491](#)

Question 18

Examine these two different PLC-based motor control programs and wiring diagrams:







Under normal operating conditions, these two motor control systems will perform identically. However, they will act differently under abnormal conditions. Identify one such “abnormal” condition that will cause these two systems to act differently, and explain what that difference is.

file i02424

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Question 19

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## Question 20

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## Question 21

Look in the manufacturer's documentation for information on the analog input channel(s) for your PLC. You will need to identify this important information before connecting any signal source to your PLC's analog input!

- What is the absolute maximum voltage that your PLC's analog input can withstand?
- Determine how you may wire a potentiometer to the analog input of your PLC in order to test that input.
- Design a circuit with a potentiometer, where the variable voltage is limited to a value that *cannot* exceed the PLC's analog input rating no matter what position the potentiometer is set to. *Hint: include some fixed-value resistors in the potentiometer circuit!*
- Identify the "full count" number value produced by the PLC's analog-to-digital converter (ADC) when it is receiving a maximum-scale voltage signal.
- Identify which register in the PLC's memory this "count" value is written to, and what format it is in (e.g. signed integer, floating-point, etc.).

If your PLC does not have any analog input channels, you will need to partner with a classmate whose PLC does have analog inputs.

[file i02545](#)

**Programming Challenge and Comparison – analog input scaling**

Work individually or in teams to wire and configure a PLC’s analog input to receive a variable voltage signal from a potentiometer, and then display that signal in three different forms on an HMI screen:

- Raw “count” value (directly read from the PLC’s input register)
- Scaled 0.0% to 100.0% (as a fixed-point integer value)
- Scaled 0.000% to 100.000% (as a floating-point value)

One important point of caution is to ensure you do not “over-voltage” the input of your PLC. Some PLCs have rather limited voltage measurement ranges on their analog input terminals, and may actually suffer *irreparable damage* if you exceed the voltage limit. If this is the case (e.g. the PLC can tolerate a maximum of 10 volts to the analog input, but the only DC power supply you have for powering the potentiometer is 24 volts), you must include a fixed-value resistor in the potentiometer circuit in order to limit its full output voltage to an acceptable level.

Another note of caution is to ensure the potentiometer has a sufficient power rating to withstand the supply voltage. For example, connecting a 1 k $\Omega$ ,  $\frac{1}{2}$  watt potentiometer directly across a 24 VDC power supply is a recipe for smoke!

You are encouraged to consult with your instructor before powering the circuit up, to make sure the PLC’s analog input will not be damaged by excessive voltage from the potentiometer. Show the sketch of your circuit as well as all relevant calculations, to prove that no ratings will be exceeded when powered.

After you’ve got the voltage limit and wiring figured out for the analog input, you should be able to turn the potentiometer throughout its full range and note the changing number in the PLC’s input register for that analog input. Often, this is a “raw count” value based on the number of bits in the input register, proportional to the input voltage but not actually scaled in volts. Your next step will be to use math instructions in the PLC program to “scale” this raw analog input value into 0-100% to be displayed on the HMI screen. Floating-point (“real”) values are easy to use if your PLC supports them. Fixed-point notation uses integer values multiplied by some power of ten: for example, 0 to 100% of range might be represented within the PLC as an integer number ranging 0 to 10000, with the HMI forcing a decimal point so that 10000 is displayed as 100.00 instead.

PLC comparison:

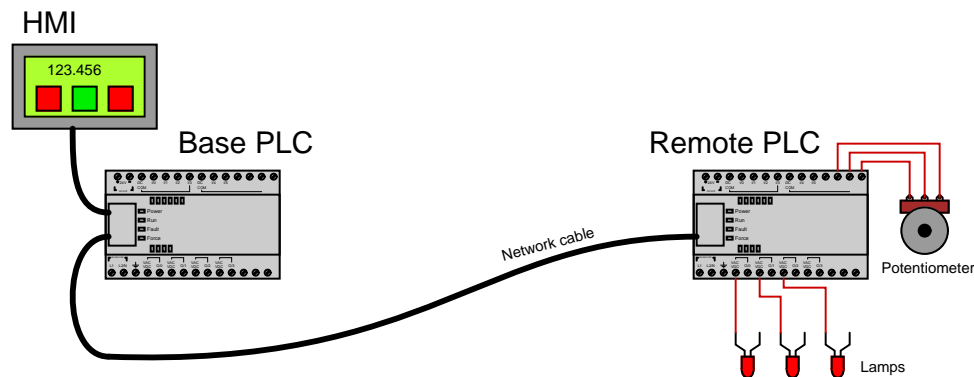
- Allen-Bradley Logix 5000: the I/O configuration menu (specifically, the *Module Properties* window) allows you to directly and easily scale analog input signal ranges into any arbitrary numerical range desired. Floating-point (“REAL”) format is standard, but integer format may be chosen for faster processing of the analog signal.
- Allen-Bradley PLC-5, SLC 500, and MicroLogix: raw analog input values are 16-bit signed integers. The SCL and SCP instructions are custom-made for scaling these raw integer ADC count values into ranges of your choosing.
- Siemens S7-200: raw analog input values are 16-bit signed integers. Interestingly, the S7-200 PLC provides built-in potentiometers assigned to special word registers (SMB28 and SMB29) with an 8-bit (0-255 count) range. These values may be used for any suitable purpose, including combination with the raw analog input register values in order to provide mechanical calibration adjustments for the analog input(s).
- Koyo (Automation Direct) DirectLogic: you must use standard math instructions (e.g. ADD, MUL) to implement a  $y = mx + b$  linear equation for scaling purposes.
- Koyo (Automation Direct) CLICK: the I/O configuration menu allows you to directly and easily scale analog input signal ranges into any arbitrary numerical range desired.



### Programming Challenge and Comparison – build a simple SCADA system

“SCADA” is an acronym meaning “Supervisory Control And Data Acquisition”, referring to control systems where remote units relay data to and from a central location, allowing human operators to monitor and control processes spread over a wide area. The term “SCADA” is broadly applied to many different types of control systems in industry. Traditionally the term has been limited to control systems spread over a wide geographic area (e.g. power distribution systems, pipeline control systems) but it is now common to see “SCADA” used to describe *any* form of computer-based control system where process data is communicated over a digital network.

Work individually or in teams to wire and configure multiple PLC’s to form a simple SCADA system, where analog data is read by a “remote” PLC and displayed by an HMI panel connected to a “base” PLC, and where virtual pushbuttons on the HMI display cause discrete outputs on the remote PLC to turn on and off.



When the potentiometer at the remote PLC is adjusted, the HMI at the base PLC should display a changing value. When buttons on the HMI screen are toggled, indicator lamps at the remote PLC should turn on and off. Feel free to include the following additional features for more fun and challenge:

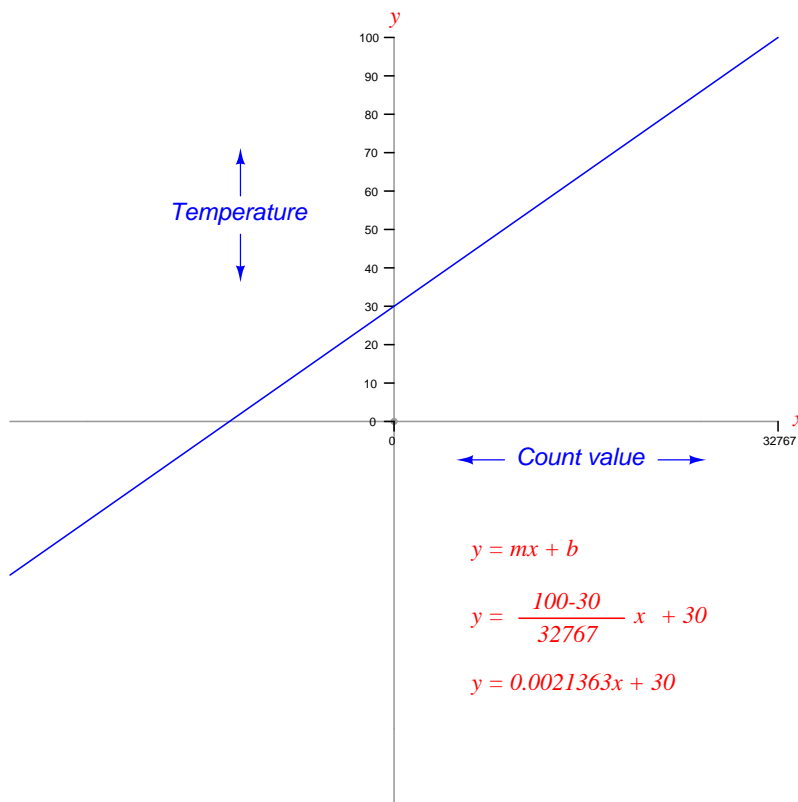
- Build a “trend graph” display on the HMI instead of a simple numerical indicator for the analog input data point
- Have discrete inputs at the remote PLC register on the HMI display as graphic indicators
- Incorporate features such as input timers, event counts, etc. in the remote PLC
- Add multiple remote PLCs (use multi-drop RS-485 serial data communication, or Ethernet communication with a multi-port hub to connect the PLCs together)

Successful completion of this system will require the use of analog scaling instructions as well as network messaging instructions. All the usual caveats apply – *have fun!*

### Programming Challenge – analog input scaling using math instructions

When any PLC receives an analog voltage or current signal from some device (such as a sensor or a potentiometer), the number value generated by the PLC's analog-to-digital converter (ADC) will be proportional to that signal, but not identical to it. For example, a PLC receiving a 5.00 volt DC signal may yield an ADC "count" value of 32,767 (equivalent to the binary number 0111111111111111). Usually the DC signal represents some physical measurement, such as machine position, temperature, pressure, speed, etc. Our desire is to have the PLC "scale" the ADC count value into a number range representing that real-world quantity, which means we must program the PLC to mathematically manipulate the ADC's count value into a number range more meaningful to us.

A common method for doing this is to program the PLC to evaluate a linear equation of the form  $y = mx + b$ , where  $x$  is the raw ADC count value and  $y$  is the scaled quantity the analog signal represents. For instance, if our PLC receives an analog voltage signal ranging 0 to 5.00 volts, converting that voltage into a count value ranging 0 to 32,767, that voltage in turn representing the temperature detected by a sensor over an equivalent temperature range of 30 degrees to 100 degrees Fahrenheit, we may sketch a linear graph of the count-to-temperature relationship and develop a linear equation expressing it:



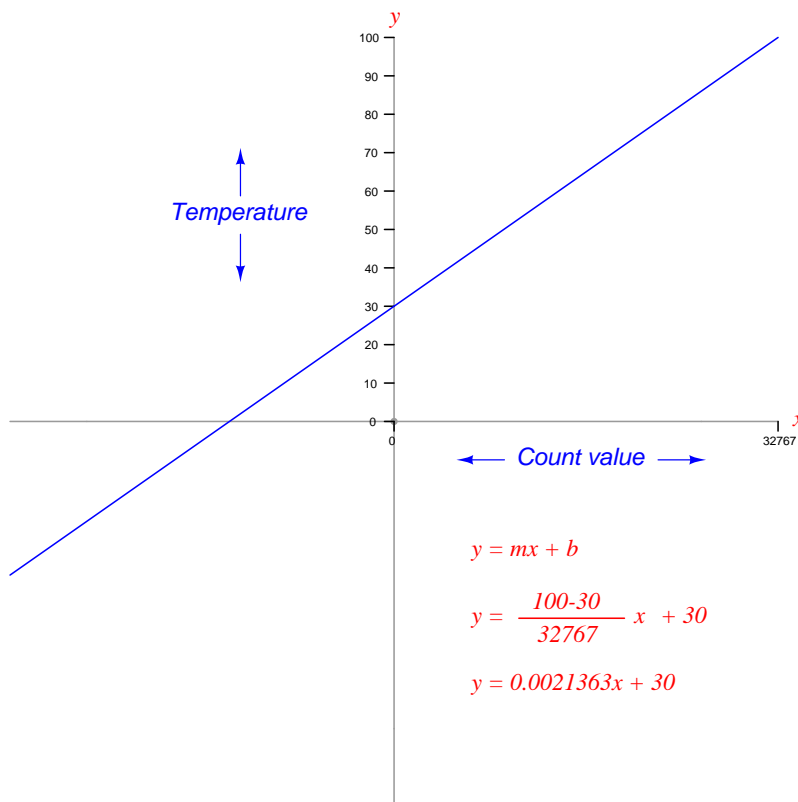
Program your PLC to convert the full range of the analog input count value into a 30 to 100 degree Fahrenheit scaled temperature value, using only simple math instructions (e.g. multiplication, division, addition, subtraction). Note that you must derive your own custom  $y = mx + b$  equation for your PLC, because the ADC count value range will likely not be 0 to 32,767 as it was in this example.

[file i02546](#)

**Programming Challenge – analog input scaling using SCP and SCL scaling instructions**

When any PLC receives an analog voltage or current signal from some device (such as a sensor or a potentiometer), the number value generated by the PLC's analog-to-digital converter (ADC) will be proportional to that signal, but not identical to it. For example, a PLC receiving a 5.00 volt DC signal may yield an ADC "count" value of 32,767 (equivalent to the binary number 0111111111111111). Usually the DC signal represents some physical measurement, such as machine position, temperature, pressure, speed, etc. Our desire is to have the PLC "scale" the ADC count value into a number range representing that real-world quantity, which means we must program the PLC to mathematically manipulate the ADC's count value into a number range more meaningful to us.

A common method for doing this is to program the PLC to evaluate a linear equation of the form  $y = mx + b$ , where  $x$  is the raw ADC count value and  $y$  is the scaled quantity the analog signal represents. For instance, if our PLC receives an analog voltage signal ranging 0 to 5.00 volts, converting that voltage into a count value ranging 0 to 32,767, that voltage in turn representing the temperature detected by a sensor over an equivalent temperature range of 30 degrees to 100 degrees Fahrenheit, we may sketch a linear graph of the count-to-temperature relationship and develop a linear equation expressing it:



Program an Allen-Bradley PLC to convert the full range of the analog input count value into a 30 to 100 degree Fahrenheit scaled temperature value, using the SCP instruction, and again using the SCL instruction. Note that you must derive your own custom  $y = mx + b$  equation for your PLC, because the ADC count value range will likely not be 0 to 32767 as it was in this example.

[file i02547](#)

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**Question 26**

Write a minimized (simplest form) Boolean expression for the logic function represented by this truth table, and then sketch both a binary (gate) logic diagram and a ladder logic diagram to implement your simplified Boolean expression:

Input A	Input B	Input C	Output
0	0	0	0
0	0	1	0
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	0
1	1	0	1
1	1	1	0

[file i02337](#)

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**Question 27**

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**Question 28**

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**Question 29**

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**Question 30**

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**Question 31**

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**Question 32**

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**Question 33**

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**Question 34**

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**Question 35**

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**Question 36**

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**Question 37**

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**Question 38**

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**Question 39**

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**Question 40**

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**Question 41**

Identify a few of the “function codes” specified within the *Modbus* standard used to read and write data between industrial devices, and provide the appropriate Modbus address ranges for each of the function codes you list.

[file i02384](#)



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Question 42

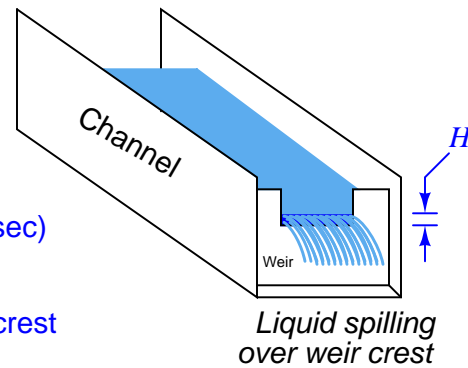
The flow rate of liquid spilling over a *rectangular weir* may be calculated by the height of that liquid over the weir by the following formula:

$$Q = 3.33 (L - 0.2H)H^{1.5}$$

$Q$  = Flow rate (cubic feet/sec)

$L$  = Width of crest (feet)

$H$  = Height of water over crest

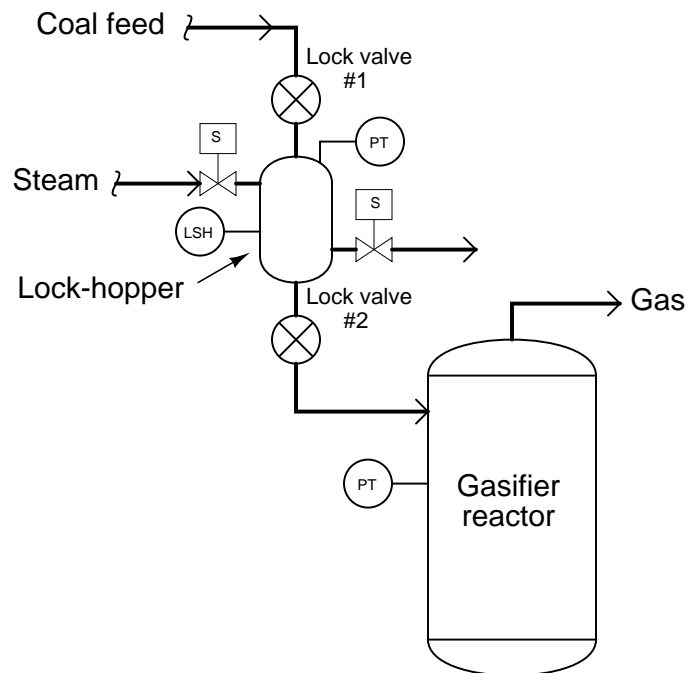


A technician tries to program a PLC to evaluate this formula so that the PLC may continuously calculate flow rate from measured liquid height, but the PLC program keeps “faulting” due to its inability to handle fractional exponents (the “1.5” power in the formula).

Find a way for the PLC to evaluate this equation using nothing but integer-value exponents.

### Question 43

A PLC is used to sequence the operation of a *lock hopper* used to feed pulverized coal into a gasification reactor where the coal is heated to release flammable gases useful as fuels. Many details on the reactor have been omitted from this diagram for simplicity:



The purpose of the “lock hopper” is to prepare a charge of coal for injection into the reactor while maintaining gas pressure in the reactor (i.e. not letting the flammable coal gases escape) and also not letting any air into the reactor where it could support an explosion.

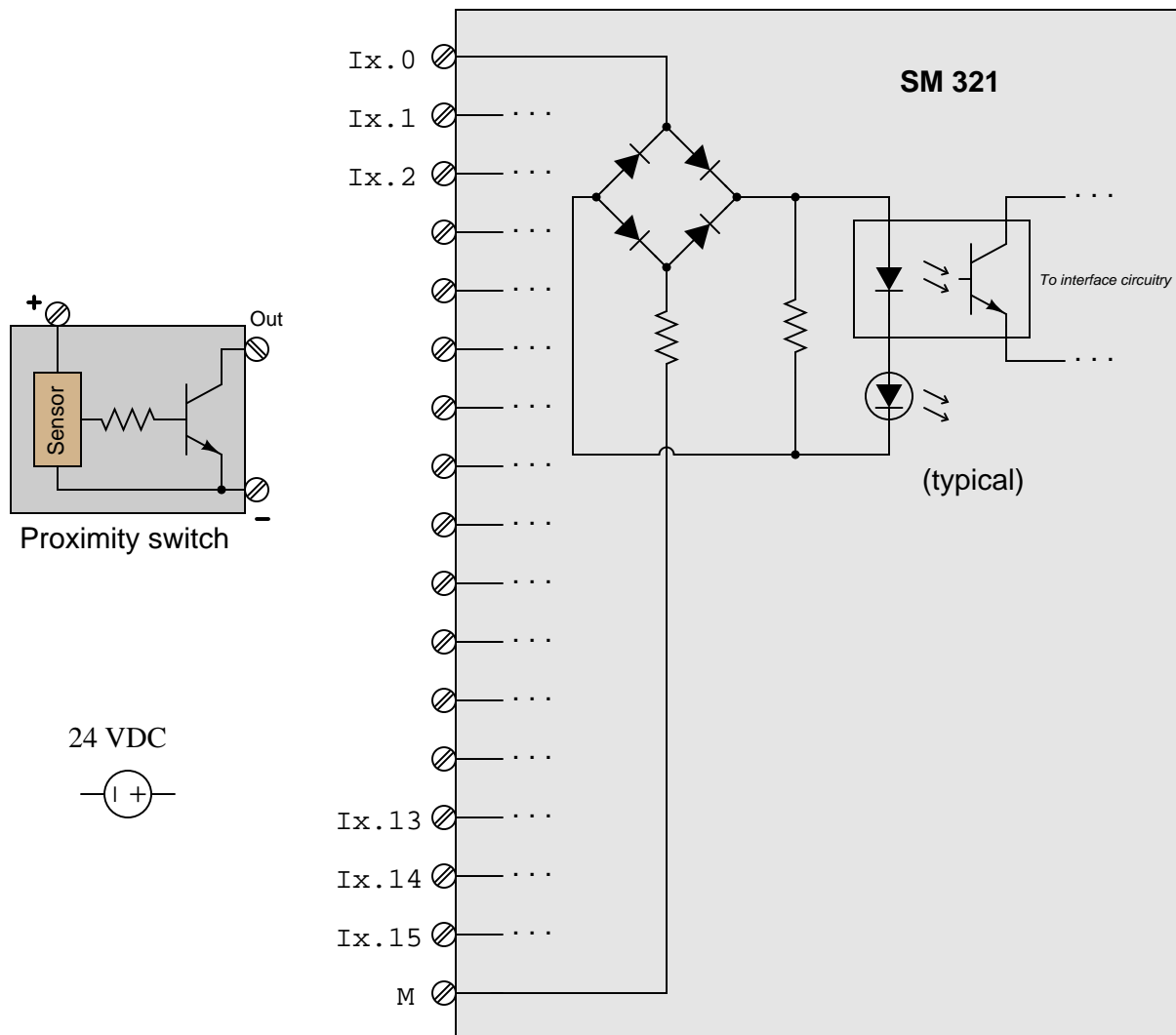
The basic sequence of the lock hopper is as follows: (1) wait for command signal from production control system to inject more coal into gasifier reactor; (2) wait for proof of valve #2 closure, then open lock valve #1 to introduce coal into lock hopper vessel; (3) wait for high level switch (LSH) to trip, then close lock valve #1; (4) wait for proof of valve #1 closure, then open steam inlet and outlet valves to purge lock-hopper of air for a set time period; (5) close steam outlet valve to allow lock-hopper to pressurize until its pressure is equal to the pressure measured inside the gasifier reactor; (6) open lock valve #2 for a set time period; (7) close steam inlet valve and close lock valve #2.

Suppose one day the proof-of-closure switch on lock valve #2 fails in such a way that it reports the valve as being open all the time even when it is closed tight. Explain how this switch failure will affect the operation of the lock hopper as controlled by the PLC.

Furthermore, suppose an instrument technician is called to investigate this problem, and decides to fix it by “forcing” the input bit of the PLC so that it sees the lock valve #2 as being closed despite the broken switch’s status. This allows the process to continue running while the technician then repairs the switch. Explain why this might not be a good way to proceed, and be specific in your answer!

# Question 44

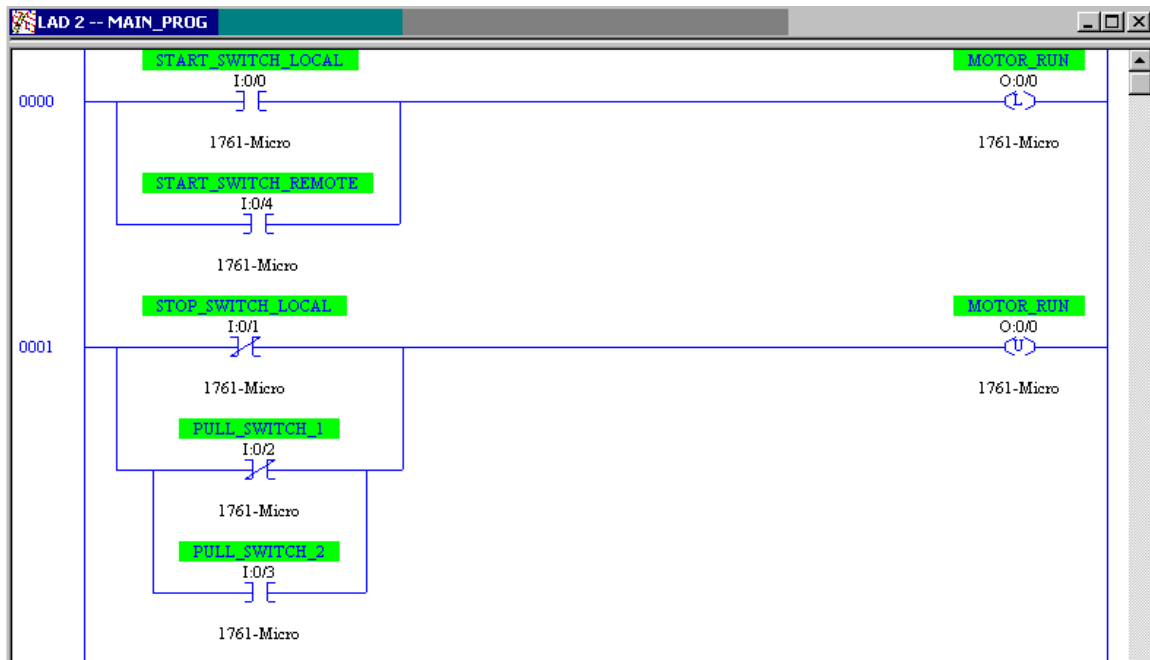
Sketch the wires necessary to connect a solid-state proximity switch to input channel Ix.8 of a Siemens SM 321 discrete input card (model 6ES7321-1BP00-0AA0). The internal schematic diagram of the first channel (Ix.0) is shown as “typical” for all the channels:



Also, identify whether this is a *sinking* or a *sourcing* proximity switch, and sketch the directions of all currents through your sketched wires.

### Question 45

Examine this ladder logic program for an Allen-Bradley MicroLogix PLC controlling a motor, with multiple “Start,” “Stop,” and safety pull-switch shutdowns:



Based on this program, determine the necessary type of hard-wired switch contact for each input switch:

- START\_SWITCH\_LOCAL: *normally-open* (NO) or *normally-closed* (NC)?
- START\_SWITCH\_REMOTE: *normally-open* (NO) or *normally-closed* (NC)?
- STOP\_SWITCH\_LOCAL: *normally-open* (NO) or *normally-closed* (NC)?
- PULL\_SWITCH\_1: *normally-open* (NO) or *normally-closed* (NC)?
- PULL\_SWITCH\_2: *normally-open* (NO) or *normally-closed* (NC)?

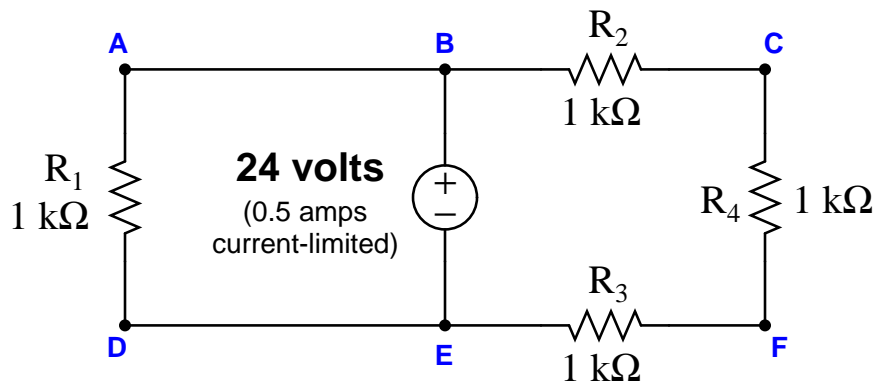
Also, identify at least two different faults independently capable of preventing the motor from starting up despite attempts actuating the local start switch *and* actuating the remote start switch:

- 
- 

file i03854

Question 46

Suppose a voltmeter registers 0 volts between test points **A** and **E** in this 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.

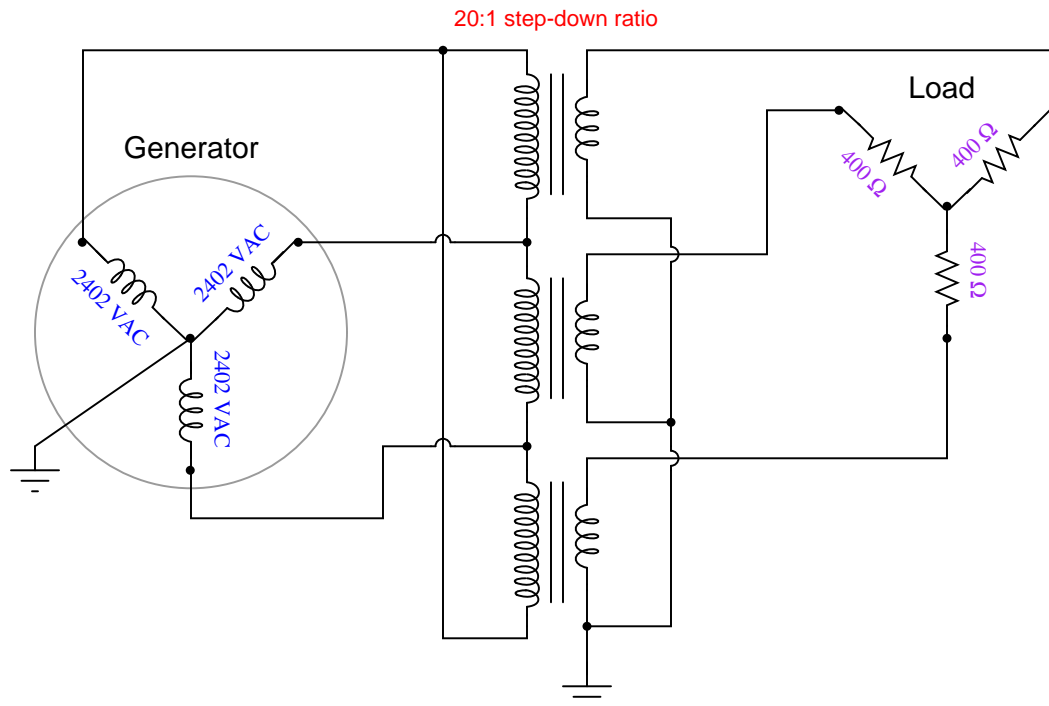
Fault	Possible	Impossible
$R_1$ failed open		
$R_2$ failed open		
$R_3$ failed open		
$R_4$ failed open		
$R_1$ failed shorted		
$R_2$ failed shorted		
$R_3$ failed shorted		
$R_4$ failed shorted		
Voltage source dead		

This question is typical of those in the “Fault Analysis of Simple Circuits” worksheet found in the *Socratic Instrumentation* practice worksheet collection, 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 i04520](#)

Question 47

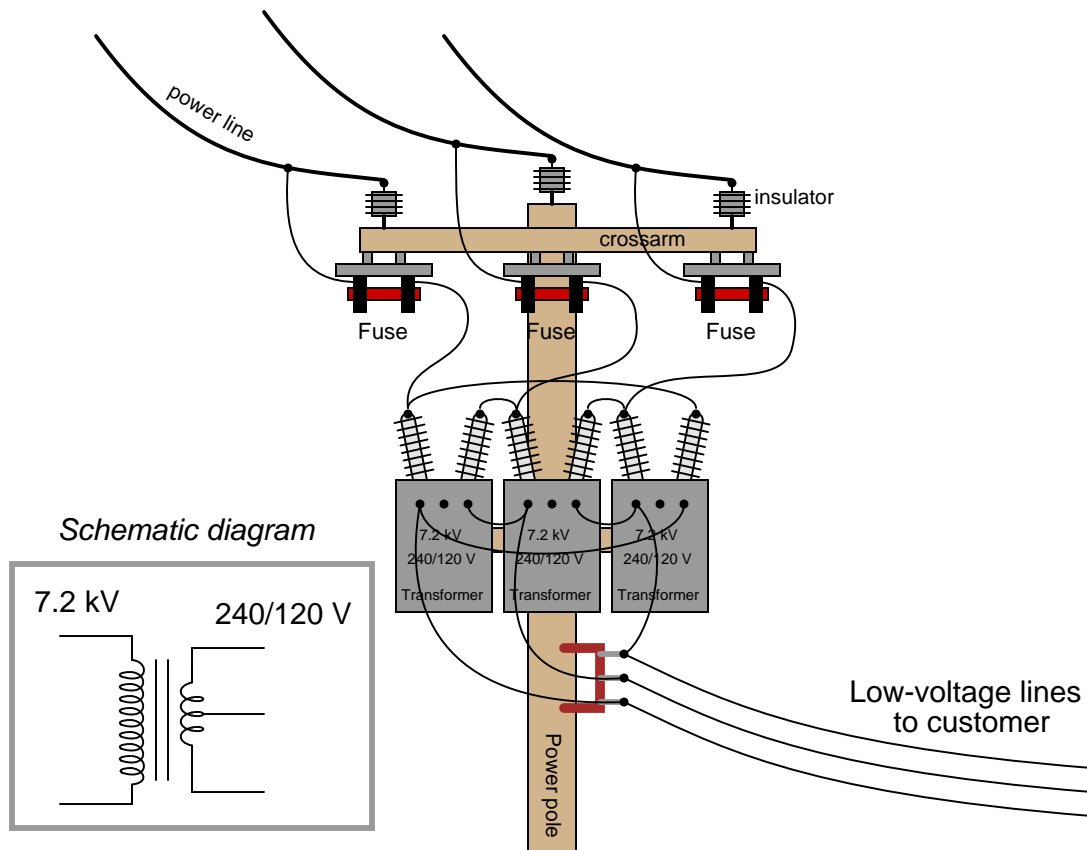
Calculate the following parameters in this three-phase (balanced) AC power system:



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

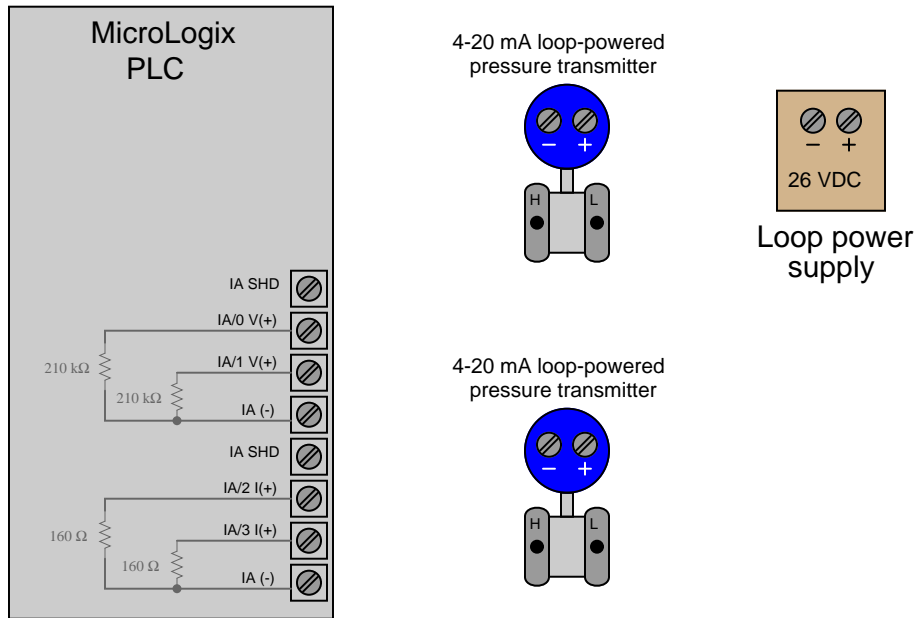
Question 48

Examine the primary and secondary connections on this three-phase transformer bank, and then determine the line voltage to the customer, assuming 7.2 kV line voltage on the distribution power lines. The schematic diagram shown in the grey box is typical for each of the three transformers:



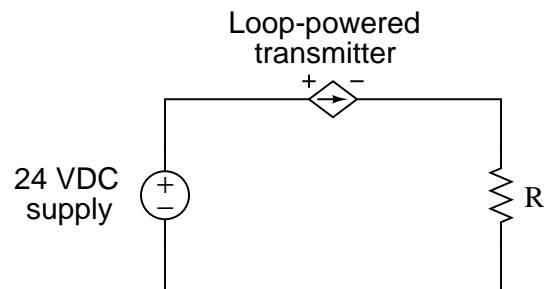
# Question 49

The Rockwell/Allen-Bradley MicroLogix 1000 programmable logic controller (PLC) can handle up to four analog input signals: two with a 0-10 V maximum range and two with a 0-20 mA maximum signal range. This PLC's analog input terminal block looks like this (the internal resistors are shown inside the PLC box):



Sketch the appropriate wiring to connect one of these loop-powered transmitters to a voltage input and the other to a current input (IA/0 and IA/2) on the PLC. Sketch a precision resistor in the appropriate location to convert the first transmitter's 4-20 mA current signal into a 1-5 V voltage signal appropriate for the voltage input channel.

A schematic diagram showing the general connection scheme for a loop-powered 4-20 mA transmitter is shown here. The transmitter acts as a *current regulator* to establish circuit current at a value depending on the physical variable being measured (e.g. pressure, temperature, level, flow, etc.):



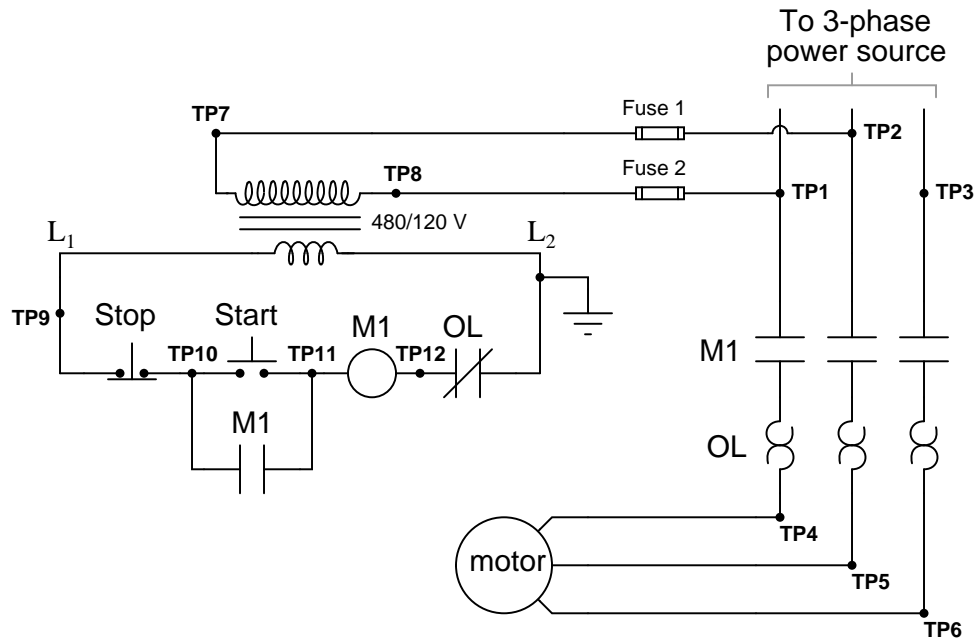
Note: the two “IA SHD” terminals are provided for cable shield conductor attachment. You may ignore cable shield wires and these terminals for simplicity's sake.

[file i04522](#)



# Question 50

The following motor control “bucket” has a problem. When the “Start” button is pressed, the motor refuses to start:



Using your digital voltmeter, you measure 54 volts AC between TP11 and Ground when the “Start” switch is pressed, but 0 volts between the same points when the switch is released. From this information, identify two possible faults (either one of which could account for the problem and all measured values in this circuit). The circuit elements you identify as possibly faulted can be wires, traces, and connections as well as components. Be as specific as you can in your answers, identifying both the circuit element and the type of fault.

- Circuit elements that are possibly faulted
  - 1.
  - 2.

Also, explain why a bad (open) connection between L2 and chassis ground would *not* account for this circuit’s problem.

**Lab Exercise – introduction**

Your team's task is to configure an HMI (Human-Machine Interface) for a system controlled by a PLC, as well as add a discrete electrical load and a three-pole contactor (energized by one of the PLC's discrete outputs) to the system. The HMI you choose to configure shall allow operator access to (at minimum) discrete input data points, discrete output data points, and either counter or timer instructions. Project ideas include:

- Air compressor control, with high and low air pressure switches
- Water sump pump control, with high and low water level switches
- Other alternatives? *Must be pre-approved by instructor!*

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 <i>first!</i> )	mastery	–	–	–	–	
Circuit design challenge	mastery					– – – –
Final tagname database for HMI	mastery	–	–	–	–	
Final wiring diagram and system inspection	mastery					– – – –
Demonstration of working system	mastery	–	–	–	–	
Final PLC program inspection	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	–	–	–	–	
Team tool locker inspection	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).

**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 and prototype sketch

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.

For example, if you intend to connect field devices to a PLC (Programmable Logic Controller), your prototype sketch must show how those devices will connect to typical input/output terminals on the PLC, where electrical power will be supplied, the placement of all overcurrent protection devices (e.g. fuses) and their current ratings, etc. Prototype sketches need not show all intermediary connections between components, such as terminal blocks in junction boxes between the field device and the controller.

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 a three-pole contactor to include in this project, choose one with a coil compatible with the discrete outputs of your PLC. If your PLC’s discrete outputs are a mis-match for the contactor coil, you will need to install an *interposing relay* to convert the PLC’s DC output control signal into a driving signal suitable for the contactor (e.g. a relay interposing between a PLC with 24 VDC discrete outputs and a contactor with a 120 VAC rated coil, or a relay interposing between a PLC with a 100 mA rated discrete output and a contactor coil drawing 500 mA).

PLC equipment manuals always provide sample diagrams showing how external components may connect to the I/O points. Feel free to use these sample diagrams as templates for your prototype sketch. *This is the most challenging portion of your wiring, so be sure to work with your teammates to get this right!*

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

### Lab Exercise – planning the interface

An essential step in programming an HMI panel is to define the list of *tagnames* and *data types* the HMI will need to reference in order to fulfill its function. While this seems like something that may be done while in the process of programming the HMI's graphical display objects, it is actually best done *before* any HMI programming is done at all. Listing all the signals and variables the HMI will need to reference within the PLC it connects to as a first step helps ensure that the naming convention you choose for these tags make sense in the grand scheme of the system design, rather than being ad-hoc in nature. Well-named tags go a long way to making the HMI easier to understand and update in the future. It also helps identify changes that may need to be made to the PLC program to provide the HMI with all the data it will need.

The next step should be finding appropriate documentation for your HMI. You may locate this on the HMI manufacturer's website. Use this documentation to identify how to properly wire, power, and program the HMI display unit.

**Planning the interface 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

Your instructor will randomly select one motor control or discrete sensing device and one brand/model of PLC I/O from the lists shown below, for which you must sketch an accurate circuit diagram showing how the PLC would connect to the motor control or sensor to control/receive its status. The instructor will also randomly select which channel to use on the PLC's I/O card (e.g. *use channel #4 on a 16-channel I/O card*). If additional electrical components are required (e.g. DC power source, electromechanical relay, etc.), those must be incorporated into your diagram as well.

This exercise tests your ability to locate appropriate information in technical manuals and sketch a correct discrete control circuit for a given PLC and sensor/motor control. The electronic Instrumentation Reference contains manuals for all brands and models listed below, and will be available to you during this exercise. Your instructor will request you show the pages from the appropriate manuals in conjunction with your finished sketch, to verify correct connections between the PLC and field device.

### Switch options

- Proximity/limit switch (generic)
  - Mechanical limit switch (3 terminals: NO, NC, and COM)
  - Mechanical process switch (3 terminals: NO, NC, and COM)
  - Inductive proximity switch, sourcing (3 wires: +, –, and Out)
  - Inductive proximity switch, sinking (3 wires: +, –, and Out)
- Electronic level switch
  - Rosemount 2120 vibrating fork level switch with relay output
  - Rosemount 2120 vibrating fork level switch with PNP output
- Electronic flowmeter
  - Rosemount 8800C flow transmitter with pulse output

### Motor Control options

- Variable Frequency Drives (VFDs)
  - Rockwell PowerFlex 4 (discrete “run” input in SNK mode)
  - Rockwell PowerFlex 4 (discrete “run” input in SRC mode)
  - Rockwell bulletin 1333 (2-wire Stop/Start control mode)
  - Automation Direct GS1 (discrete “forward” input)
  - Automation Direct GS1 (discrete “reverse” input)
- Soft-start
  - Rockwell bulletin 150 SMC-Flex (discrete “start” control)

*Note: instructor will specify which channel to use on the PLC's I/O card.*

#### **Programmable Logic Controller options**

- Automation Direct “CLICK” I/O cards
  - Input module: C0-08ND3 (8-channel DC)
  - Input module: C0-08NE3 (8-channel AC/DC)
  - Input module: C0-08NA (8-channel AC)
  - Output module: C0-08TD1 (8-channel DC sinking)
  - Output module: C0-08TD2 (8-channel DC sourcing)
  - Output module: C0-08TA (8-channel AC)
  - Output module: C0-04TRS (4-channel relay)
- Siemens S7-300 I/O cards
  - Input module: DI 32 x AC 120 V (6ES7321-1EL00-0AA0)
  - Input module: DI 32 x DC 24 V (6ES7321-1BL00-0AA0)
  - Input module: DI 16 x DC 24 V (6ES7321-1BH50-0AA0)
  - Input module: DI 16 x DC 48-125 V (6ES7321-1CH20-0AA0)
  - Output module: DO 32 x AC 120/230 V/1A (6ES7322-1FL00-0AA0)
  - Output module: DO 16 x DC 24 V/0.5A (6ES7322-1BH01-0AA0)
  - Output module: DO 16 x Rel (6ES7322-1HH01-0AA0)
- Rockwell (Allen-Bradley) ControlLogix 5000 I/O cards
  - Input module: 1756-IA16 (16-channel 120 VAC)
  - Input module: 1756-IB16 (16-channel 24 VDC)
  - Output module: 1756-OA8 (8-channel 120 VAC)
  - Output module: 1756-OB8 (8-channel 24 VDC)
  - Output module: 1756-OW16I (16-channel relay)
- Emerson ROC800 SCADA/RTU
  - Input module: 8-channel discrete DI
  - Input module: 6-channel AC discrete (AC I/O set for “input” mode)
  - Output module: 5-channel discrete DO
  - Output module: 5-channel discrete relay DO-Relay
  - Output module: 6-channel AC discrete (AC I/O set for “output” mode)

It is highly recommended that you approach this exercise the same as for the design of any other electrical circuit: carefully identify all *sources* and *loads* in the circuit, identify devices requiring DC versus devices requiring AC, trace directions of all currents (DC only), and mark the polarities of all voltages (DC only). Most of the mistakes made in this type of circuit design challenge may be remedied by careful consideration of these specific circuit-analysis details.

Note: a very effective problem-solving strategy for determining how to connect different electrical components together to create a DC circuit is to first identify whether each component acts as a *source* or a *load* in that circuit. Then, label voltage polarities (+, −) and directions of current accordingly. Knowing which way current must flow through each component and which polarity each voltage must have is key to ensuring the inter-component connections are correct.

#### **Common mistakes:**

- Failing to use the provided Instrumentation Reference and instead wasting time looking up manuals on the internet.
- Neglecting to consider voltage ratings of field devices vs. PLC I/O channels.
- Not noticing which “common” terminals on PLC I/O cards serve which group of I/O points.
- Mis-matching sinking and sourcing DC devices.
- Misinterpreting “typical” schematic diagrams shown for I/O cards or multi-channel field devices. Note that a “typical” diagram shows you how just *one* of the channels is wired, because the diagram would become too crowded if that same diagram were repeated for every channel on the device!

- Assuming sinking/sourcing characteristic when undocumented (*remember, it's always safe to use an interposing relay if you are not sure!*).

### **Lab Exercise – documenting the system**

Since this lab exercise involves the inclusion of a three-pole electrical contactor and load, you may have to modify your wiring diagram from the previous lab exercise. The same standards from the last lab exercise apply here: it must show every connection, every cable, every terminal block, etc.

When your entire team is finished updating your individual wiring 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 wiring 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 wiring diagram for that system!



## 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 loop 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 loop 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 field components and a PLC I/O card to create a working PLC input or output circuit, based on diagrams of components with terminals labeled
- Correctly determine all electrical sources and loads, as well as all voltage polarities and current directions in a DC input or output circuit, based on diagrams of field components and the PLC's I/O card with terminals labeled

- **Commissioning and Documentation**

- Explain what a “boolean” data point is in a PLC or an HMI
- Explain what an “integer” data point is in a PLC or an HMI
- Explain what a “fixed point” data point is in a PLC or an HMI
- Explain what a “floating point” data point is in a PLC or an HMI
- Explain what an “ASCII” data point is in a PLC or an HMI

- **Mental math** (no calculator allowed!)

- Convert a binary number into decimal
- Convert a binary number into hexadecimal
- Convert a decimal number into binary
- Convert a hexadecimal number into binary
- Convert a hexadecimal number into decimal

- **Diagnostics**

- Examine a PLC program and identify any mistakes in it
- 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

file i03741

The maintenance of a working lab facility is extensive, especially for a program such as Instrumentation, where most of the equipment comes in the form of donations which must be pieced together, and where many of the systems are custom-built for the purpose. Every student bears a responsibility for helping maintain the lab facility, because every student benefits from its provisions.

On the last day of every quarter, time is allocated to the clean-up and re-organization of the lab facility. This is a full work day, with attendance enforced as per usual. In order to help students focus on the tasks that need to be done, the following list documents some of the work necessary to make the lab ready for next quarter. Tasks preceded by a blank line will be assigned to lab teams for completion.

### Lab tasks

- Check to see that all small items bearing BTC inventory tags are painted a bright color to make them easy to spot for each year's inventory check.
- \_\_\_\_\_ Sweep all lab floor areas, recycling or discarding any waste material.
- \_\_\_\_\_ Sweep all storage room floor areas, recycling or discarding any waste material. Place items found on floor back on shelves where they belong.
- \_\_\_\_\_ Collect all copper tube segments and place them in the copper/brass recycling receptacle.
- \_\_\_\_\_ Collect all aluminum, stainless steel, brass, and copper wire scrap (pieces shorter than 1 foot) in the scrap metal buckets near the north-west exit door.
- \_\_\_\_\_ Haul recyclable metals to a local scrap dealer, and return with cash to buy pizza for today's lunch.
- \_\_\_\_\_ Organize storage bins for danger tags and masking tape. Collect any unused danger tags from around the lab room and place them in that bin.
- \_\_\_\_\_ Help search for any missing Team Tool Locker items.
- \_\_\_\_\_ Clean all workbench and table surfaces.
- \_\_\_\_\_ Remove items from the compressor room, sweep the floor, and make sure there is no junk being stored there.
- \_\_\_\_\_ Collect lengths of cable longer than 1 foot and place in the storage bins inside the DCS cabinets for future use.
- \_\_\_\_\_ Re-organize wire spool storage area: remove any empty spools from the rack, ensure all boxes and unmounted spools are neatly stacked on the floor.
- \_\_\_\_\_ Collect all plastic tubes and return them to the appropriate storage bin.
- \_\_\_\_\_ Re-organize tube fitting drawers (north-west corner of lab room), ensuring no pipe fittings are mixed in, that all fittings are found in the proper drawers, and that all drawers are properly labeled (these drawers should have sample fittings attached to the fronts).
- \_\_\_\_\_ Re-organize pipe fitting drawers (north-west corner of lab room), ensuring no tube fittings are mixed in.
- \_\_\_\_\_ Re-organize hose fitting drawers (north-west corner of lab room).
- \_\_\_\_\_ Re-organize terminal block and ice-cube relay drawers (north end of lab room).
- \_\_\_\_\_ Drain condensed water out of air compressor tank (in the compressor room).
- \_\_\_\_\_ Return all books and manuals to bookshelves.
- \_\_\_\_\_ Inspect each and every control panel in the lab, removing all wiring except for those which should be permanently installed (120 VAC power, signal cables between junction boxes). Ensure that each junction box's power cords are securely fastened and grounded.
- \_\_\_\_\_ Inspect each and every signal wiring junction box in the lab, removing all wiring except for those which should be permanently installed (e.g. 120 VAC power, signal cables between junction boxes.). Ensure that each junction box's power cords are securely fastened and grounded.
- \_\_\_\_\_ Check condition of labels on all junction boxes and control panels, making new labels if the old labels are missing, damaged, or otherwise hard to read.
- \_\_\_\_\_ Check condition of labels on all permanently-installed cables (e.g. between junction boxes), making new labels if the old labels are missing, damaged, or otherwise hard to read.

- \_\_\_\_\_ Check condition of labels on all terminal blocks inside control panels and junction boxes, making new labels if the old labels are missing or otherwise hard to read.
- \_\_\_\_\_ Remove all debris left in control panels and junction boxes throughout the lab room, using a vacuum cleaner if necessary.
- \_\_\_\_\_ Clean up deadweight testers (they tend to leak oil). *Hint: WD-40 works nicely as a solvent to help clean up any leaked oil.*
- \_\_\_\_\_ Maintenance on turbocompressor system: (safety tag-out, check oil level, repair any oil leaks, repair any poor wire connections, clean debris out of control cabinet, re-tighten all power terminal connections).
- \_\_\_\_\_ Return all shared tools (e.g. power drills, saws) to the proper storage locations (hand tools to the tool drawer in the north-east corner of the lab room, and power tools to the tool shelf in the upstairs storage area).
- \_\_\_\_\_ Remove items from all storage cabinets on the north end of the lab room, cleaning all shelves of junk (e.g. pH probes that have been left dry) and returning all items to their proper places. Install covers on all transmitters missing them, especially on pneumatic transmitters which are vulnerable to damage without their covers attached.
- \_\_\_\_\_ Visually inspect all general-purpose pressure regulators stored in the north storage shelves for missing adjustment bolts, missing tube connectors, damaged port threads, etc. Make repairs as necessary.
- \_\_\_\_\_ Test all pressure transmitters not labeled “good” to see if they are indeed defective. Repair if possible, salvage parts and discard if not. Check for stripped screw heads and replace screws if necessary. *Do not discard any instrument with a BTC inventory tag!*
- \_\_\_\_\_ Test all temperature transmitters not labeled “good” to see if they are indeed defective. Repair if possible, salvage parts and discard if not. Check for stripped screw heads and replace screws if necessary. *Do not discard any instrument with a BTC inventory tag!*
- \_\_\_\_\_ Test all I/P converters not labeled “good” to see if they are indeed defective. Repair if possible, salvage parts and discard if not. Check for stripped screw heads and replace screws if necessary. *Do not discard any instrument with a BTC inventory tag!*
- \_\_\_\_\_ Test all precision pressure gauges not labeled “good” to see if they are indeed defective. Repair if possible, salvage parts and discard if not. *Do not discard any instrument with a BTC inventory tag!*
- \_\_\_\_\_ Test all precision pressure regulators not labeled “good” to see if they are indeed defective. Repair if possible, salvage parts and discard if not. *Do not discard any instrument with a BTC inventory tag!*
- \_\_\_\_\_ Test all hand air pumps used for pressure calibration work. If a pump leaks, disassemble the pump to clean and inspect its internal parts. Repair if possible, salvage parts and discard if not. *Do not discard any instrument with a BTC inventory tag!*
- \_\_\_\_\_ Return all field instruments (e.g. transmitters) and miscellaneous devices (e.g. pressure gauges and regulators) to their proper storage locations. *Note that I/P transducers and valve positioners should remain near their respective control valves rather than be put away in storage!*
- \_\_\_\_\_ Store all 2×2 foot plywood process boards in secure locations, ensuring each one is ready to use next quarter.
- \_\_\_\_\_ Ensure that each and every control valve mounted on the racks in the lab room has an I/P transducer mounted nearby, complete with Swagelok tube connectors in good condition for connecting compressed air supply and signal to the valve.
- \_\_\_\_\_ Check to make sure that each valve is securely mounted to the rack, and if there is a positioner attached that the feedback arm is properly connected to the valve stem (e.g. no missing tension springs, bent linkages, obvious misalignments).
- \_\_\_\_\_ Remove all items from the flammables cabinet, wipe all shelves of liquid and residue, then re-stock in a neat and safe manner.
- \_\_\_\_\_ Clean all bar-be-que grills of residue left over from lunches and fundraisers. *Note: you may need to take the grill racks and grease drip trays to a car wash station and use the engine degreaser solution to clean them thoroughly enough!*

- \_\_\_\_\_ Re-set all function block parameters in the DCS “Generic Loops” to their default settings. See the documentation on the main BTC\_PPlus workstation for instructions on parameter values.
- \_\_\_\_\_ Check manometers on the calibration bench, ensuring those filled with red fluid are at their fluid levels and that all the others (normally filled with distilled water) are completely drained.
- \_\_\_\_\_ Turn on compressed air to the calibration bench, checking for leaks and ensuring every pressure regulator is functioning as it should.
- \_\_\_\_\_ Clean refrigerators, throwing away any food items remaining within.
- \_\_\_\_\_ Thoroughly clean all food ovens and any other cooking tools.
- \_\_\_\_\_ Return all shelf boards to their appropriate places on the racks.
- \_\_\_\_\_ Clean and re-organize all shelves in classroom DMC 130 storing components for the hands-on mastery assessments. Throw away any damaged jumper wires, battery clips, etc. Discard any batteries whose terminal voltages are less than 80% of their rating (e.g. less than 7.2 volts for a 9-volt battery).
- \_\_\_\_\_ Shut off power to all control systems except for the DCS.
- \_\_\_\_\_ Store any donated components in the proper locations.
- \_\_\_\_\_ Clean all whiteboards using Windex, so they actually look white again!

• *Instructors may add items to this list as necessary:*

- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

#### **Personal tasks**

- Apply “sick hours” to missed time this quarter (remember, this is *not* automatically done for you!).
- Donate unused “sick hours” to classmates in need.
- Take any quizzes missed due to classroom absence this quarter (remember, a quiz not taken will be counted as a failed quiz!).

file i01229

## Answers

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Answer 1

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Answer 2

Process level being below 11 feet and process pressure being above 45 PSI accounts for all the color status highlighting we see in the program, as well as the LED statuses on the front of the PLC.

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Answer 3

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Answer 4

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Answer 5

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Answer 6

**Partial answer:**

Fault	Possible	Impossible
Dead power supply		✓
Relay coil failed open		
Pushbutton switch failed open		
NO contact failed open		
NC contact failed open		✓
Relay coil failed shorted		
Pushbutton switch failed shorted		
Break in wire between points A and G		✓
Break in wire between points C and E		
Break in wire between point F and relay coil		

Many students may find themselves fooled by the 0 volt measurement, thinking this proves points C and E are continuous. The fallacy at work here is thinking 0 volts proves continuity, just because continuity *does* guarantee 0 volts. In fact, it *is* possible for there to be a break between C and E (and still have a 0 volt measurement) if something *else* is open within that loop. For example, the lower NO relay contact could be failed open!

If the same C-to-E measurement were taken with the pushbutton switch pressed, you would find a 24 volt measurement given a broken wire between those two points.

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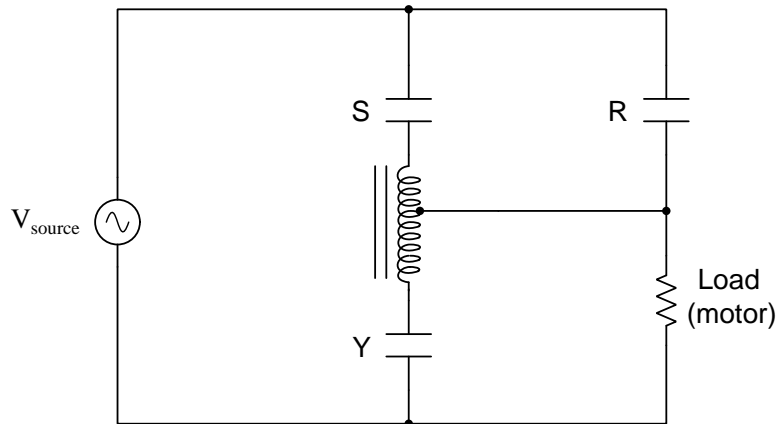
Answer 7

When the “S” and “Y” contacts are all closed, the autotransformers form a three-phase “Y” connection, with line voltage (L1, L2, and L3) applied to the “tips” of the “Y,” and a reduced motor voltage tapped off a portion of each autotransformer winding.

When the “Y” contacts open, the three autotransformers now function merely as series-connected inductors, limiting current with their inductive reactance.

When the “R” contacts close, the motor receives direct power from L1, L2, and L3.

Here is a *single-phase equivalent* circuit, representing the motor as a resistive load:



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Answer 8

**Partial answer:**

$$I_{\text{phase}(\text{source})} = 0.621 \text{ A}$$

$$I_{\text{phase}(\text{load})} = 0.358 \text{ A}$$

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Answer 9

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Answer 10

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Answer 11

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Answer 12

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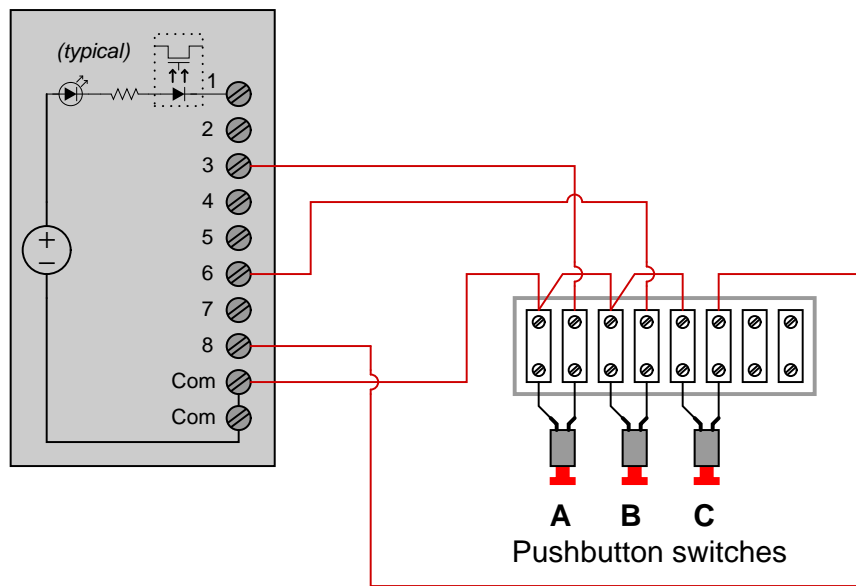
Answer 13

**Possible faults:** (not an exhaustive list)

- Tripped overload (OL) block
- Open fault in output circuit
- Loss of 3-phase power to motor
- Open fault in level switch input circuit
- Open fault in pressure switch input circuit
- Shorted temperature switch contacts
- Shorted temperature switch contacts

Bear in mind that this is not the *only* possible circuit solution:

### ROC 809 discrete input module



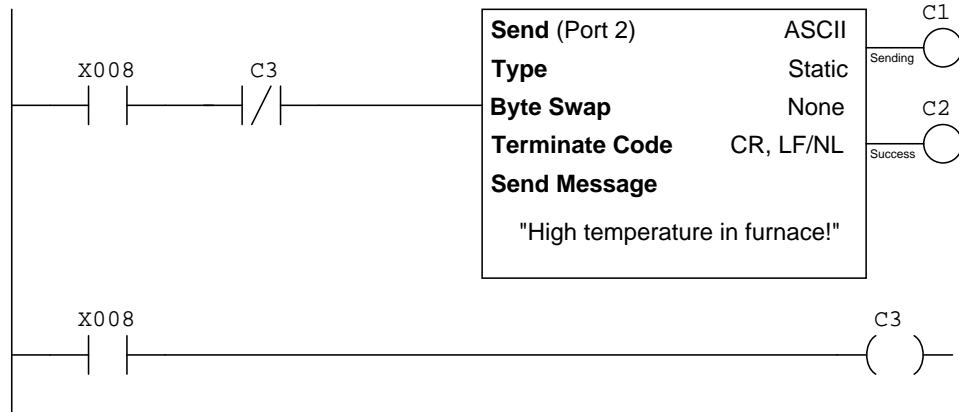
This input module **sources** current.



We can tell that the high-temperature switch must have normally-open (NO) contacts, because it is on the *positive* edge transition that the PLC transmits the message (i.e. when the temperature switch *closes*). Thus, the switch must transition from open to close as temperature rises, making it an NO contact.

The edge-transition contact instruction is used so that the PLC does not continually repeat the message if a high-temperature condition continues unabated over time.

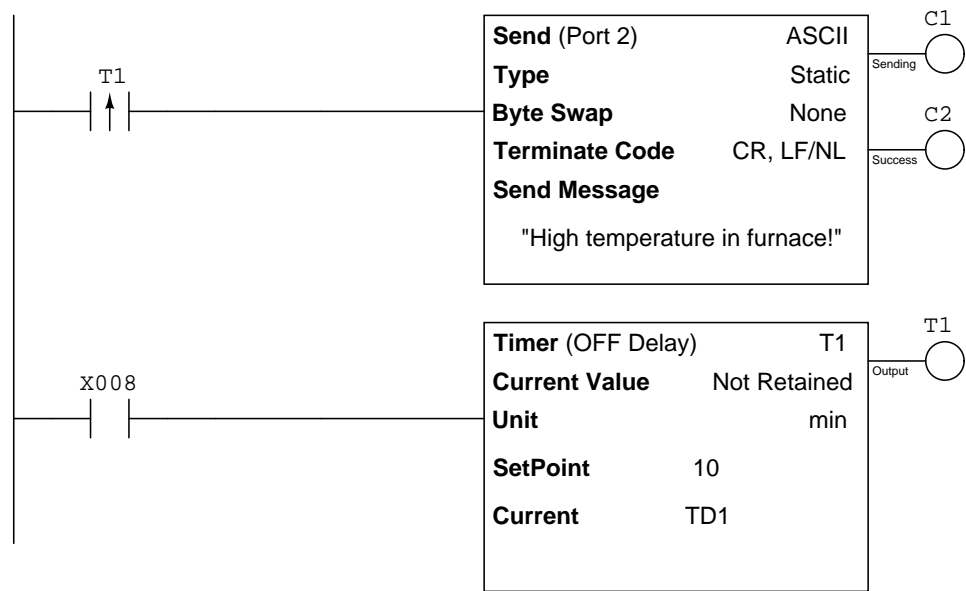
Modification of program to avoid using edge-transition instruction:



*Note: the order in which these ladder-logic rungs appear in this example are essential to the program operating properly. The “Send” rung must precede the interlock (C3 coil) rung.*

The program shown here does the same thing as a positive edge-detect instruction, and it does so by exploiting the scan order of the PLC. When X8 first transitions from low to high (0 to 1) and the PLC scans the program from top to bottom, the first rung is executed because X8 = 1 and C3 = 0. After the second rung scans, however, bit C3 becomes set, preventing any further executions of the Send instruction in the top rung.

Modification of program to avoid nuisance alarm messages:



Answer 16

If you happen to be using the Automation Direct model GS-1 variable frequency motor drive (an inexpensive option), be prepared to use a rather strange convention for network control bits. Rather than have certain commands such as “Run” and “Stop” be distinct bits in a longer digital word as is the case with other motor drives, the GS-1 drive reserves entire 16-bit registers for each bit function. For example, register 091B (hex) in the GS-1 drive is the Run/Stop command: setting that entire 16-bit word to 1 (i.e. 0000000000000001) makes the drive run; setting that entire word to 0 (0000000000000000) makes the drive stop. The direction control register 091C is the same way: setting that entire 16-bit word to 1 (i.e. 0000000000000001) makes the drive go reverse while setting the whole word to 0 (0000000000000000) makes it go forward.

Most other industrial motor drives have a single 16-bit word where individual bits of that word do different functions (e.g. bit 0 is Run/Stop, bit 1 is Fwd/Rvs, bit 2 is Jog, bit 3 is . . .), and the PLC must write individual bit values to the respective places within that 16-bit word in order to command the drive. While this approach is more efficient in terms of memory usage within the drive, it is less convenient when used with Automation Direct’s Koyo “DirectLogic” and “CLICK” series of PLCs because these PLCs do not provide convenient ways to specify bit-wise addresses. By contrast, Allen-Bradley and Siemens PLCs make it very easy to address individual bits within a multi-bit register.

Answer 17

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Answer 18

The latter system “reads back” the motor’s status from the auxiliary contact on the contactor, rather than from a bit internal to the PLC (Y1). This gives it the ability to “sense” what is going on in the real world.

Imagine a case where the motor control power circuit fuse blew, preventing the motor contactor from energizing even when PLC output Y1 activates. The internally-latched PLC program would blissfully maintain an energized condition on Y1 output after someone presses the Start pushbutton even though the motor is not running (and will suddenly start if anyone replaces the blown fuse!). The externally-latched PLC program refuses to latch output Y1 on unless it senses the contactor has actually energized, making it a safer system.

A similar system of external latching is used on electric clothes dryers, to latch the motor control circuit on only when an external speed switch senses drum rotation. This prevents the unwanted condition of continuous motor and heater operation in the event of a broken belt (which would prevent the drum from turning).

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Answer 19

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Answer 20

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Answer 21

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Answer 22

A helpful reference for you, especially if programming an Allen-Bradley SLC 500 or MicroLogix PLC, is the subsection entitled “Example Calculation: PLC analog input scaling” in the “Relating 4 to 20 mA Signals to Instrument Variables” section of the “Analog Electronic Instrumentation” chapter of the *Lessons In Industrial Instrumentation* textbook.

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Answer 23

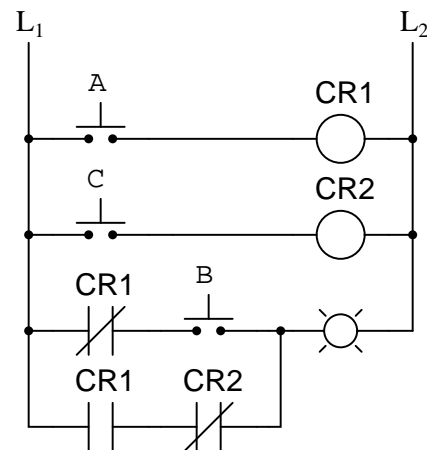
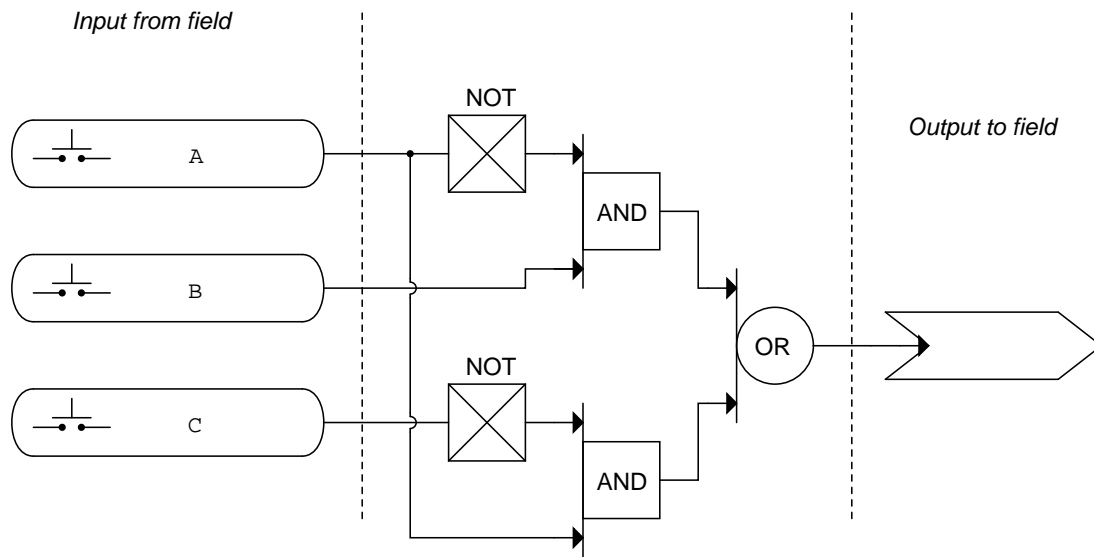
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Answer 24

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Answer 25

The SCL instruction is much faster for the PLC to execute than the SCP instruction, but it only operates using integer values. The SCP instruction is not only easier to set up, but it also has the ability to write to a floating-point register.



Boolean expression =  $\overline{A}B + A\overline{C}$

If complete a Karnaugh map for this truth table, you get the following result:

		C	
		0	1
AB	00	0	0
	01	1	1
	11	1	0
	10	1	0

The best grouping for this map is as follows:

		C		
		0	1	
AB	00	0	0	
	01	1	1	$\overline{A}B$
	11	1	0	
	10	1	0	$A\overline{C}$

This grouping yields the following (simplified) expression:  $\overline{A}B + A\overline{C}$ .

One year in class, a student asked what would happen if we made a third group in the Karnaugh map like this:

		C		
		0	1	
AB	00	0	0	
	01	1	1	$\overline{A}B$
	11	1	0	
	10	1	0	$A\overline{C}$

Now, certainly this new group ( $B\overline{C}$ ) does not contribute anything to the answer other than a redundant term. However, the remark was made that the new (three-term) expression did not appear to be reducible to the first (two-term) expression:

Is  $\overline{A}B + A\overline{C}$  the same as  $\overline{A}B + A\overline{C} + B\overline{C}$  ???

It turns out the answer is yes, and it takes the form of a new Boolean reduction rule I was not previously aware of, the general form being:

$$AX + \overline{A}Y + XY = AX + \overline{A}Y$$

Here is the proof, starting with the rule and progressing to show an equality. My first step is to use the rule  $A + AB = A$  to expand two terms on the right-hand side of the equation:

$$AX + \overline{A}Y + XY = (A + AY)X + (\overline{A} + \overline{A}X)Y$$

Next, I distribute:

$$AX + \overline{A}Y + XY = AX + AXY + \overline{A}Y + \overline{A}XY$$

Finally, factoring  $XY$  from two of the new terms, and simplifying:

$$AX + \overline{A}Y + XY = AX + \overline{A}Y + XY(A + \overline{A})$$

$$AX + \overline{A}Y + XY = AX + \overline{A}Y + XY(1)$$

$$AX + \overline{A}Y + XY = AX + \overline{A}Y + XY$$

Applying this rule to the three-term SOP expression resulting from the Karnaugh map with the extra group:

$$\overline{A}B + A\overline{C} + B\overline{C}$$

Here, we take  $\overline{A}$  to be  $A$  in the rule,  $B$  to be  $X$  in the rule, and  $\overline{C}$  to be  $Y$  in the rule:

$$\overline{A}B + A\overline{C}$$

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Answer 27

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Answer 28

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Answer 29

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Answer 30

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Answer 31

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Answer 32

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Answer 33

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Answer 34

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Answer 35

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Answer 36

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Answer 37

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Answer 38

Answer 39
Answer 40
Answer 41
This is a graded question – no answers or hints given!
Answer 42
This is a graded question – no answers or hints given!
Answer 43
This is a graded question – no answers or hints given!
Answer 44
This is a graded question – no answers or hints given!
Answer 45
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Answer 49
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Answer 50
This is a graded question – no answers or hints given!
Answer 51
Answer 52