IEETI-215 – PLC/HMI Theory

NAME: _____ Last update 24 April 2026

Session	Topic	Journal	P.S.	Comments
Session 01	Introduction to the course			
Session 02	Circuit fundamentals and relays			
Session 03	Basic principles of digital			
Session 04	Relay ladder logic circuits			
Session 05	Contact and coil programming			
Session 06	Contact, coil, and I/O states			
Session 07	Discrete I/O and data types			
Session 08	Latching logic programming			
Session 09	Special coils and contacts			
Session 10	PLC troubleshooting			
Session 11	ORAL PRESENTATIONS			
Session 12	EXAM			

Session	Topic	Journal	P.S.	Comments
Session 13	PLC combinational logic			
Session 14	Introduction to HMIs			
Session 15	HMI discrete programming			
Session 16	PLC counter instructions (I)			
Session 17	PLC counter instructions (II)			
Session 18	PLC counter instructions (III)			
Session 19	Counter programming challenges			
Session 20	Place-weighted numeration			
Session 21	Unsigned binary integers			
Session 22	Practice session			
Session 23	ORAL PRESENTATIONS			
Session 24	EXAM			

Session	Topic	Journal	P.S.	Comments
Session 25	Octal and hex notation			
Session 26	Signed binary integers			
Session 27	PLC integer data types			
Session 28	HMI integer programming			
Session 29	PLC timer instructions (I)			
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Session 32	Timer programming challenges			
Session 33	PLC troubleshooting			
Session 34	Practice session			
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Session 36	EXAM			

Session	Topic	Journal	P.S.	Comments
Session 37	Floating-point numeration			
Session 38	HMI floating-point programming			
Session 39	PLC comparison instructions			
Session 40	PLC arithmetic instructions			
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Session 42	Analog-digital conversion			
Session 43	PLC analog I/O			
Session 44	Analog signal scaling			
Session 45	Analog programming challenges			
Session 46	Practice session			
Session 47	ORAL PRESENTATIONS			
Session 48	EXAM			

Session	Topic	Journal	P.S.	Comments
Session 49	PLC communication functions			
Session 50	Serial data communication			
Session 51	Multi-point data communication			
Session 52	RS-232 and RS-485 networks			
Session 53	Ethernet networks			
Session 54	Internet protocols			
Session 55	Modbus			
Session 56	Modbus/TCP			
Session 57	Comms programming challenges			
Session 58	Practice session			
Session 59	ORAL PRESENTATIONS			
Session 60	EXAM			

Essential information about this course:

- The purpose of this entire program is to empower you with knowledge, skill, and habits for your chosen craft, and doing your own work is absolutely necessary to that end. Relying on other people and/or artificial intelligence (AI) to read, write, design, plan, analyze, diagnose, or in any other way *think for you* defeats this purpose and will be considered plagiarism. Appropriate help always sharpens and never replaces a person's own ability to think and to do. Bear this in mind both when seeking help and when assisting classmates!
- The difference between *education* and *training* is learning to reason from principles versus following instructions. In this course you will learn principles of circuits and sharpen your reasoning skills by *reading* extensively, *writing* your thoughts, and *dialoguing* with the instructor(s) and with classmates rather than consuming lectures. Preparatory work precedes each class session.
- Learning trustworthy and responsible habits is just as important to your career as developing knowledge and skill, and responsibility develops only with application. You bear responsibility in this course to manage your time, clearly and promptly communicate, and set priorities. Your instructor(s) will provide ample guidance and feedback.
- Assignments and assessments are just means to an end, and that end is learning. Similarly, grades, certificates, and degrees are just symbols of that same end. Prioritize *learning* and you will do well on your assignments and assessments, and your grades will reflect that. If you instead treat activity

completion as the goal and grades as a prize, you'll not only sacrifice learning but also struggle to complete the assignments and obtain the grades you desire. Don't confuse the means versus the end; don't chase symbols in lieu of what they're supposed to represent.

- Half of your course grade comes from "oral presentations" designed to mimic technical job interviews. The other half comes from written "mastery exams" requiring correct answers on every question to pass, with multiple re-tries allowed on different exam versions. Answers must be accurate *and* well-reasoned from appropriate principles to count as correct.
- Late arrival and/or unpreparedness for theory sessions will result in point deductions. Demonstrations of unprofessional behavior will trigger private meetings with your instructor(s).
- You should budget a minimum of 12 hours per week for this course, approximately 4 hours in-class and at least 8 hours out-of-class preparation.
- Successful students (1) prioritize their study time, (2) test themselves on upcoming oral presentation and written exam topics, (3) and master principles rather than memorize procedures.

Values

This educational program exists for one purpose: to empower you with a comprehensive set of knowledge, skills, and habits to unlock opportunities in your chosen profession. The following values articulate personal attitudes guaranteed to fulfill this purpose, and the principles upon which this program is designed. They embody what I like to call a *strong learning ethic*, similar to a strong work ethic but applied to the learning process rather than a job.

Ownership – you are the sole proprietor of your education, of your career, and to a great extent your quality of life. No one can force you to learn, make you have a great career, or grant you a fulfilling life – these accomplishments are possible only when you accept responsibility for them.

Responsibility – *ensuring* the desired outcome, not just *attempting* to achieve the outcome. Responsibility is how we secure rights and privileges.

Initiative – independently recognizing needs and taking responsibility to meet them.

Integrity – living in a consistently principled manner, communicating clearly and honestly, applying your best effort, and never trying to advance at the expense of others. Integrity is the key to trust, and trust is the glue that binds all relationships personal, professional, and societal.

Perspective – prioritizing your attention and actions to the things we will all care about for years to come. Never letting short-term concerns eclipse the long-term.

Humility – no one is perfect, and there is always something new to learn. Making mistakes is a symptom of living, and for this reason we need to be gracious to ourselves and to others.

Safety – assessing hazards and avoiding unnecessary risk to yourself and to others.

Competence – your ability to consistently and independently apply knowledge and skill to the solution of practical problems. Competence includes the ability to verify the appropriateness of your solutions and the ability to communicate so that others understand how and why your solutions work.

Diligence – exercising self-discipline and persistence in learning, accepting the fact there is no easy way to absorb complex knowledge, master new skills, or overcome limiting habits. Diligence in work means the job is not done until it is done *correctly*: all objectives achieved, all documentation complete, and all root-causes of problems identified and corrected.

Community – your actions impact other peoples' lives, for good or for ill. Conduct yourself not just for your own interests, but also for the best interests of those whose lives you affect.

Respect is the acknowledgment of others' intrinsic capabilities, responsibilities, and worth. Everyone has something valuable to contribute, and everyone deserves to fully *own* their lives.

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EET Program Learning Outcomes

(1) **COMMUNICATION and TEAMWORK** – Accurately communicate ideas across a variety of media (oral, written, graphical) to both technical and non-technical audiences; Function effectively as a member of a technical team.

(2) **SELF-MANAGEMENT** – Arrive on time and prepared; Work diligently until the job is done; Budget resources appropriately to achieve objectives.

(3) **SAFE WORK HABITS** – Comply with relevant national, state, local, and college safety regulations when designing, prototyping, building, and testing systems.

(4) **ANALYSIS and DIAGNOSIS** – Select and apply appropriate principles and techniques for both qualitative and quantitative circuit analysis; Devise and execute appropriate tests to evaluate electronic system performance; Identify root causes of electronic system malfunctions.

(5) **PROBLEM-SOLVING** – Devise and implement solutions for technical problems appropriate to the discipline.

(6) **DOCUMENTATION** – Interpret and create technical documents (e.g. electronic schematic diagrams, block diagrams, graphs, reports) relevant to the discipline.

(7) **INDEPENDENT LEARNING** – Select and research information sources to learn new principles, technologies, and/or techniques.

Course description

This course teaches the theory of programmable logic controller (PLC) operation, wiring, and programming with an emphasis on general principles common to all makes and models of PLC. Students research and apply wiring and programming techniques from multiple PLC manufacturers, with specific focus on learning how to relate internal PLC data states with real-world signals and conditions. This course also teaches the programming of human-machine interfaces (HMIs) and the communication networks connecting PLCs with HMIs and other field devices. Mastery-style written exams guarantee attainment of conceptual learning outcomes, while oral presentations and Socratic dialogue demonstrate communicative learning outcomes.

Course learning outcomes

- Accurately relate real-world electrical I/O status with internal digital states inside a PLC, as well as live data views and color-highlighting of ladder-logic programs.
- Design and sketch wired circuits to connect PLC I/O cards to external devices such as switches, sensors, relays, and motor controllers. (Addresses Program Learning Outcomes 4, 5, 6)
- Edit ladder-logic code to instruct a PLC to perform stated tasks. (Addresses Program Learning Outcomes 4, 6)
- Articulate and apply technical principles related to PLCs and HMIs as requested by a critical audience. (Addresses Program Learning Outcomes 1, 2, 4, 6, 7)
- Identify probable wiring and/or programming errors in PLC-controlled systems given schematic diagrams, ladder-logic code listings, and reported symptoms. (Addresses Program Learning Outcomes 5, 6)
- Summarize concepts related to PLC wiring and programming, acquired from technical literature, and clearly present them in both written (journal) and oral formats. (Addresses Program Learning Outcomes 1, 6, 7)

Grading standards for Theory courses

Your grade for this course is based on percentage scores (in every calculation rounded *down* to whole-numbered values), with each category weighted as follows:

- Oral presentation scores = 50%
- Written exam scores = 50% (Note: all exams are mastery-based, which means they must be eventually passed with correct answers for every question in order to pass the course)
- Missing Theory Journal entry = −1% per session
- Unattempted problem(s) = −1% per session

All theory sessions are based on an "inverted" model of instruction rather than lecture. Instead of passively listening to the instructor explain new concepts, students independently explore those new concepts outside of class, journal their thoughts on these new concepts, and then spend the entire class time discussing those concepts and solving practical problems. This instructional model has proven far more effective than lecture, principally because student engagement is mandatory and not optional. Inverted instruction also reveals to the instructor *how each student thinks*, enhancing the instructor's ability to coach students on sound reasoning. It also greatly minimizes the classroom time necessary to achieve the same learning outcomes (approximately *half* the time as required by lecture to achieve the same results).

You must keep a Theory Journal, written entirely in your own words, as a tool to document your learning and to sharpen your understanding of the concepts. Any format is acceptable so long as relevant portions of it may be electronically shared during class sessions. You are strongly encouraged to log all of your work in this Theory Journal, including assigned problems, practice problems, etc.

Penalties apply to any lack of documented effort for theory sessions: a −1% deduction to your course grade will be levied if you arrive to class late or without a Theory Journal entry for that session's assigned reading, and a separate −1% deduction will occur if any assigned problem is unattempted. Note that your journal entries and solution attempts need not be error-free and that misconceptions and mistakes are expected.

If you must be late or absent for a theory session, submitting your work in electronic form (e.g. email attachment) prior to the scheduled time is acceptable for full credit:

- For preparation, submission of your Theory Journal entry before the scheduled start time of that theory session will count as full credit. If you know you will be late to class, sending the journal entry before the start of class will excuse the tardiness.
- For problem-solving, *correctly* answering all assigned problems in order to ensure you understand the day's topic. Partial credit will be awarded for this based on how many of the answers are correct versus incorrect.

Absence during a scheduled oral presentation or a scheduled written exam will result in a 0% score for that assessment, except in the case of a *documented emergency*. In such emergency cases, written exams may be taken at some later time for full credit, and oral presentations may also be completed at a later date for full credit. Taking an exam in advance of the scheduled date is always allowed. During any assessment you are free to ask the instructor for clarification, but the instructor will not help you solve any problem nor will confirm if an answer is correct prior to its submission for scoring. Only answers supported by proper principles and sound reasoning will be counted as correct – "right" answers based on guessing or luck will not.

A failing (F) grade will be earned for the entire course if any written exam is not passed (i.e. *all* answers correct) on or before the deadline date, or for any behavior that would result in being fired from a job, including false testimony (lying), cheating on any assignment or assessment, plagiarism (relying on another's work instead of your own, including artificial intelligence), willful violation of a safety policy, habitual tardiness or absenteeism, theft, harassment, sabotage, destruction of property, or intoxication.

file `eet_grading_t`

Instructor guidelines

The design and structure of this course is quite unconventional, but proven to deliver robust outcomes. In addition to imparting technical knowledge and skill related to the subjects of electricity and electronics, this course seeks to also teach students how to think clearly and critically about these subjects. To this end, students first encounter new subject matter through independent reading rather than by lecture, their time in class spent actively sharing, debating, and solving problems rather than passively listening. Your job as the instructor is to hold students accountable for good-faith preparation, and to ensure they *reason* from basic principles rather than merely recall facts and follow procedures.

Every class session should begin with a review of students' assigned reading. Have students share what they learned by presentation of their written journal entries and orally by speaking to the class as a whole. Good-faith effort is the standard of acceptance here, with errors and misconceptions expected since this material is new to them. At minimum every student should be able to show written summaries of the major concept(s) *in their own words* with any verbatim citations indicated as such. Intelligent questions are always welcome journal entries! Maintaining a thoughtful journal and presenting orally in class are non-negotiable requirements, as the skills of clear writing and public speaking do not grow any other way than by exercising them, and also because these activities help foster critical thinking. *You should also write your own journal if teaching the course for the first time*, both to set a good example for students as well as better understanding their learning experience.

Students must also be held accountable for attempting to solve each and every problem assigned to them in advance of their arrival. Again, the standard of acceptance is good-faith effort, with errors and misconceptions expected. Every student is capable of applying *at least one* problem-solving strategy to every problem (e.g. identifying relevant principles, sketching a diagram to visualize the problem, simplifying the problem, converting it from quantitative to qualitative or vice-versa, trying limiting cases, etc.). A blank page is unacceptable. You should demonstrate general problem-solving strategies every day, encouraging students to record those strategies in their journals, so that no one can ever claim "I don't know where to begin" when faced with a new problem.

Exactly how you hold students accountable for their preparatory work is left up to your professional discretion, so long as they indeed do the work. Be flexible and open-minded in your methods, but firm in holding students accountable to *reading*, *writing*, *speaking*, and *reasoning*.

Class sessions should feature students talking more than you. Your job is to probe their understanding with questions, and to guide their thinking without thinking for them. Socratic dialogue is a good model to follow: question students' responses whether correct or incorrect, asking them to provide reasons for their answers. The most important question you can ask is, "Why?" Give students enough time to carefully consider the question when answering. Silent problem-solving sessions are good, too, to give students room to think independently while you offer individual assistance. Students should update their journals with any insights gained during class time, treating it as a living document of their learning.

Suggested learning outcomes and methods to measure student learning appear in the "Recommendations for instructors" section of each module's Introduction chapter. These may be used to help design a course of study, and/or as focal points for classroom discussions around that module's tutorial(s).

When students ask for help, *don't solve the problem for them.* Instead, suggest appropriate problem-solving strategies and observe them doing the work. When students ask you to review a concept they've studied previously, point them to a trusted source of information (e.g. their learning modules) and offer to discuss what they read together. Also, don't be too quick to confirm their solutions – instead, show them appropriate ways to validate the correctness of their own work (e.g. working the problem backwards, verifying by computer simulation, etc.). Always remember that you are preparing students to be *independent* learners and problem-solvers, as they will not have your assistance after they complete your course. Far too many students focus on the myopic goals of completing assignments, achieving good grades, passing a course, and earning a degree to the detriment of long-term value found in professional knowledge, skill, and habits. *Your job as the instructor is to draw students' attention toward what matters most.*

Theory session 01

Complete the following *during* the scheduled session:

- Discuss time commitment: *a minimum of 3 hours per week per enrolled credit is necessary for success!*
  → Make *daily contact* with instructor, even if absent
  → Exert *honest effort* to solve every problem before asking for help
  → *Self-start* when faced with challenges and take ownership of your education
  → Never *procrastinate*, as this invites failure
- Discuss how theory sessions work, and how they differ from traditional lecture
- Identify the pre-work for *tomorrow's* theory session
- Identify required tools and supplies to procure, and where to obtain:
  → Laptop PC running Microsoft Windows operating system
  → Hand calculator
  → EETREF collection (bring flash drive to copy)
  → (for IETTI-216 *PLC/HMI Experiment* course only) Multimeter
  → (for IETTI-216 *PLC/HMI Experiment* course only) basic hand tools such as needle-nose pliers, small screwdriver set, diagonal wire cutters, wire strippers
- Explore how to download and install Automation Direct *Do-More Designer* software which has the ability to simulate a virtual PLC
- Visit `automationdirect.com` and identify input/output (I/O) component options and prices necessary to build a simple PLC system, required if you are taking the IETTI-216 *PLC/HMI Experiments* course:
  → CLICK Basic PLC processor model C0-00DD1-D recommended, model C0-10DD1E-D is more expensive but offers Ethernet connectivity
  → CLICK AC power supply model C0-00AC recommended
  → CLICK discrete "combo" I/O module, model C0-16CDD1
  → Programming cable assembly model EA-MG-PGM-CBL recommended, not necessary for Ethernet-ready PLC
- [Optional] – sign FERPA release forms

Forms provided by the instructor for today's session:

- FERPA release form
- IETTI-215 PLC/HMI Theory course document (printed from cover page through Theory Session 2)
- IETTI-216 PLC/HMI Experiments course document (only if you are enrolled in this course as well)

`Important resources:`

- `https://ibiblio.org/kuphaldt/socratic/model`, the *Modular Electronics Learning Project* web page containing all course documents, tutorials, and problem sets you will need in these courses
- `https://ibiblio.org/kuphaldt/socratic/model/calendar.html`, our semester calendar showing dates for theory sessions, special events, and all-lab project sessions
- `https://ibiblio.org/kuphaldt/socratic/model/daily_schedule.pdf`, showing Monday-Friday class schedule

  file wt_1005

Theory session 02

Source text – *Electromechanical relays* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_relay.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Concept review
  → What is a relay?
  → Contact arrangements
  → Relay ratings
  → Solid-state relays
- Be sure to update the "Conceptual Toolbox" section of your Theory Journal with any important concepts discussed in the Tutorial chapter, and prepare to share these entries with your instructor and classmates. The purpose of your "Conceptual Toolbox" is to serve as a ready reference of ideas to try when solving problems, accumulating new ideas and strategies as you learn more about electric circuits throughout this program of study.
- Complete "Sketching connections for a dual lamp circuit" in the Conceptual Reasoning section of the Questions chapter.
- Complete "5 Volt relay powered by a 24 Volt source" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Find the mistake" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0322

Theory session 03

Source text – *Basic Principles of Digital* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_digital.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Analog versus digital
  → Logic states
  → Logic functions
  → Boolean expressions
- Complete "Analog versus digital quantities" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Switch states" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Electrical faults in a simple battery/lamp circuit" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

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Theory session 04

Source text – *Relay Ladder Logic* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_ladderlogic.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete "Ladder-diagram switch circuit" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Truth table for a relay circuit" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Effects of a ground fault in a relay control circuit" in the Diagnostic Reasoning section of the Questions chapter.
- Time permitting, your instructor will run a simulation of a "simple one-resistor circuit" (Circuit_000) using `tshoot` software to practice efficient circuit fault diagnosis.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs.
  → e.g. explore the instruction library for a PLC, noting different types of contacts, coils, and other instructions available for making programs

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0321

Theory session 05

Source text – *Introduction to PLCs* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Examine and reflect on the Example: NAND function in a PLC section of the Case Tutorial chapter, and answer the following questions:
  → Explain the relationship between each virtual contact's and virtual coil's *color highlighting* shown on the Relay Ladder Logic (RLL) program display and the real-world electrical statuses of switches and lamp shown in the PLC schematic diagram.
- Complete "Relay ladder logic analogy for a PLC" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Determining bit statuses from switch conditions" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Determining color highlighting from bit statuses" in the Conceptual Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs.
  → e.g. PLC programs implementing basic 2-input logic functions such as AND, OR, NAND, NOR, XOR

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0301

Theory session 06

Source text – *PLC Contact and Coil Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_discrete.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Ladder diagram virtual elements and I/O status
- Complete "Determining necessary switch conditions for bit statuses" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Determining color highlighting from switch conditions" in the Conceptual Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

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Theory session 07

Source text – *PLC Inputs and Outputs* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_io.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Types and sizes of PLCs
  → PLC hardware inputs and outputs (I/O)
  → Discrete PLC I/O
- Complete "Sourcing versus sinking PLC I/O" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Sketching wires to PLC discrete I/O" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Incorrect PLC output wiring" in the Diagnostic Reasoning section of the Questions chapter.
- Look ahead to the Oral Presentations (session 11) to see what challenges await.
- Look ahead to the Written Exam (session 12) to see what challenges await.
- Time permitting, your instructor will run a simulation of a "simple one-resistor circuit" (Circuit_000) using `tshoot` software to practice efficient circuit fault diagnosis.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

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Theory session 08

Source text – *PLC Contact and Coil Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_discrete.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Ladder diagram latching functions
  → Fault-tolerant latch programming
- Complete "Determining bit statuses from color highlighting" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Troubleshooting motor control program" in the Diagnostic Reasoning section of the Questions chapter.
- Complete "Troubleshooting motor control PLC from I/O indicators" in the Diagnostic Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs.
  → e.g. motor start-stop latching PLC programs

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

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Theory session 09

Source text – *PLC Contact and Coil Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_discrete.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Ladder diagram retentive coils
  → Ladder diagram transition contacts
- Complete "Two different motor control programs" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Turbine low-oil trip" in the Diagnostic Reasoning section of the Questions chapter.
- Complete "Motor starter diagnosis from color highlighting" in the Diagnostic Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs.
  → e.g. motor start-stop latching PLC programs

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

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Theory session 10

Source text – *PLC Contact and Coil Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_discrete.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Complete "Determining process switch stimuli from color highlighting" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Redundant coils in a program" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Air compressor troubleshooting from observation" in the Diagnostic Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs.
  → e.g. motor start-stop latching PLC programs

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0370

Theory session 11

Oral Presentations

Today's class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. When you are chosen to present, you will have a brief period of time to gather your thoughts and set up for your presentation.

A format proven to work well is that all students in the class are given a unique problem to solve, and 15 minutes of time to independently devise solutions. These 15-minute periods are closed-book and closed-note just like written exams. After that 15-minute period, the instructor collects all the papers (each with the student's name written on top) and gives each student 10 minutes to present their solution before the entire class while everyone else observes.

Your instructor will not provide answers to you prior to or during the presentation; you are solely responsible for any research, experimentation, and other actions necessary to adequately prepare for your presentation. If you inquire for help, the instructor may clarify what you will need to present on, and/or point you toward specific resources (e.g. "Try setting up a SPICE simulation", "Try building a test circuit on your breadboard", "Find and read the datasheet(s)", "Research application notes written on this topic", etc.), but do not expect them to give you answers or check your work because by this point in time you will have studied the necessary concepts to verify results for yourself, or at least to know where to go to find verification.

During your presentation the instructor and audience members are free to pose questions relevant to the graded objectives for your assigned problem. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions.

The benefits of this exercise include honing your independent research skills, reinforcing your foundational knowledge of electronics, gaining confidence speaking to groups, and preparation for job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.

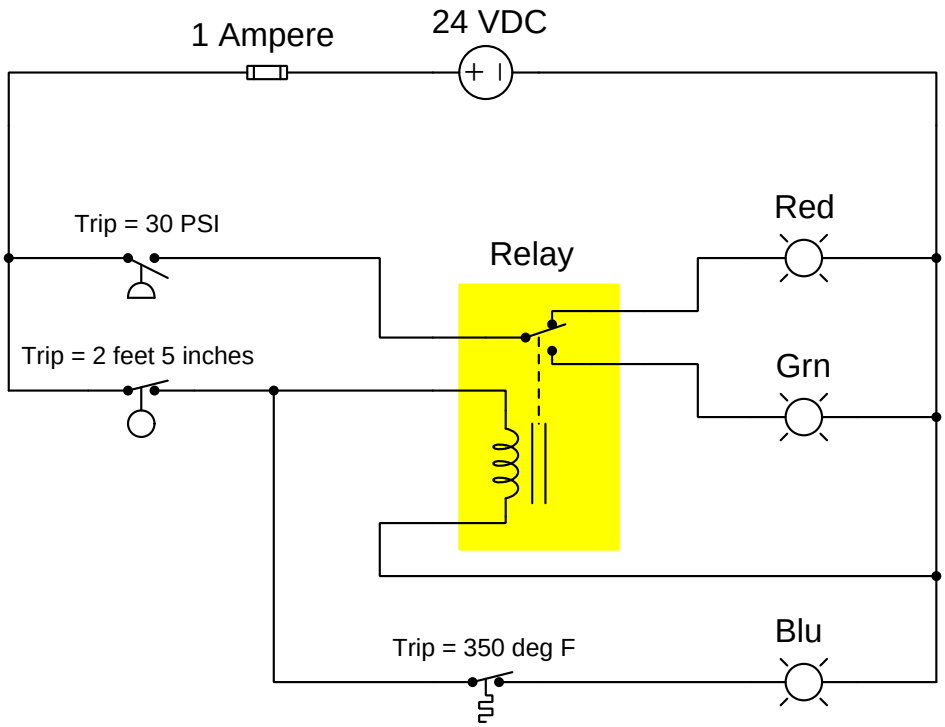
A problem will be randomly assigned to you from the options listed on the next several pages. No student will know which problem will be assigned to them until it is their turn to present, which means all students should be prepared to present on *every* problem shown. Furthermore, problems may contain unspecified parameters which will also be randomized at presentation time. Full credit will be given only for answers that are correct *and* logically supported by trusted principles and sources (e.g. Conservation of Energy, Ohm's Law, datasheets, etc.).

You are to regard your audience as technically adept (i.e. assuming everyone in attendance is familiar with the technical concepts and language; "skilled in the art").

file wt_0382

Problem #1

Identify component statuses both before and after _____ fails (*open/shorted*), assuming the specified process conditions:



- Pressure = _____ PSI
- Level = _____ feet
- Temperature = _____ degrees F

`Grading`

◯ [10%] Red lamp status (*on/off*) before the fault occurs =
◯ [10%] Green lamp status (*on/off*) before the fault occurs =
◯ [10%] Blue lamp status (*on/off*) before the fault occurs =
◯ [10%] Relay coil status (*energized/de-energized*) before the fault occurs =

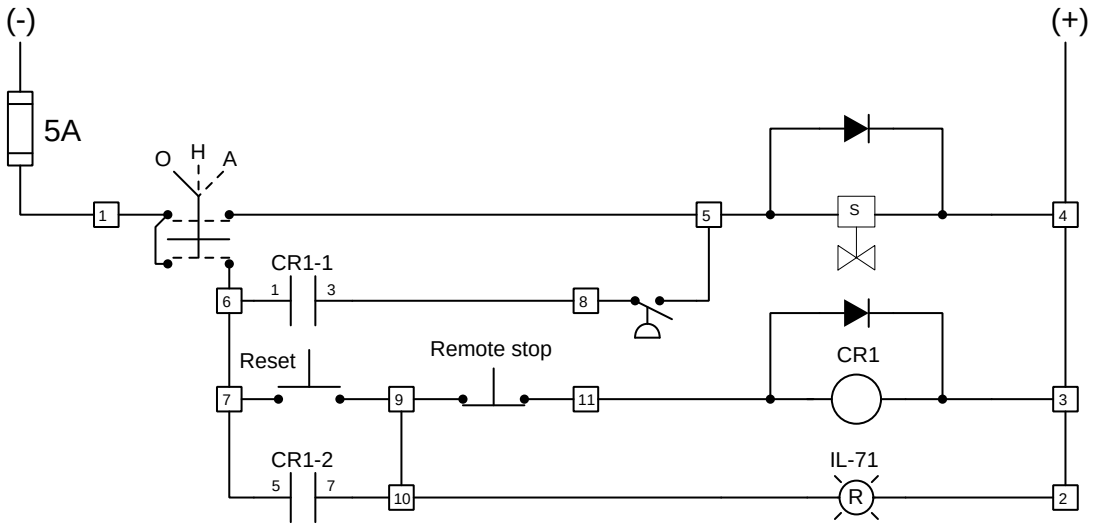
◯ [10%] Red lamp status (*on/off*) after the fault occurs =
◯ [10%] Green lamp status (*on/off*) after the fault occurs =
◯ [10%] Blue lamp status (*on/off*) after the fault occurs =
◯ [10%] Relay coil status (*energized/de-energized*) after the fault occurs =

◯ [20%] Source current change (*increase/decrease/same as before the fault*) =

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #2

This relay-controlled solenoid system is supposed to energize the solenoid valve whenever the selector switch is in the "Hand" position, or when the pressure switch commands it to while in "Auto" (and the Reset switch has been pressed):



Here are the symptoms:

- Solenoid valve not energizing when _____
-
-
-

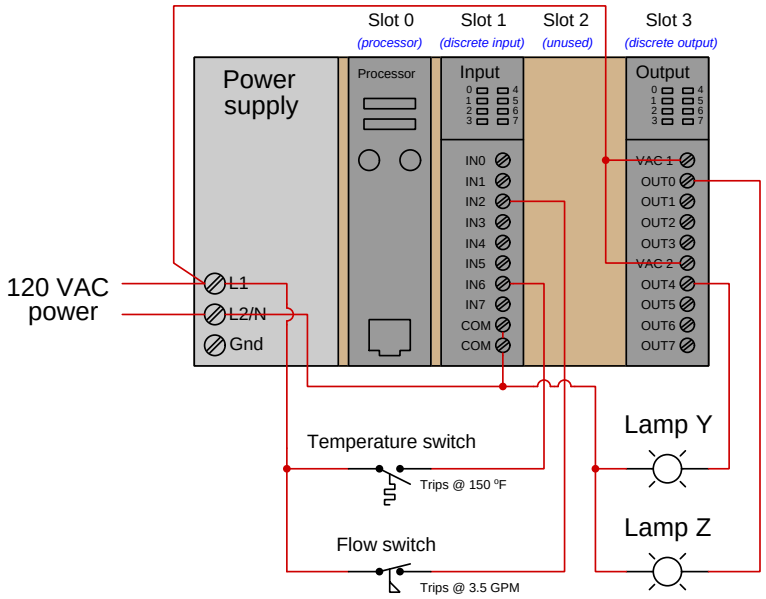
`Grading`

◯ [20%] Identify one physical fault sufficient to account for all symptoms
◯ [20%] Describe a diagnostic test that would confirm your first proposed fault
◯ [20%] Identify another physical fault sufficient to account for all symptoms
◯ [20%] Describe a diagnostic test that would confirm your second proposed fault
◯ [20%] Describe how the system would behave if the fault was _____ instead

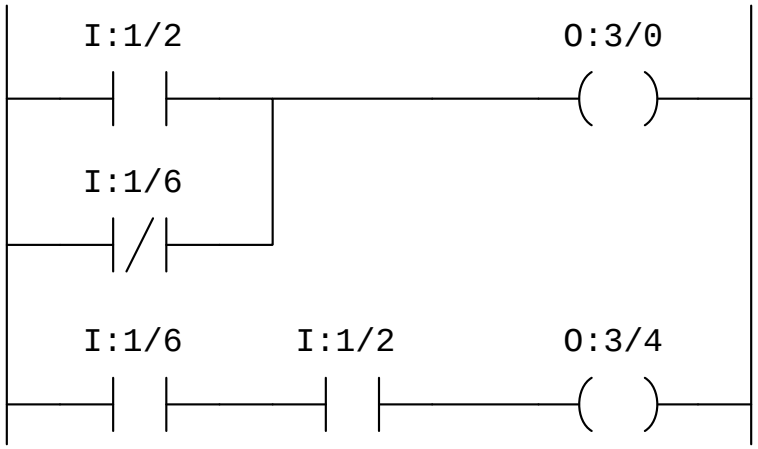
Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #3

A PLC connects to a pair of process switches and lamps as shown below:



"Offline-view" (i.e. non-color-highlighted) relay ladder logic (RLL) program:



Instructor-provided: Temperature = _____ Flow rate = _____

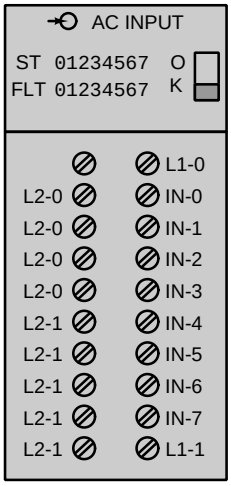
`Grading`

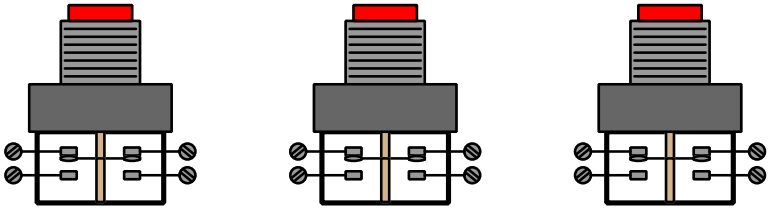
- ◯ [20%] Color highlighting of `I:1/2` contact instructions
- ◯ [20%] Color highlighting of `I:1/6` contact instructions
- ◯ [20%] Color highlighting of `O:3/0` coil instruction
- ◯ [20%] Color highlighting of `O:3/4` coil instruction
- ◯ [20%] Effect on Lamp ____ if _____ switch fails (*open* or *shorted*)

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #4

Sketch wires to properly connect a Rockwell (Allen-Bradley) model 1756-IA8D discrete input module to three normally-open pushbutton switches. Connect one switch to input _____, one switch to input _____, and one switch to input _____.





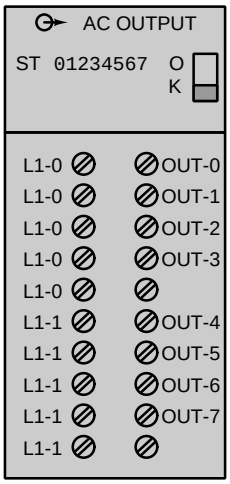
`Grading`

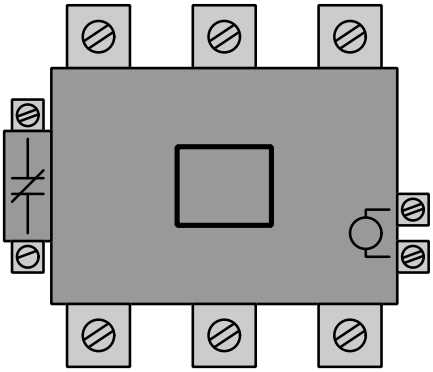
- ◯ [20%] Proper electrical source (*AC versus DC, Voltage value*)
- ◯ [20%] First switch is fully functional, including open-wire detection resistor
- ◯ [20%] Second switch is fully functional, including open-wire detection resistor
- ◯ [20%] Third switch is fully functional, including open-wire detection resistor
- ◯ [20%] "Loss of field power" connections correct

Note: access to the appropriate Rockwell Automation technical documentation is permitted for this assessment. As usual, full credit given only for answers that are correct <u>and</u> logically supported by trusted principles.

Problem #5

Sketch wires to properly connect a Rockwell (Allen-Bradley) model 1756-OA8 discrete output module to two lamps and one motor contactor (relay) coil. Connect one lamp to output _____, one lamp to output _____, and the motor contactor coil to output _____.





`Grading`

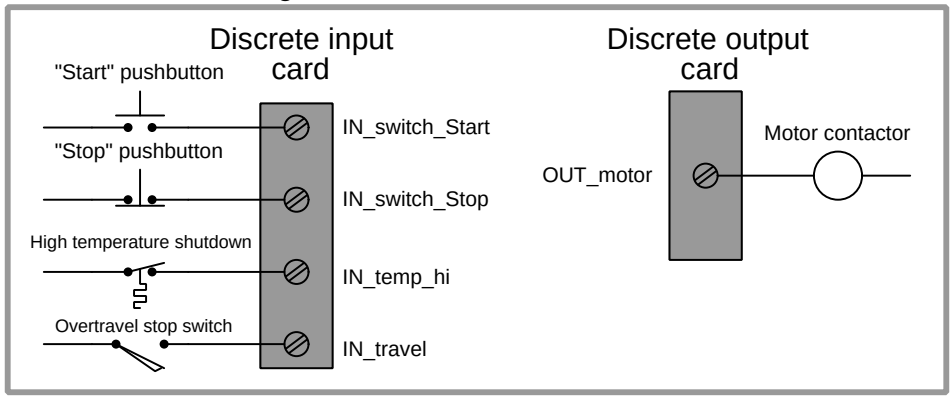
- ◯ [20%] Proper electrical source (*AC versus DC, Voltage value*)
- ◯ [20%] First lamp is fully functional
- ◯ [20%] Second lamp is fully functional
- ◯ [20%] Motor contactor is fully functional
- ◯ [20%] Fuse(s) installed in appropriate location(s)

Note: access to the appropriate Rockwell Automation technical documentation is permitted for this assessment. As usual, full credit given only for answers that are correct <u>and</u> logically supported by trusted principles.

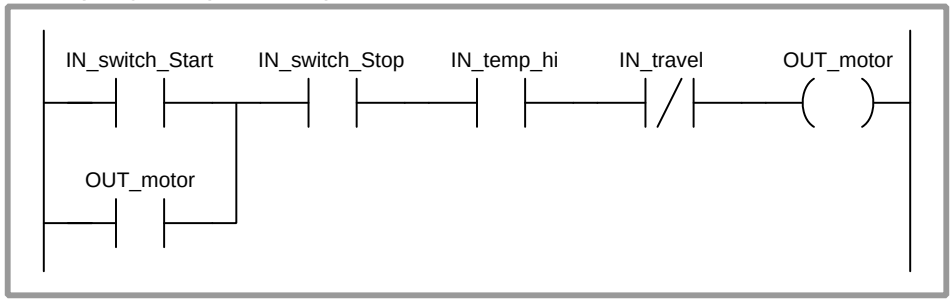
Problem #6

The following diagrams show I/O wiring and a "live" view of the PLC's ladder diagram program for a motor control system. This system used to function quite well, but suddenly stopped working correctly: when the operator presses the Start pushbutton, the motor refuses to start up. The "live" PLC program view shows conditions with no pushbuttons being pressed, after one of the operator's failed attempts to start the motor:

Real-world I/O wiring



PLC program (live view)



Note: the instructor will provide color-highlighting of the program.

`Grading`

- ◯ [20%] Identify one physical fault sufficient to account for all symptoms
- ◯ [20%] Describe a diagnostic test that would confirm your first proposed fault
- ◯ [20%] Identify another physical fault sufficient to account for all symptoms
- ◯ [20%] Describe a diagnostic test that would confirm your second proposed fault
- ◯ [20%] Describe how the system would behave if the fault was _____ instead

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Theory session 12

The written exam will consist of the following types of questions and their *related principles*:

- (Question #1) Determine PLC output states based on pushbutton switch stimuli, schematic diagrams, and PLC ladder-diagram code.
  PLC ladder-diagram programming, normally-open versus normally-closed switch behavior, color highlighting of PLC instructions

- (Question #2) Sketch wire connections for sourcing/sinking PLC outputs.
  Sources versus loads, definitions of "sinking" and "sourcing" current, BJT switching circuits, MOSFET switching circuits, optocoupler function

- (Question #3) Sketch wire connections for sourcing/sinking PLC inputs.
  Sources versus loads, definitions of "sinking" and "sourcing" current, electrical switch wiring, optocoupler function, normally-open versus normally-closed switch contacts

- (Question #4) Determine possible faults in a PLC-controlled motor system given I/O wiring diagram and the ladder-diagram program running in the PLC.
  PLC ladder-diagram programming, normally-open versus normally-closed switch behavior, series versus parallel switching circuit properties

- (Question #5) Determine possible faults in a relay ladder logic circuit.
  Properties of series and parallel networks, effects of opens vs. shorts, relay behavior, relay ladder diagram symbols and conventions

file wt_0305

Theory session 13

Source text – *PLC Contact and Coil Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_discrete.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Ladder diagram logic functions
  → Ladder diagram combinational logic
- Complete "Determining truth table from PLC program" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Design a PLC program to spec" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Troubleshooting motor control PLC using voltmeter" in the Diagnostic Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0371

Theory session 14

Source text – *Human-Machine Interfaces* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_hmi.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Human-Machine Interface basics
  → Tag name databases
  → Advanced HMI functionality
- Complete "Possible faults in a PLC/HMI pump control system" in the Diagnostic Reasoning section of the Questions chapter.
- Complete "Diagnostic tests on a failed PLC/HMI pump control system" in the Diagnostic Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with building and running HMI displays in either HMI simulation software or on a real HMI.
  → e.g. explore the graphical object library for an HMI to see what control and display objects are available
  → e.g. navigate the tag name database and try configuring some tags

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!
- Some HMI programming software has the ability to simulate the operation of a programmed HMI, and Automation Direct's *C-More Micro* and *C-More EA9* packages will do this. The software is free and easy to use!

file wt_0331

Theory session 15

Source text – *Human-Machine Interfaces* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_hmi.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Discrete (Boolean) tag programming
- Complete "Troubleshooting a new HMI/PLC system" in the Diagnostic Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with building and running HMI displays in either HMI simulation software or on a real HMI.
  → e.g. configure a pushbutton control to set and clear a discrete tag, then display that tag's status using one or more indicator objects

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!
- Some HMI programming software has the ability to simulate the operation of a programmed HMI, and Automation Direct's *C-More Micro* and *C-More EA9* packages will do this. The software is free and easy to use!

file wt_0332

Theory session 16

Source text – *PLC Counter Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_counter.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete "Experiment: up counter instruction behavior" in the Projects and Experiments chapter.
- Complete "Experiment: down counter instruction behavior" in the Projects and Experiments chapter.
- Complete "Experiment: up/down counter instruction behavior" in the Projects and Experiments chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0366

Theory session 17

Source text – *PLC Counter Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_counter.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Examine and reflect on the Example: PLC counters and timing diagrams section of the Case Tutorial chapter, and explain why each counter instruction's output signal is as shown (in red) on each timing diagram.
- Complete "Room occupancy counter" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Counter status and timing diagrams" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Cannery counter diagnosis" in the Diagnostic Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0372

Theory session 18

Source text – *PLC Counter Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_counter.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Complete "Rockwell Logix5000 PLC counter instructions" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Allen-Bradley counter program" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Counter output and timing diagrams" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Parking garage counter faults" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0324

Theory session 19

Source text – *PLC Counter Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_counter.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Complete "Experiment: hour/minute/second clock" in the Projects and Experiments chapter.
- Complete "Experiment: hydro turbine shutdown counter" in the Projects and Experiments chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0373

Theory session 20

Source text – *Digital Numeration* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_number.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Numbers versus numeration
  → Place-weighted numeration
- Complete "Counting in binary, octal, and hexadecimal" in the Quantitative Reasoning section of the Questions chapter.
- If time permits, use PLC programming/simulation software to explore hexadecimal and binary expressions of counter instruction count values.
  → e.g. configure a counter to count up and/or down, then display the counter's value in different numerical formats. When viewing the PLC's program "live" using programming software, Rockwell Logix5000 PLCs offer a *Controller tags* folder to see variable values, older Rockwell (Allen-Bradley) PLCs offer *Data Files* which may be viewed, Siemens S7 PLCs offer a *Status Chart* for viewing variable values, and Koyo PLCs offer *Data View* windows.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0374

Theory session 21

Source text – *Digital Numeration* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_number.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Unsigned integers
- Complete "Unsigned decimal-binary and binary-decimal conversions" in the Quantitative Reasoning section of the Questions chapter.
- If time permits, use PLC programming/simulation software to explore hexadecimal and binary expressions of counter instruction count values.
  → e.g. configure a counter to count up and/or down, then display the counter's value in different numerical formats. When viewing the PLC's program "live" using programming software, Rockwell Logix5000 PLCs offer a *Controller tags* folder to see variable values, older Rockwell (Allen-Bradley) PLCs offer *Data Files* which may be viewed, Siemens S7 PLCs offer a *Status Chart* for viewing variable values, and Koyo PLCs offer *Data View* windows.

Theory Session Expectations:

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file wt_0375

Theory session 22

During today's theory session we will spend time reviewing and practicing any concepts you wish prior to the upcoming Oral Presentations and Written Exam. These may include review of past topics, assigned questions, and/or experiments as well as topics or questions you're interested in exploring that we did not specifically address in a prior theory session. Feel free to look ahead in your course document to the next set of Oral Presentations as well as to the next written exam description to see what challenges await.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0309

Theory session 23

Oral Presentations

Today's class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. When you are chosen to present, you will have a brief period of time to gather your thoughts and set up for your presentation.

A format proven to work well is that all students in the class are given a unique problem to solve, and 15 minutes of time to independently devise solutions. These 15-minute periods are closed-book and closed-note just like written exams. After that 15-minute period, the instructor collects all the papers (each with the student's name written on top) and gives each student 10 minutes to present their solution before the entire class while everyone else observes.

Your instructor will not provide answers to you prior to or during the presentation; you are solely responsible for any research, experimentation, and other actions necessary to adequately prepare for your presentation. If you inquire for help, the instructor may clarify what you will need to present on, and/or point you toward specific resources (e.g. "Try setting up a SPICE simulation", "Try building a test circuit on your breadboard", "Find and read the datasheet(s)", "Research application notes written on this topic", etc.), but do not expect them to give you answers or check your work because by this point in time you will have studied the necessary concepts to verify results for yourself, or at least to know where to go to find verification.

During your presentation the instructor and audience members are free to pose questions relevant to the graded objectives for your assigned problem. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions.

The benefits of this exercise include honing your independent research skills, reinforcing your foundational knowledge of electronics, gaining confidence speaking to groups, and preparation for job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.

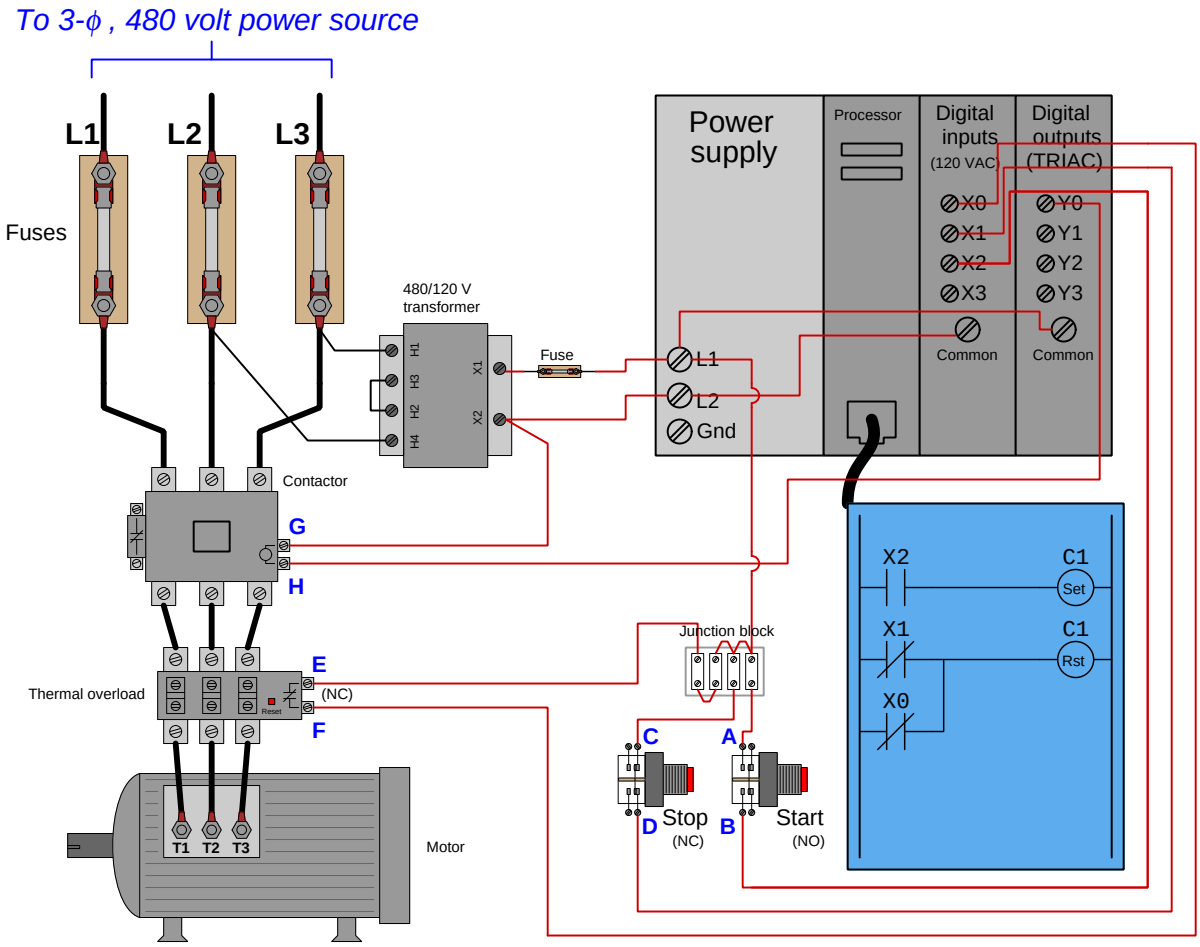
A problem will be randomly assigned to you from the options listed on the next several pages. No student will know which problem will be assigned to them until it is their turn to present, which means all students should be prepared to present on *every* problem shown. Furthermore, problems may contain unspecified parameters which will also be randomized at presentation time. Full credit will be given only for answers that are correct *and* logically supported by trusted principles and sources (e.g. Conservation of Energy, Ohm's Law, datasheets, etc.).

You are to regard your audience as technically adept (i.e. assuming everyone in attendance is familiar with the technical concepts and language; "skilled in the art").

file wt_0380

Problem #1

A newly constructed PLC-controlled motor starter system refuses to work – the motor shaft does not turn after the operator presses the "Start" switch and waits. A laptop PC shows the PLC program displayed in offline mode, without any colored status highlighting:



A voltage measurement taken between test points ____ and ____ shows _____ Volts AC with the "Start" pushbutton (*pressed / unpressed*).

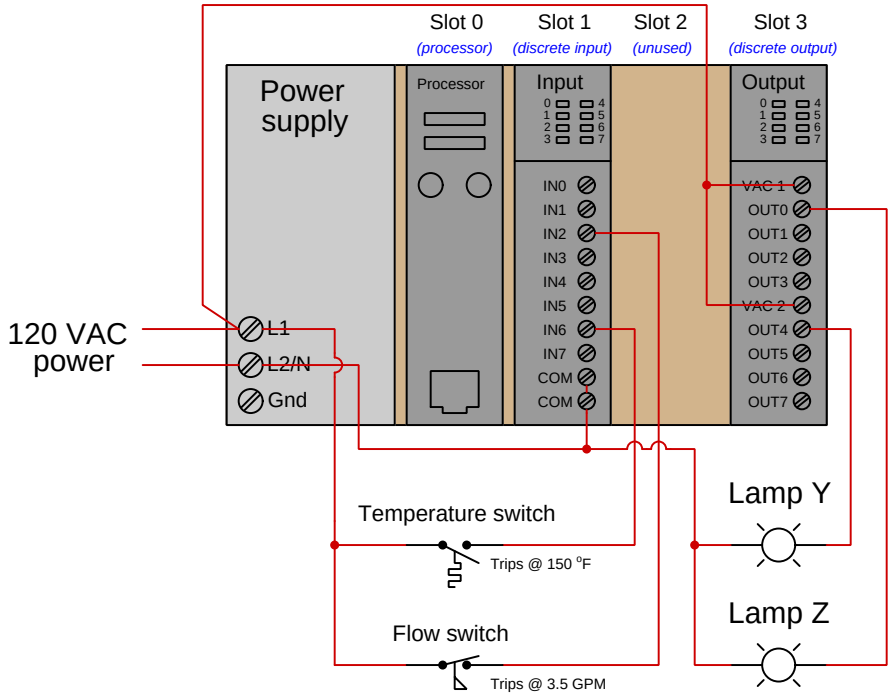
`Grading`

- ◯ [20%] Identify one physical fault sufficient to account for all symptoms
- ◯ [20%] Describe a diagnostic test that would confirm your first proposed fault
- ◯ [20%] Identify another physical fault sufficient to account for all symptoms
- ◯ [20%] Describe a diagnostic test that would confirm your second proposed fault
- ◯ [20%] Describe how the system would behave if the fault was _____ instead

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #2

Determine the states of the two lamps as well as all virtual contact coloring in a "live" (online) display of this PLC's program when the temperature is _____ degrees F and the flow rate is _____ gallons per minute:



Offline PLC program: *(instructor draws RLL program with contacts and coils only)*

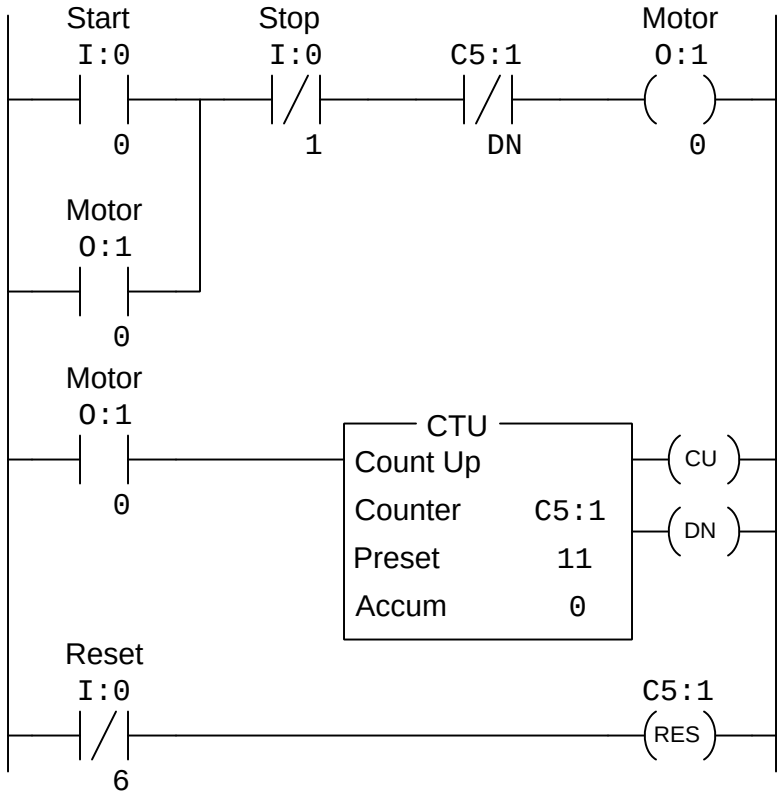
`Grading`

- ◯ [20%] Energization status of lamp Y
- ◯ [20%] Energization status of lamp Z
- ◯ [20%] Color-highlighting status of instruction _____
- ◯ [20%] Color-highlighting status of instruction _____
- ◯ [20%] Effect(s) of _____ electrically failing (*open / shorted*)

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #3

Answer questions related to this Allen-Bradley MicroLogix PLC program:



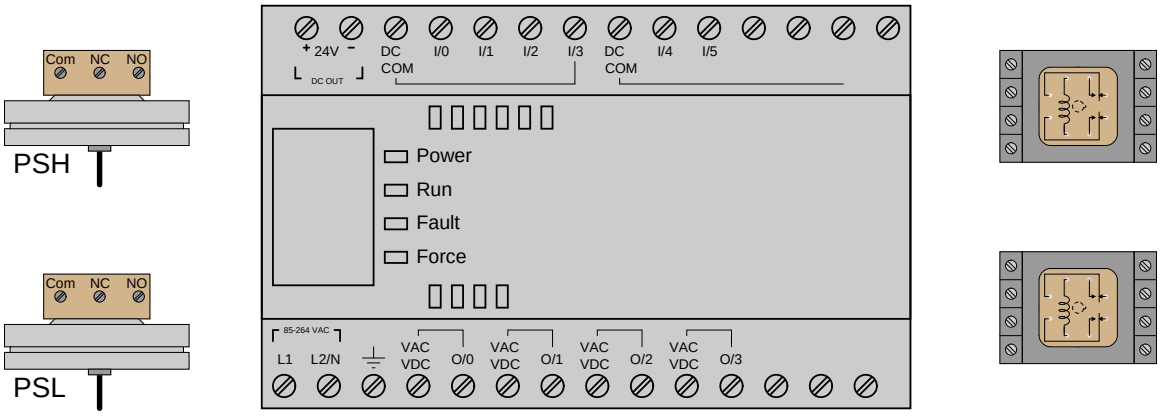
`Grading`

- ◯ [20%] Under what condition(s) will the motor start up?
- ◯ [20%] Under what condition(s) will the motor shut off?
- ◯ [20%] What purpose does the Reset input do in this system?
- ◯ [20%] Necessary NO/NC contact types for the Start, Stop, and Reset pushbutton switches
- ◯ [20%] Effect(s) of _____ electrically failing (*open / shorted*)

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #4

Sketch the wires necessary to connect two pressure switches and two relay coils to the following Allen-Bradley MicroLogix 1000 PLC (model 1761-L10BWA, with 6 discrete DC inputs either sourcing or sinking, and 4 discrete relay contact outputs):



Be sure to wire the two pressure switches and relay coils according to these specifications:

- The high pressure switch (PSH) (*sources / sinks*) current to/from input `I/2` when its sensed fluid pressure is (*higher than / lower than*) its trip setting
- The low pressure switch (PSL) (*sources / sinks*) current to/from input `I/4` when its sensed fluid pressure is (*higher than / lower than*) its trip setting
- Output `O:0` (*sources / sinks*) current to/from one relay coil rated for _____ Volts (*AC / DC*)
- Output `O:3` (*sources / sinks*) current to/from the other relay coil rated for _____ Volts (*AC / DC*)

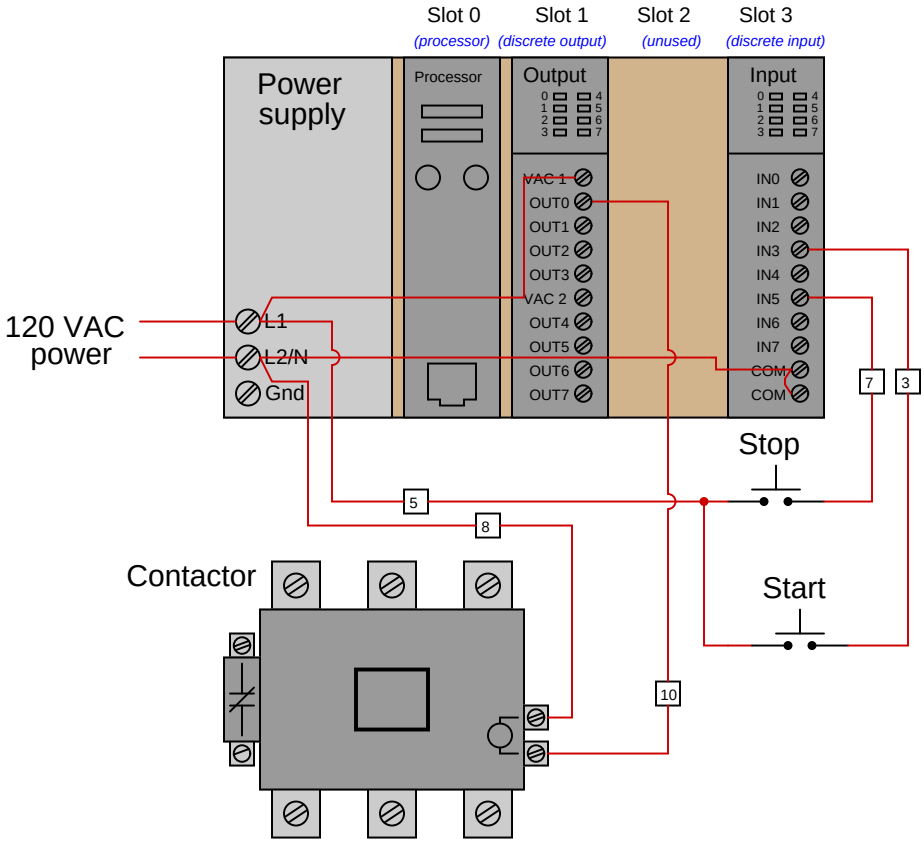
`Grading`

◯ [20%] Proper switch contact and I/O wiring for the PSH switch
◯ [20%] Proper switch contact and I/O wiring for the PSL switch
◯ [20%] Proper relay coil and I/O wiring for the first relay
◯ [20%] Proper relay coil and I/O wiring for the second relay
◯ [20%] Explain how to thoroughly test one of the relays when unplugged from its socket

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #5

Suppose _____ electrically fails (*open / shorted*) in this PLC-controlled motor starter system:



`Grading`

- ◯ [20%] Explain how this fault could be identified using a multimeter
- ◯ [20%] Explain how this fault could be identified by examining a "live" (online) display of the PLC's program
- ◯ [20%] Sketch a plausible ladder-logic program for this system
- ◯ [20%] Sketch wires showing how to connect the contactor's auxiliary contact to input `IN0` on the PLC
- ◯ [20%] Sketch wires showing how a three-phase AC power source would connect to a three-phase motor through the contactor

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #6

Build an HMI program with the following objects, using software installed on your computer, according to the following specifications. Assume the HMI will be communicating with a Koyo brand "CLICK" PLC, even though a PLC will not be needed for this:

- Virtual pushbutton labeled "Start" writes to discrete address _____ in the PLC
- Virtual pushbutton labeled "Stop" writes to discrete address _____ in the PLC
- Virtual lamp shows when counter _____ in the PLC is "complete" and reached the SetPoint value

`Grading`

◯ [20%] PLC device type (Koyo CLICK) is properly configured in the HMI software
◯ [20%] All tag names configured for proper PLC data types in the tag name database
◯ [20%] All graphical objects properly linked to tag
◯ [20%] All graphical objects reasonably labeled
◯ [20%] All graphical objects positioned neatly on the HMI screen

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Theory session 24

The written exam will consist of the following types of questions and their *related principles*:

- (Question #1) Convert between unsigned binary and decimal values.
  Place-weighted integer interpretation

- (Question #2) Associate PLC ladder-diagram programs containing counter instructions with timing diagrams showing bit and/or register states.
  PLC ladder-diagram programming, normally-open versus normally-closed switch behavior, color highlighting of PLC instructions, properties of series and parallel networks, PLC "up" counter instruction behavior, PLC "down" counter instruction behavior, PLC "up/down" counter instruction behavior

- (Question #3 – REVIEW) Determine PLC I/O statutes, bit statuses, and color-highlighting from process switch stimuli, schematic diagrams, and PLC ladder-diagram code.
  PLC ladder-diagram programming, normally-open versus normally-closed switch behavior, color highlighting of PLC instructions, process switch (e.g. pressure, flow, temperature) operation

- (Question #4 – REVIEW) Determine possible faults in a PLC-controlled motor system given I/O wiring diagram and the ladder-diagram program running in the PLC.
  PLC ladder-diagram programming, normally-open versus normally-closed switch behavior, series versus parallel switching circuit properties

- (Question #5 – REVIEW) Determine possible faults in a relay ladder logic circuit.
  Properties of series and parallel networks, effects of opens vs. shorts, relay behavior, relay ladder diagram symbols and conventions

file wt_0381

Theory session 25

Source text – *Digital Numeration* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_number.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Shorthand representations of digital words
- Complete "Binary to decimal and hex conversions" in the Quantitative Reasoning section of the Questions chapter.
- If time permits, use PLC programming/simulation software to explore hexadecimal and binary expressions of counter instruction count values.
  → e.g. configure a counter to count up and/or down, then display the counter's value in different numerical formats. When viewing the PLC's program "live" using programming software, Rockwell Logix5000 PLCs offer a *Controller tags* folder to see variable values, older Rockwell (Allen-Bradley) PLCs offer *Data Files* which may be viewed, Siemens S7 PLCs offer a *Status Chart* for viewing variable values, and Koyo PLCs offer *Data View* windows.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0386

Theory session 26

Source text – *Digital Numeration* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_number.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Signed integers
- Complete "Four-bit signed binary integers" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Signed decimal-binary and binary-decimal conversions" in the Quantitative Reasoning section of the Questions chapter.
- If time permits, use PLC programming/simulation software to explore hexadecimal and binary expressions of counter instruction count values.
  → e.g. configure a counter to count up and/or down, then display the counter's value in different numerical formats. When viewing the PLC's program "live" using programming software, Rockwell Logix5000 PLCs offer a *Controller tags* folder to see variable values, older Rockwell (Allen-Bradley) PLCs offer *Data Files* which may be viewed, Siemens S7 PLCs offer a *Status Chart* for viewing variable values, and Koyo PLCs offer *Data View* windows.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0384

Theory session 27

Source text – *Digital Numeration* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_number.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Complete "Rockwell Logix5000 PLC integer data types" in the Quantitative Reasoning section of the Questions chapter.
- If time permits, use PLC programming/simulation software to explore hexadecimal and binary expressions of counter instruction count values.
  → e.g. configure a counter to count up and/or down, then display the counter's value in different numerical formats. When viewing the PLC's program "live" using programming software, Rockwell Logix5000 PLCs offer a *Controller tags* folder to see variable values, older Rockwell (Allen-Bradley) PLCs offer *Data Files* which may be viewed, Siemens S7 PLCs offer a *Status Chart* for viewing variable values, and Koyo PLCs offer *Data View* windows.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0385

Theory session 28

Source text – *Human-Machine Interfaces* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_hmi.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Integer tag programming
  → Integer incompatibility
- Complete "Possible faults in a PLC/HMI package-counting system" in the Diagnostic Reasoning section of the Questions chapter.
- Complete "Failed parking garage counter" in the Diagnostic Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with intentional mis-configurations between a PLC and an HMI to see how integer values may be wrongly displayed on the HMI as a result.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!
- Some HMI programming software has the ability to simulate the operation of a programmed HMI, and Automation Direct's *C-More Micro* and *C-More EA9* packages will do this. The software is free and easy to use!

file wt_0387

Theory session 29

Source text – *PLC Timer Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_timer.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the Tutorial chapter in its entirety.
- Complete "Experiment: on-delay timer instruction behavior" in the Projects and Experiments chapter.
- Complete "Experiment: off-delay timer instruction behavior" in the Projects and Experiments chapter.
- Complete "Experiment: retentive timer instruction behavior" in the Projects and Experiments chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0376

Theory session 30

Source text – *PLC Timer Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_timer.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Examine and reflect on the Example: Example: PLC timers and timing diagrams section of the Case Tutorial chapter, and explain why each timer instruction's output signal is as shown (in red) on each timing diagram.
- Complete "PLC timing diagrams" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Switch contact types for a timed conveyor control" in the Conceptual Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs.
  → For example, experiment with timer instructions
- Time permitting during the class session, experiment with building and running HMI displays in either HMI simulation software or on a real HMI.
  → For example, experiment with having the HMI display a PLC timer instruction's current value
  → For example, experiment with having the HMI set a PLC timer instruction's preset value

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0377

Theory session 31

Source text – *PLC Timer Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_timer.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Complete "Rockwell Logix5000 PLC timer instructions" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Air compressor control program" in the Conceptual Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs.
- Time permitting during the class session, experiment with building and running HMI displays in either HMI simulation software or on a real HMI.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0378

Theory session 32

Source text – *PLC Timer Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_timer.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Complete "Experiment: mixer motor control program" in the Projects and Experiments chapter.
- Complete "Experiment: model rocket launcher program" in the Projects and Experiments chapter.
- Time permitting, run experiments implementing any concepts learned previously. Look ahead to upcoming assessments such as the Oral Presentations session (#35) and/or the written exam session (#36) for ideas on what to practice.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0379

Theory session 33

Source text – *PLC Timer Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_timer.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Complete "Correcting PLC program errors" in the Diagnostic Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs.
- Time permitting during the class session, experiment with building and running HMI displays in either HMI simulation software or on a real HMI.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0396

Theory session 34

During today's theory session we will spend time reviewing and practicing any concepts you wish prior to the upcoming Oral Presentations and Written Exam. These may include review of past topics, assigned questions, and/or experiments as well as topics or questions you're interested in exploring that we did not specifically address in a prior theory session. Feel free to look ahead in your course document to the next set of Oral Presentations as well as to the next written exam description to see what challenges await.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0309

Theory session 35

Oral Presentations

Today's class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. When you are chosen to present, you will have a brief period of time to gather your thoughts and set up for your presentation.

A format proven to work well is that all students in the class are given a unique problem to solve, and 15 minutes of time to independently devise solutions. These 15-minute periods are closed-book and closed-note just like written exams. After that 15-minute period, the instructor collects all the papers (each with the student's name written on top) and gives each student 10 minutes to present their solution before the entire class while everyone else observes.

Your instructor will not provide answers to you prior to or during the presentation; you are solely responsible for any research, experimentation, and other actions necessary to adequately prepare for your presentation. If you inquire for help, the instructor may clarify what you will need to present on, and/or point you toward specific resources (e.g. "Try setting up a SPICE simulation", "Try building a test circuit on your breadboard", "Find and read the datasheet(s)", "Research application notes written on this topic", etc.), but do not expect them to give you answers or check your work because by this point in time you will have studied the necessary concepts to verify results for yourself, or at least to know where to go to find verification.

During your presentation the instructor and audience members are free to pose questions relevant to the graded objectives for your assigned problem. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions.

The benefits of this exercise include honing your independent research skills, reinforcing your foundational knowledge of electronics, gaining confidence speaking to groups, and preparation for job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.

A problem will be randomly assigned to you from the options listed on the next several pages. No student will know which problem will be assigned to them until it is their turn to present, which means all students should be prepared to present on *every* problem shown. Furthermore, problems may contain unspecified parameters which will also be randomized at presentation time. Full credit will be given only for answers that are correct *and* logically supported by trusted principles and sources (e.g. Conservation of Energy, Ohm's Law, datasheets, etc.).

You are to regard your audience as technically adept (i.e. assuming everyone in attendance is familiar with the technical concepts and language; "skilled in the art").

Problem #1

Convert between the following unsigned integer values:

Convert _____ (binary) to hexadecimal

Convert _____ (binary) to decimal

Convert _____ (decimal) to binary

Convert _____ (decimal) to binary

Convert _____ (hexadecimal) to binary

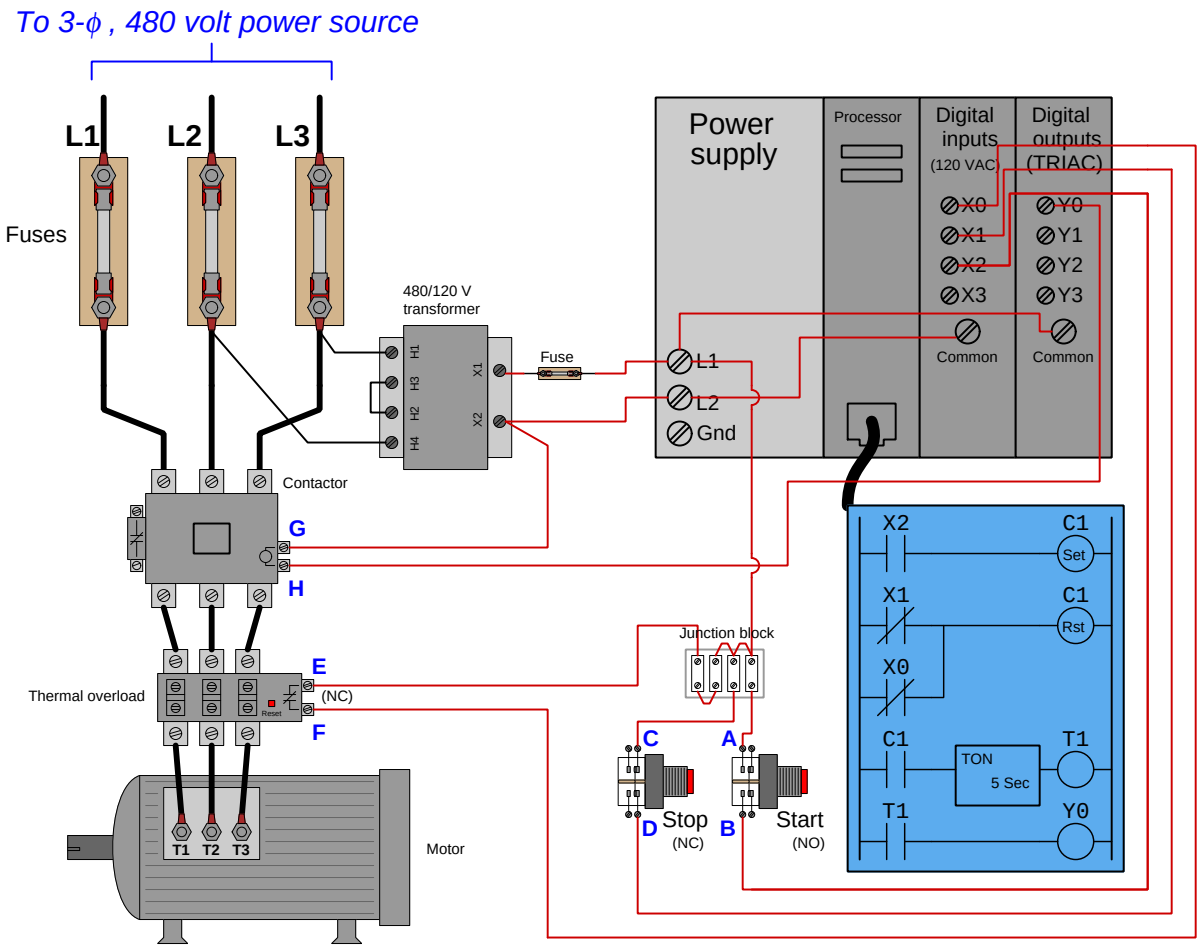
`Grading`

- ◯ [20%] Correct first conversion
- ◯ [20%] Correct second conversion
- ◯ [20%] Correct third conversion
- ◯ [20%] Correct fourth conversion
- ◯ [20%] Correct fifth conversion

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #2

A newly constructed PLC-controlled motor starter system refuses to work – the motor shaft does not turn after the operator presses the "Start" switch and waits. A laptop PC shows the PLC program displayed in offline mode, without any colored status highlighting:



A voltage measurement taken between test points ____ and ____ shows _____ Volts AC with the "Start" pushbutton (*pressed / unpressed*).

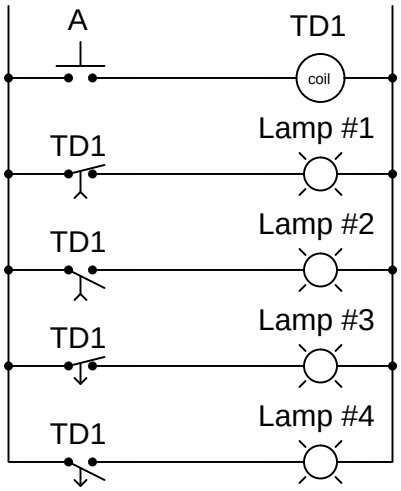
`Grading`

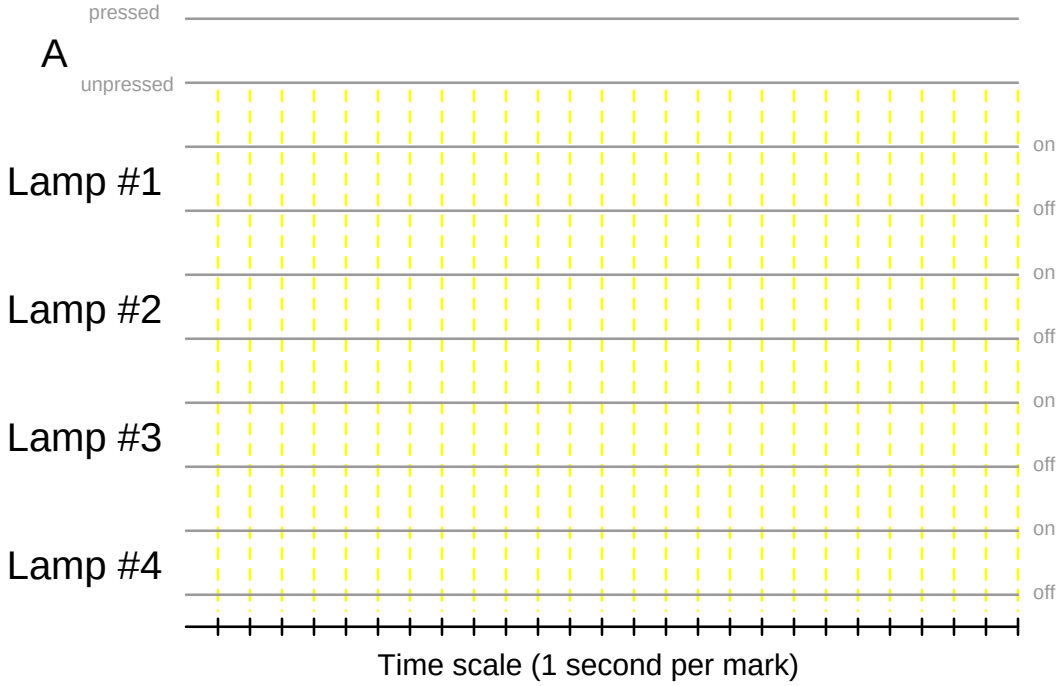
- ◯ [20%] Identify one physical fault sufficient to account for all symptoms
- ◯ [20%] Describe a diagnostic test that would confirm your first proposed fault
- ◯ [20%] Identify another physical fault sufficient to account for all symptoms
- ◯ [20%] Describe a diagnostic test that would confirm your second proposed fault
- ◯ [20%] Describe how the system would behave if the fault was _____ instead

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #3

Determine what each of the lamps will do in the following circuit when pushbutton "A" is pressed and released according to the timing diagram drawn by the instructor. The instructor will also denote the amount of time delay provided for each of TD1's four contacts:





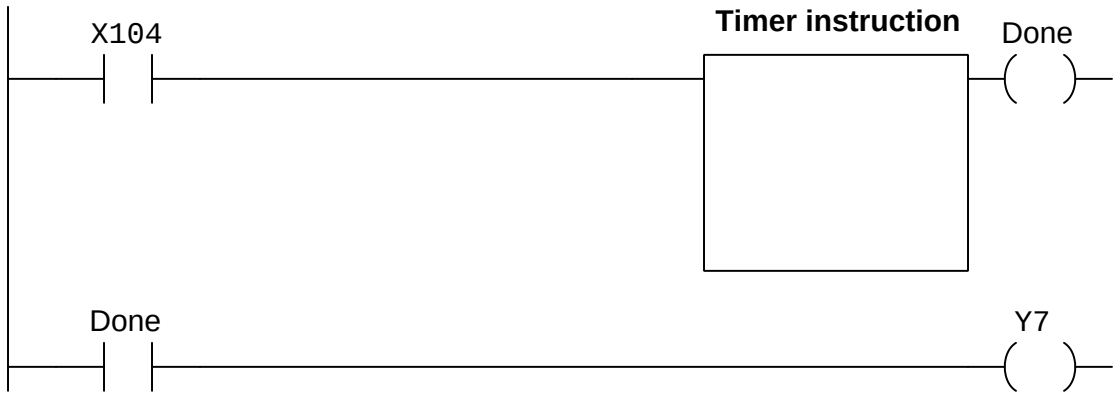
`Grading`

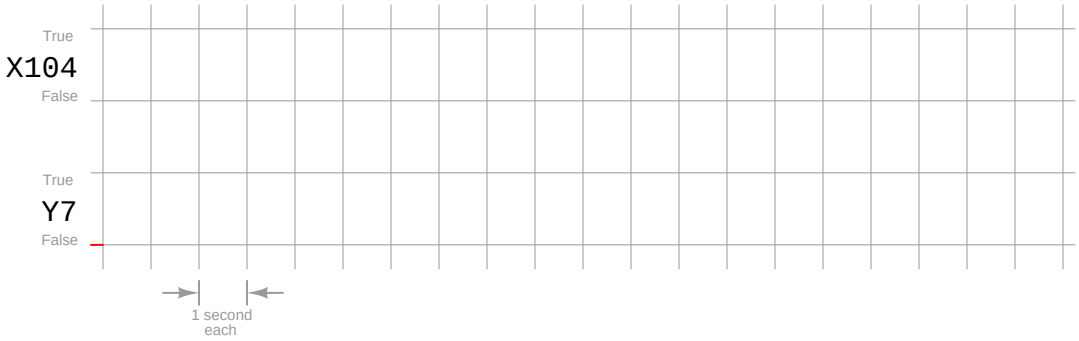
- ◯ [20%] Correctly drawn timing diagram for lamp #1
- ◯ [20%] Correctly drawn timing diagram for lamp #2
- ◯ [20%] Correctly drawn timing diagram for lamp #3
- ◯ [20%] Correctly drawn timing diagram for lamp #4
- ◯ [20%] Effect(s) of _____ electrically failing (*open / shorted*)

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #4

Complete the timing diagram for this PLC timer-based program to show the state of output bit `Y7` over time. The instructor will sketch the states of the input bit `X104`, specify the type of timer instruction (*on-delay / off-delay / retentive on-delay*), and also the NO/NC contact instruction types:





Assume the timer instruction has not yet been enabled since the PLC was powered up prior to the start of this timing diagram.

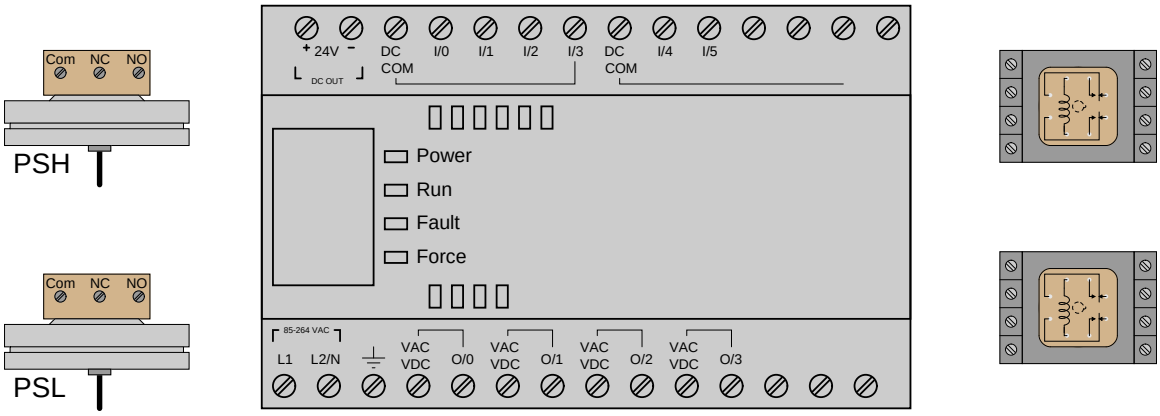
`Grading`

◯ [5%] for each of the twenty periods in the timing diagram

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #5

Sketch the wires necessary to connect two pressure switches and two relay coils to the following Allen-Bradley MicroLogix 1000 PLC (model 1761-L10BWA, with 6 discrete DC inputs either sourcing or sinking, and 4 discrete relay contact outputs):



Be sure to wire the two pressure switches and relay coils according to these specifications:

- The high pressure switch (PSH) (*sources / sinks*) current to/from input `I/2` when its sensed fluid pressure is (*higher than / lower than*) its trip setting
- The low pressure switch (PSL) (*sources / sinks*) current to/from input `I/4` when its sensed fluid pressure is (*higher than / lower than*) its trip setting
- Output `O:0` (*sources / sinks*) current to/from one relay coil rated for _____ Volts (*AC / DC*)
- Output `O:3` (*sources / sinks*) current to/from the other relay coil rated for _____ Volts (*AC / DC*)

`Grading`

◯ [20%] Proper switch contact and I/O wiring for the PSH switch
◯ [20%] Proper switch contact and I/O wiring for the PSL switch
◯ [20%] Proper relay coil and I/O wiring for the first relay
◯ [20%] Proper relay coil and I/O wiring for the second relay
◯ [20%] Explain how to thoroughly test one of the relays when unplugged from its socket

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #6

Build an HMI program with the following objects, using software installed on your computer, according to the following specifications. Assume the HMI will be communicating with a Koyo brand "CLICK" PLC, even though a PLC will not be needed for this:

- Virtual pushbutton labeled "Start" writes to discrete address _____ in the PLC
- Virtual pushbutton labeled "Stop" writes to discrete address _____ in the PLC
- Horizontal bargraph display shows the current time value for timer _____ in the PLC
- Virtual lamp shows when timer _____ in the PLC is "done"

`Grading`

◯ [20%] PLC device type (Koyo CLICK) is properly configured in the HMI software
◯ [20%] All tag names configured for proper PLC data types in the tag name database
◯ [20%] All graphical objects properly linked to tag
◯ [20%] All graphical objects reasonably labeled
◯ [20%] All graphical objects positioned neatly on the HMI screen

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Theory session 36

The written exam will consist of the following types of questions and their *related principles*:

- (Question #1) Convert between different forms of digital numeration (e.g. binary, hexadecimal, decimal) for unsigned integer values.
  Unsigned binary integers, hexadecimal notation

- (Question #2) Associate PLC ladder-diagram programs containing timing instructions with timing diagrams showing bit and/or register states.
  PLC ladder-diagram programming, normally-open versus normally-closed switch behavior, color highlighting of PLC instructions, properties of series and parallel networks, PLC non-retentive "on-delay" timer instruction behavior, PLC retentive "on-delay" timer instruction behavior, PLC non-retentive "off-delay" timer instruction behavior

- (Question #3 – REVIEW) Determine PLC I/O statutes, bit statuses, and color-highlighting from process switch stimuli, schematic diagrams, and PLC ladder-diagram code.
  PLC ladder-diagram programming, normally-open versus normally-closed switch behavior, color highlighting of PLC instructions, process switch (e.g. pressure, flow, temperature) operation

- (Question #4 – REVIEW) Determine possible faults in a PLC-controlled motor system given I/O wiring diagram and the ladder-diagram program running in the PLC.
  PLC ladder-diagram programming, normally-open versus normally-closed switch behavior, series versus parallel switching circuit properties

- (Question #5 – REVIEW) Determine possible faults in a relay ladder logic circuit.
  Properties of series and parallel networks, effects of opens vs. shorts, relay behavior, relay ladder diagram symbols and conventions

file wt_0383

Theory session 37

Source text – *Digital Numeration* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_number.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Floating-point notation
- Complete "Dissecting floating-point numbers" in the Quantitative Reasoning section of the Questions chapter.
- If time permits, use PLC programming/simulation software to explore floating-point values. Note that all PLCs offer some form of instruction to either "copy" or "move" some specified numerical value into a variable stored in memory of the appropriate data type. You could use one of these to move a floating point value such as 3.1416 into a floating-point ("real") variable and then use the PLC software's viewing capability to monitor that value in decimal, hexadecimal, or binary forms.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

file wt_0388

Theory session 38

Source text – *Human-Machine Interfaces* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_hmi.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Floating-point (real) tag programming
- Complete "Decoding 32-bit real numbers" in the Quantitative Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with building and running HMI displays in either HMI simulation software or on a real HMI.
  → e.g. configure a numerical control to set values for a floating-point tag, then display that tag's value using one or more indicator objects

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0389

Theory session 39

Source text – *PLC Math Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_math.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Ladder diagram comparison instructions
- Complete "Rockwell PLC comparison instructions" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Experiment: counter comparator program" in the Projects and Experiments chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0390

Theory session 40

Source text – *PLC Math Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_math.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Ladder diagram arithmetic instructions
- Complete "Integer format error between PLC and HMI" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Experiment: tank fillage indicator program" in the Projects and Experiments chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0391

Theory session 41

Source text – *PLC Math Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_math.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Complete "Incorrect valve-control program" in the Diagnostic Reasoning section of the Questions chapter.
- Complete "Timed motor start system failure" in the Diagnostic Reasoning section of the Questions chapter.
- Complete "Failed water flow measuring system" in the Diagnostic Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0392

Theory session 42

Source text – *PLC Analog Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_analog.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Analog-to-digital conversion
  → Digital-to-analog conversion
  → Converter resolution
  → Converting between digital count and analog values
- Complete "Count values for analog PLC I/O" in the Quantitative Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0393

Theory session 43

Source text – *PLC Analog Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_analog.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → PLC analog I/O
- Complete "Rockwell ControlLogix analog module types" in the Conceptual Reasoning section of the Questions chapter.
- Complete "PLC sensing a potentiometer position" in the Conceptual Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs.
  → Try configuring your PLC's analog input(s) to sense signal voltage(s)

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0394

Theory session 44

Source text – *PLC Analog Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_analog.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → PLC analog signal scaling
- Complete "Scale weight indicator" in the Quantitative Reasoning section of the Questions chapter.
- Complete "Incorrect thermostat program" in the Diagnostic Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs.
  → Try programming your PLC's analog input(s) to control discrete outputs based on the sensed signal voltage(s)

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0395

Theory session 45

Source text – *PLC Analog Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_analog.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Complete "Experiment: furnace over-temperature shutdown program" in the Projects and Experiments chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0346

Theory session 46

During today's theory session we will spend time reviewing and practicing any concepts you wish prior to the upcoming Oral Presentations and Written Exam. These may include review of past topics, assigned questions, and/or experiments as well as topics or questions you're interested in exploring that we did not specifically address in a prior theory session. Feel free to look ahead in your course document to the next set of Oral Presentations as well as to the next written exam description to see what challenges await.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0309

Theory session 47

Oral Presentations

Today's class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. When you are chosen to present, you will have a brief period of time to gather your thoughts and set up for your presentation.

A format proven to work well is that all students in the class are given a unique problem to solve, and 15 minutes of time to independently devise solutions. These 15-minute periods are closed-book and closed-note just like written exams. After that 15-minute period, the instructor collects all the papers (each with the student's name written on top) and gives each student 10 minutes to present their solution before the entire class while everyone else observes.

Your instructor will not provide answers to you prior to or during the presentation; you are solely responsible for any research, experimentation, and other actions necessary to adequately prepare for your presentation. If you inquire for help, the instructor may clarify what you will need to present on, and/or point you toward specific resources (e.g. "Try setting up a SPICE simulation", "Try building a test circuit on your breadboard", "Find and read the datasheet(s)", "Research application notes written on this topic", etc.), but do not expect them to give you answers or check your work because by this point in time you will have studied the necessary concepts to verify results for yourself, or at least to know where to go to find verification.

During your presentation the instructor and audience members are free to pose questions relevant to the graded objectives for your assigned problem. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions.

The benefits of this exercise include honing your independent research skills, reinforcing your foundational knowledge of electronics, gaining confidence speaking to groups, and preparation for job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.

A problem will be randomly assigned to you from the options listed on the next several pages. No student will know which problem will be assigned to them until it is their turn to present, which means all students should be prepared to present on *every* problem shown. Furthermore, problems may contain unspecified parameters which will also be randomized at presentation time. Full credit will be given only for answers that are correct *and* logically supported by trusted principles and sources (e.g. Conservation of Energy, Ohm's Law, datasheets, etc.).

You are to regard your audience as technically adept (i.e. assuming everyone in attendance is familiar with the technical concepts and language; "skilled in the art").

file wt_0400

Problem #1

Convert between the following integer values:

Convert _____ (binary) to hexadecimal

Convert _____ (8-bit signed binary) to decimal

Convert _____ (8-bit signed binary) to decimal

Convert _____ (decimal) to binary

Convert _____ (hexadecimal) to binary

`Grading`

- ◯ [20%] Correct first conversion
- ◯ [20%] Correct second conversion
- ◯ [20%] Correct third conversion
- ◯ [20%] Correct fourth conversion
- ◯ [20%] Correct fifth conversion

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #2

Write a ladder-diagram program, either for a real PLC or a simulated PLC, using software installed on your computer, to perform the following arithmetic and comparison tasks. The instructor will specify the type of task to be performed and may also specify what data type(s) must be used. Additionally, the instructor will specify how the input numerical values are to be sourced (e.g. by using counter instructions, HMI numerical input, etc.):

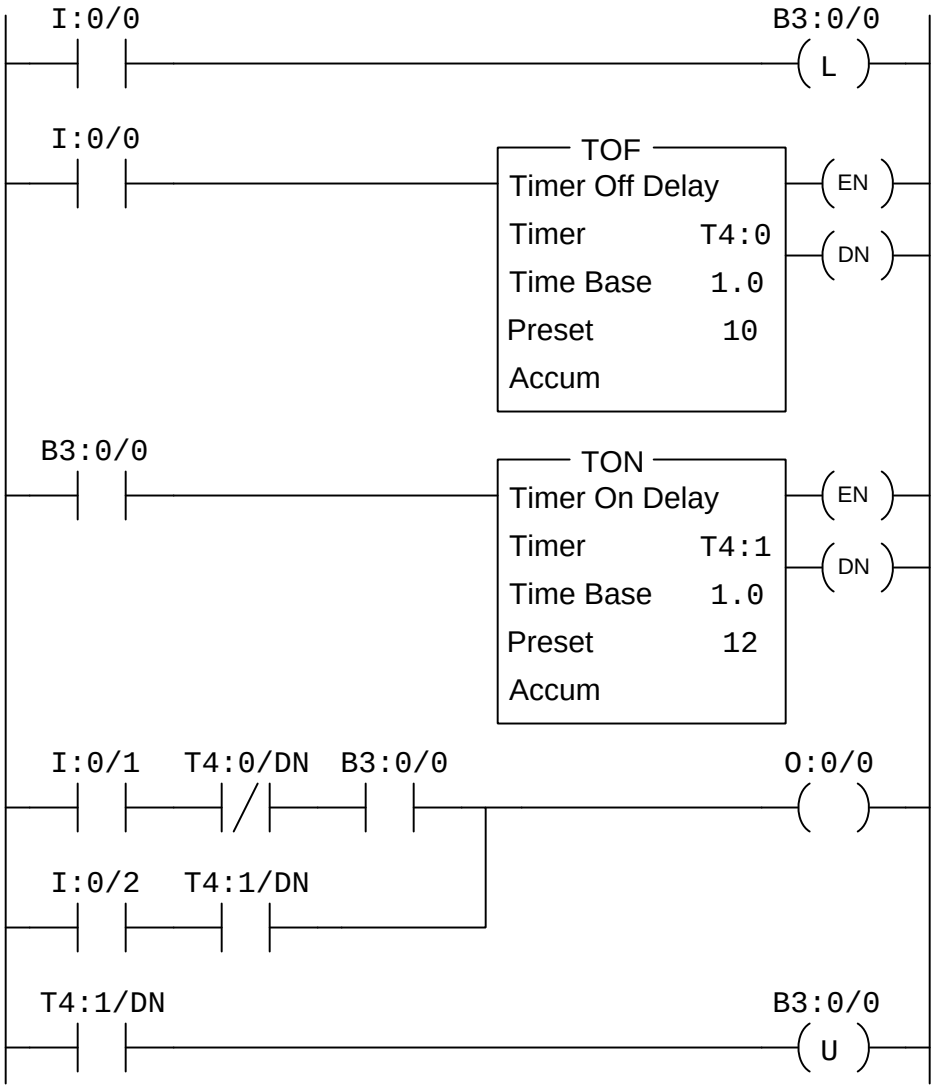
`Grading`

- ◯ [20%] Numerical value(s) properly sourced
- ◯ [20%] Arithmetic function(s) execute properly
- ◯ [20%] Comparison function(s) execute properly
- ◯ [20%] Explain the capabilities of the specified data types (e.g. `DINT`, `REAL`)
- ◯ [20%] Results of calculation output correctly

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #3

Predict the operation of the following Allen-Bradley MicroLogix PLC timer program, assuming the momentary normally-open pushbutton switch connected to input `I:0/0` was pressed and immediately released by someone, and that input `I:0/1` is (*energized / de-energized*) and input `I:0/2` is (*energized / de-energized*):



`Grading`

◯ [20%] Status of `T4:0/DN` bit _____ seconds after switch was quickly pressed and released
◯ [20%] Status of `B3:0/0` bit _____ seconds after switch was quickly pressed and released
◯ [20%] Accumulator value of `T4:0` _____ seconds after switch was quickly pressed and released
◯ [20%] Accumulator value of `T4:1` _____ seconds after switch was quickly pressed and released
◯ [20%] Conditions necessary to make output `O:0/0` energize 6 seconds after the switch's actuation and remain on for exactly 4 more seconds after that

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #4

Convert between the following analog voltage values into digital counts, and the following digital count values into analog voltages, assuming an analog PLC card having ____ bits of resolution and an analog signal range of _____ to _____ Volts. In all cases assume the digital value is an unsigned integer:

- _____ Volts
- _____ Volts
- _____ Volts
- _____ Counts
- _____ Counts

`Grading`

◯ [20%] First conversion
◯ [20%] Second conversion
◯ [20%] Third conversion
◯ [20%] Fourth conversion
◯ [20%] Fifth conversion

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #5

Sketch a diagram showing how a CO2 gas sensor outputting a 0-3.5 Volt DC analog signal could connect to one of the inputs on an analog input PLC module (*instructor chooses* from the list below). You will be permitted access to any manufacturer documentation you wish, in order to identify the analog card's terminals and capabilities.

- Automation Direct model BX-04AD-2B for the BRX model of PLC
- Automation Direct model C0-04AD-2 for the CLICK model of PLC
- Rockwell model 5094-IY8 (part of the FLEX I/O system)
- Rockwell model 1756-IF16 for the ControlLogix model of PLC
- Rockwell model 1769-IF4 for the CompactLogix model of PLC

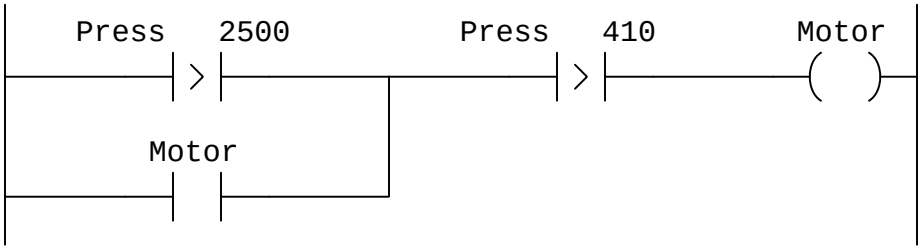
`Grading`

◯ [20%] Signal applied to input channel with proper voltage polarity
◯ [20%] Identify whether the module is single-ended or differential, or may do either
◯ [20%] Identify maximum signal voltage range for the module
◯ [20%] Identify whether the module has a unipolar or bipolar signal range, or may do either
◯ [20%] Any necessary external power supply connected properly

Note: access to the appropriate technical documentation is permitted for this assessment. As usual, full credit given only for answers that are correct and logically supported by trusted principles.

Problem #6

Edit the following PLC program so that the pump motor starts up whenever the sensed pressure (*rises above / drops below*) _____ PSI and and shuts down whenever the sensed pressure (*rises above / drops below*) _____ PSI. Assume the pressure sensor's analog signal coming into the PLC's analog input module generates a count value of 0 at 0 PSI and a count value of 4095 at 60 PSI, stored in an integer variable named `Press`:



Presently the program is designed to start and stop the pump at completely different analog values. Note that in addition to re-calculating proper count values you may also need to change relational contact types from one type to another (e.g. greater-than, less-than).

`Grading`

- ◯ [20%] Correct ADC count value for Start
- ◯ [20%] Correct relational contact type for Start
- ◯ [20%] Correct ADC count value for Stop
- ◯ [20%] Correct relational contact type for Stop
- ◯ [20%] Sensed pressure at a count value of _____ counts

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Theory session 48

The written exam will consist of the following types of questions and their *related principles*:

- (Question #1) Convert between different forms of digital numeration (e.g. binary, hexadecimal, decimal) for signed integer values.
  Unsigned binary integers, signed binary integers, hexadecimal notation

- (Question #2) Edit an existing PLC system, either its programming or its wiring, to either correct an error or modify its behavior.
  PLC ladder-diagram programming, normally-open versus normally-closed switch behavior, color highlighting of PLC instructions, process switch (e.g. pressure, flow, temperature) operation, latching (start-stop) PLC programs, PLC counter instructions, PLC timer instructions, analog signal scaling, PLC program scan order, discrete PLC I/O wiring

- (Question #3 – REVIEW) Determine PLC I/O statutes, bit statuses, and color-highlighting from process switch stimuli, schematic diagrams, and PLC ladder-diagram code.
  PLC ladder-diagram programming, normally-open versus normally-closed switch behavior, color highlighting of PLC instructions, process switch (e.g. pressure, flow, temperature) operation

- (Question #4 – REVIEW) Determine possible faults in a PLC-controlled motor system given I/O wiring diagram and the ladder-diagram program running in the PLC.
  PLC ladder-diagram programming, normally-open versus normally-closed switch behavior, series versus parallel switching circuit properties

- (Question #5 – REVIEW) Associate PLC ladder-diagram programs containing timing instructions with timing diagrams showing bit and/or register states.
  PLC ladder-diagram programming, normally-open versus normally-closed switch behavior, color highlighting of PLC instructions, properties of series and parallel networks, PLC non-retentive "on-delay" timer instruction behavior, PLC retentive "on-delay" timer instruction behavior, PLC non-retentive "off-delay" timer instruction behavior

file wt_0398

Theory session 49

Source text – *PLC Communications Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_comms.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → PLC communication functions (note that this section contains several sub-sections!)
- Complete "Rockwell ControlLogix 5000 PLC networking options" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Determining load statuses from switch conditions" in the Conceptual Reasoning section of the Questions chapter.
- Time permitting during the class session, research communication options for your own PLC/HMI trainer system.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0404

Theory session 50

Source text – *PLC Communications Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_comms.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Serial data communication
- Complete "Morse messages" in the Conceptual Reasoning section of the Questions chapter.
- Complete "ASCII messages" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0401

Theory session 51

Source text – *PLC Communications Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_comms.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Multi-point data communication
- Complete "Determining necessary switch conditions to activate load" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Faults in a multi-point telegraph" in the Diagnostic Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs.
- Time permitting during the class session, experiment with building and running HMI displays in either HMI simulation software or on a real HMI.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0403

Theory session 52

Source text – *PLC Communications Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_comms.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → RS-232
  → RS-485
- Complete "Faults in an RS-232 network" in the Diagnostic Reasoning section of the Questions chapter.
- Complete "Faulty PLC pressure warning system" in the Diagnostic Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in either PLC simulation software or on real PLCs.
  → e.g. Experiment with instructions designed to send ASCII messages

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0402

Theory session 53

Source text – *PLC Communications Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_comms.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Ethernet
- Complete "Possible faults in an Ethernet network" in the Diagnostic Reasoning section of the Questions chapter.
- Visit online retailers of consumer-grade communication equipment and find examples of Ethernet hubs or switches.
  → How expensive are these, typically?
  → What speeds (data rates in millions of bits per second) will they support?
- Visit online retailers of industrial communication equipment and find examples of Ethernet hubs or switches.
  → How expensive are these, typically?
  → What speeds (data rates in millions of bits per second) will they support?
- Investigate the Ethernet capabilities of your own PLC and/or HMI based on manufacturer documentation.
  → What speeds (data rates in millions of bits per second) will they support?
  → Which pins in the RJ-45 connectors are responsible for transmit (Tx) versus receive (Rx)?

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

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Theory session 54

Source text – *PLC Communications Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_comms.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following sections of the Tutorial chapter:
  → Internet protocols
  → Protocol encapsulation
  → Network diagnostic tools
- Use `Wireshark` "packet-sniffing" software to monitor network traffic on your personal computer, and then identify encapsulation of TCP segments within IP packets, and IP packets within Ethernet frames for some of the captured data.
- Complete "PLC transmitting ASCII message via UDP" in the Quantitative Reasoning section of the Questions chapter.
- Complete "PLC transmitting ASCII message to itself" in the Quantitative Reasoning section of the Questions chapter.
- Complete "PLC transmitting integer data over network" in the Quantitative Reasoning section of the Questions chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

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Theory session 55

Source text – *PLC Communications Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_comms.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Modbus
- Complete "Koyo CLICK PLC Modbus program" in the Conceptual Reasoning section of the Questions chapter.
- Complete "Faulty remote bit control program" in the Diagnostic Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in real PLCs where an input bit in one PLC controls an output bit in another.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

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Theory session 56

Source text – *PLC Communications Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_comms.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Read, reflect, and update your Theory Journal on the following section of the Tutorial chapter:
  → Analyzing a Modbus/TCP message
- Complete "Modbus/TCP message analysis" in the Quantitative Reasoning section of the Questions chapter.
- Time permitting during the class session, experiment with creating and running programs in real or simulated PLCs to generate network messages and then intercept those messages using `Wireshark` software.
  → Automation Direct *Do-More Designer* PLC programming software offers a simulation mode capable of transmitting actual messages on Ethernet networks! You may set the IP address to `127.0.0.1` (loopback) and have `Wireshark` analyze messages sent to that "dummy" address by the simulated PLC.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

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Theory session 57

Source text – *PLC Communications Programming* learning module

URL – `https://ibiblio.org/kuphaldt/socratic/model/mod_plc_comms.pdf`

Complete the following *prior to* the scheduled session with your instructor:

- Complete "Experiment: communication demonstration program" in the Projects and Experiments chapter.
- Complete "Experiment: remote PLC motor control" in the Projects and Experiments chapter.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0410

Theory session 58

During today's theory session we will spend time reviewing and practicing any concepts you wish prior to the upcoming Oral Presentations and Written Exam. These may include review of past topics, assigned questions, and/or experiments as well as topics or questions you're interested in exploring that we did not specifically address in a prior theory session. Feel free to look ahead in your course document to the next set of Oral Presentations as well as to the next written exam description to see what challenges await.

Theory Session Expectations:

Send your Theory Journal entry documenting your original thoughts and questions on the reading, as well as your solutions for assigned problems, to the instructor before class begins. Session grading is based on good-faith effort: the minimum expectation being an honest and documented attempt to understand all portions of the assigned reading and to solve every assigned problem. Expect the instructor to question your answers – even when correct – and always challenge you to reason from first principles.

`Additional resources:`

- PLC simulation software is useful for exploring ladder-logic programming concepts. Automation Direct offers *Do-More Designer* software for their Do-More line of programmable logic controllers with simulation capability. The software is free and easy to use!

  file wt_0309

Theory session 59

Oral Presentations

Today's class session will consist of oral presentations made to the entire group. Each presentation will be time-limited, be graded on technical accuracy, and be followed by constructive criticism from the audience. When you are chosen to present, you will have a brief period of time to gather your thoughts and set up for your presentation.

A format proven to work well is that all students in the class are given a unique problem to solve, and 15 minutes of time to independently devise solutions. These 15-minute periods are closed-book and closed-note just like written exams. After that 15-minute period, the instructor collects all the papers (each with the student's name written on top) and gives each student 10 minutes to present their solution before the entire class while everyone else observes.

Your instructor will not provide answers to you prior to or during the presentation; you are solely responsible for any research, experimentation, and other actions necessary to adequately prepare for your presentation. If you inquire for help, the instructor may clarify what you will need to present on, and/or point you toward specific resources (e.g. "Try setting up a SPICE simulation", "Try building a test circuit on your breadboard", "Find and read the datasheet(s)", "Research application notes written on this topic", etc.), but do not expect them to give you answers or check your work because by this point in time you will have studied the necessary concepts to verify results for yourself, or at least to know where to go to find verification.

During your presentation the instructor and audience members are free to pose questions relevant to the graded objectives for your assigned problem. This may be done for the simple purpose of clarifying an unclear answer, or to probe for misconceptions.

The benefits of this exercise include honing your independent research skills, reinforcing your foundational knowledge of electronics, gaining confidence speaking to groups, and preparation for job interviews where being able to articulate your knowledge and solve realistic problems before a critical audience sets you apart from lesser-qualified candidates.

A problem will be randomly assigned to you from the options listed on the next several pages. No student will know which problem will be assigned to them until it is their turn to present, which means all students should be prepared to present on *every* problem shown. Furthermore, problems may contain unspecified parameters which will also be randomized at presentation time. Full credit will be given only for answers that are correct *and* logically supported by trusted principles and sources (e.g. Conservation of Energy, Ohm's Law, datasheets, etc.).

You are to regard your audience as technically adept (i.e. assuming everyone in attendance is familiar with the technical concepts and language; "skilled in the art").

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Problem #1

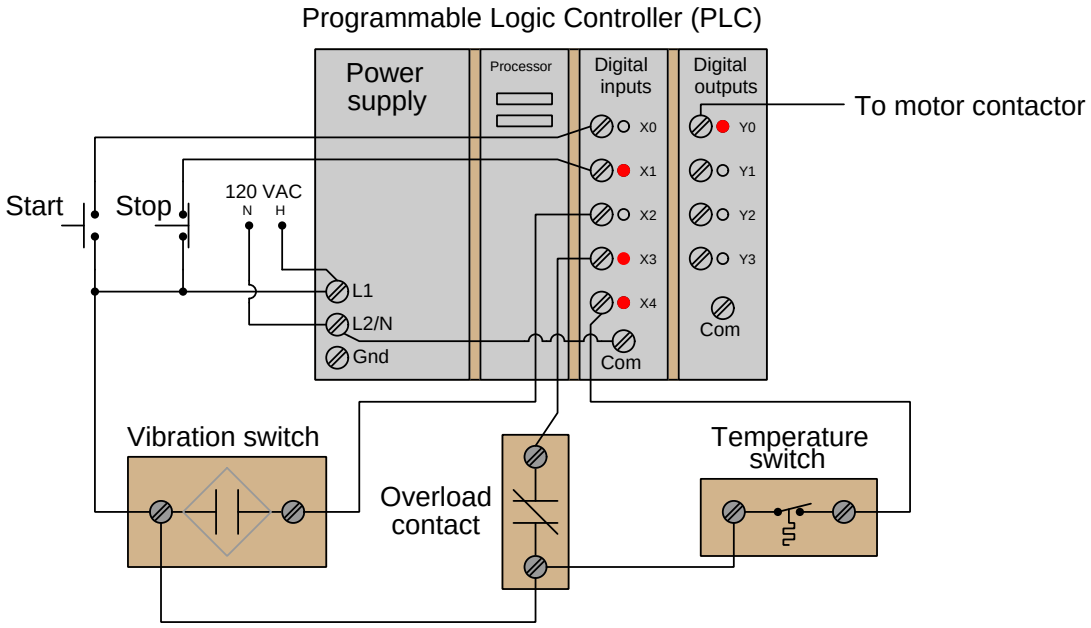
Use network diagnostic utilities on your own computer to identify specific information about the network(s) it is connected to.

`Grading`

- ◯ [20%] Identify the IPv4 address of your computer's network connection
- ◯ [20%] Show associations between IP addresses and Ethernet MAC addresses
- ◯ [20%] Demonstrate how to "ping" another device on the network
- ◯ [20%] Use a network protocol analyzer to inspect the contents of a TCP message
- ◯ [20%] Use a network protocol analyzer to inspect the contents of a UDP message

Problem #2

A Programmable Logic Controller (PLC) serves as the logic controller for a large motor-driven pump. It is programmed to shut off the pump if any dangerous conditions occur:



LED indicator lights on the input and output cards of the PLC indicate if those respective I/O channels are energized. The light statuses shown in the above diagram are when the pump is running as it should (i.e. no abnormal conditions).

Suppose this pump is running just as it should. Identify how you could electrically simulate each of the following "trip" conditions, causing the pump to shut down even though nothing is physically wrong with the pump or the motor driving it.

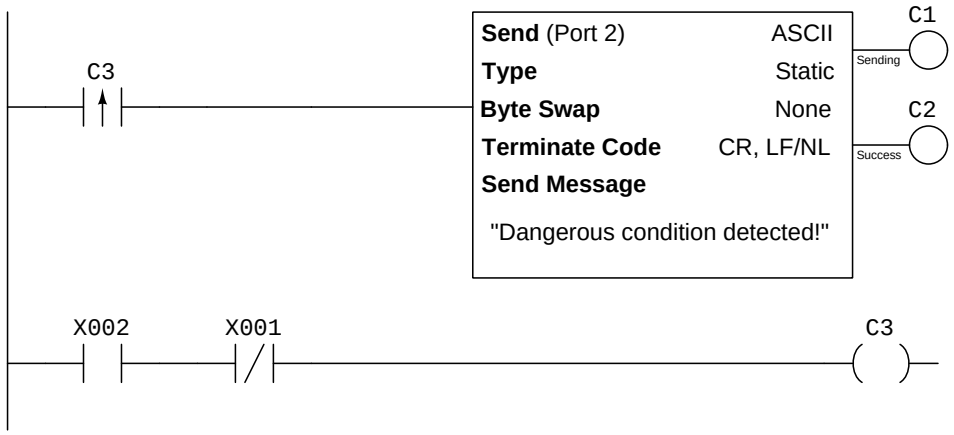
`Grading`

- ◯ [20%] Explain how to simulate excessive vibration
- ◯ [20%] Explain how to simulate an overloaded motor condition
- ◯ [20%] Explain how to simulate excessive temperature
- ◯ [20%] Identify how the system would behave if _____ failed (*open / shorted*)
- ◯ [20%] Identify how the system would behave if _____ failed (*open / shorted*)

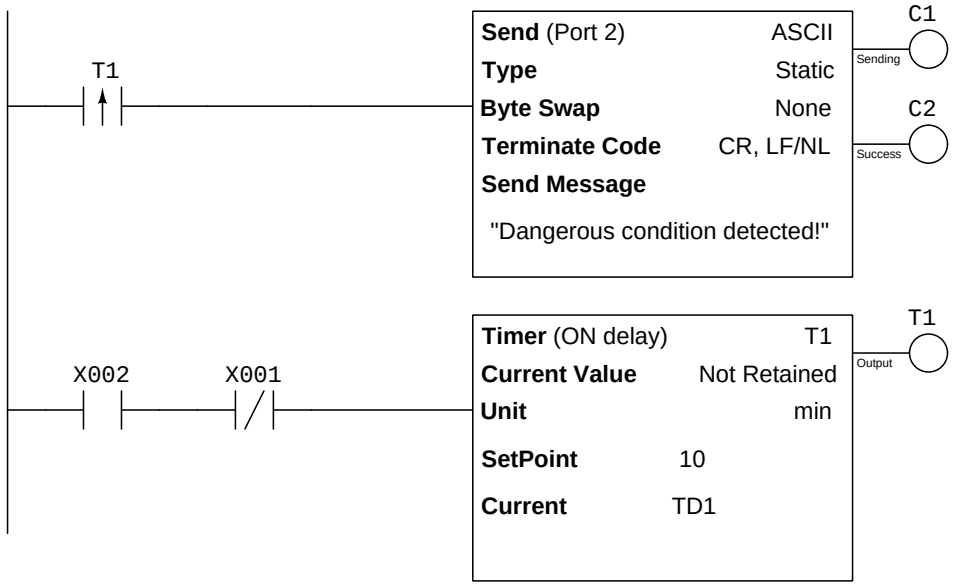
Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #3

The following Koyo CLICK PLC program is designed to transmit an ASCII serial message whenever a dangerous condition is detected by a (*NO / NC*) pressure switch wired to input `X001` and a (*NO / NC*) temperature switch wired to input `X002`:



Later, the program was modified to include a timer instruction:



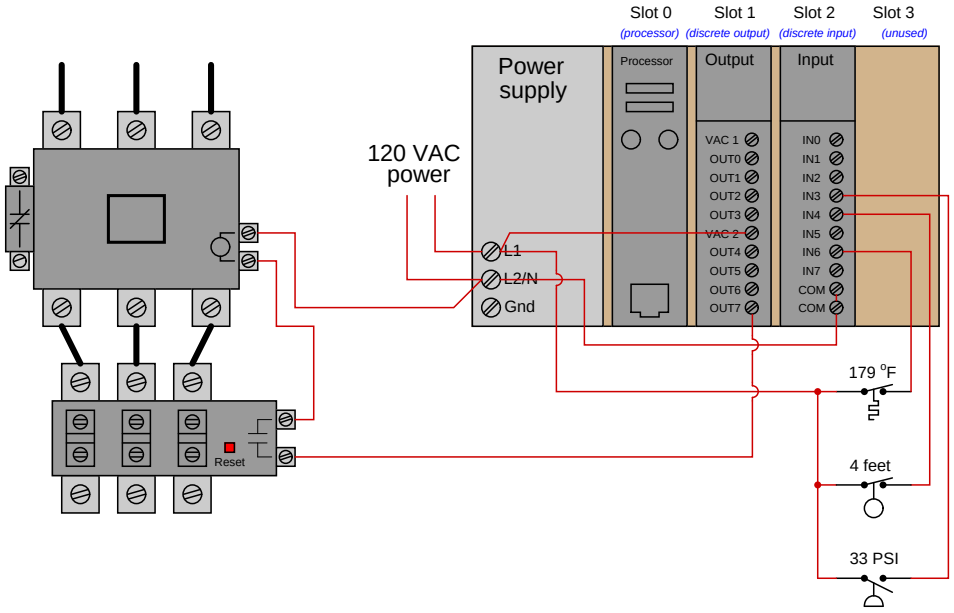
`Grading`

- ◯ [20%] Identify the dangerous condition(s) triggering the serial message
- ◯ [20%] Explain the purpose for the program modification with the timer instruction
- ◯ [20%] Identify a fault that could cause the message to never be sent when needed
- ◯ [20%] Identify another fault that could cause the message to never be sent when needed
- ◯ [20%] Identify whether or not the order of the rungs in this program matters

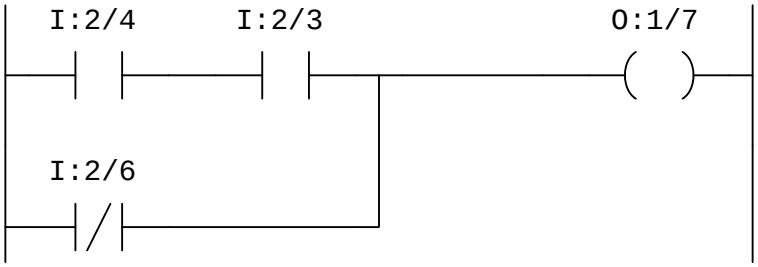
Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #4

The following Allen-Bradley model "SLC 500" PLC connects to three process switches and a motor contactor as shown in this illustration:



Suppose the process temperature is _____ ^{o}F, the liquid level is _____ feet, and the pressure is _____ 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.

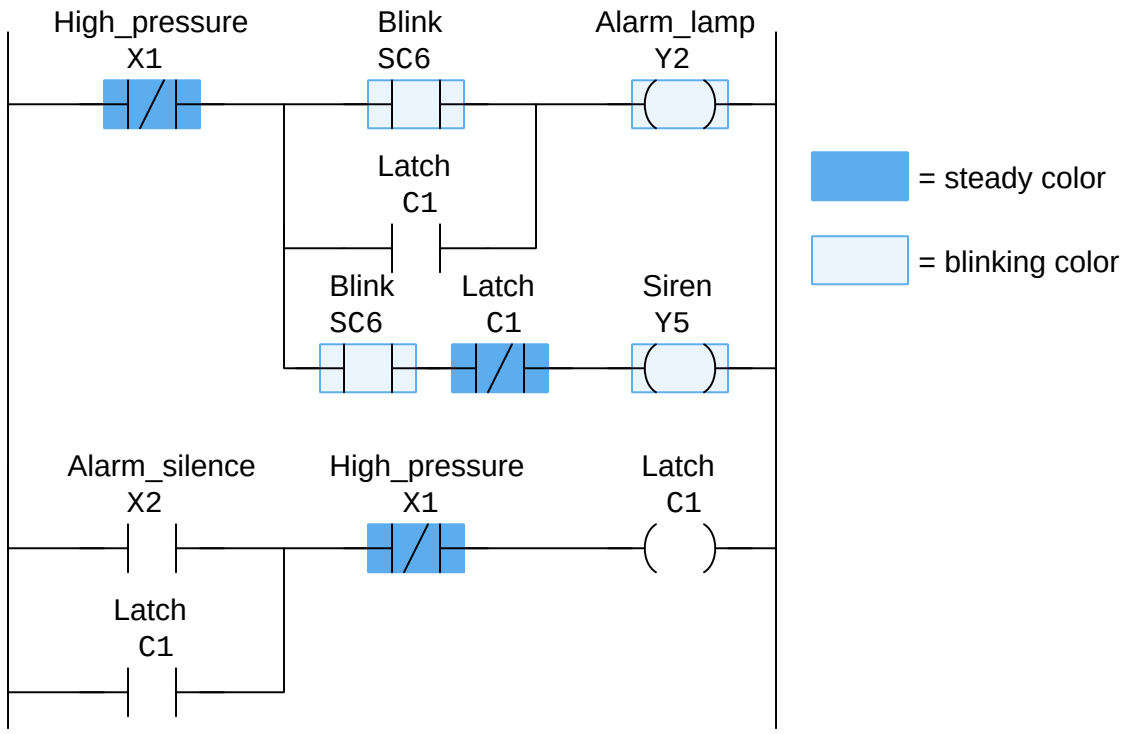
`Grading`

- ◯ [20%] Identify one electrical fault that could account for the motor not starting
- ◯ [20%] Identify another electrical fault that could account for the motor not starting
- ◯ [20%] Identify another electrical fault that could account for the motor not starting
- ◯ [20%] Show the color highlighting that *should* appear in a live program view with no faults
- ◯ [20%] Describe a diagnostic test to confirm one of your specified faults

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #5

A PLC-controlled alarm system has a problem, and you are called to diagnose what that problem is. The alarm lamp and siren are supposed to both "pulse" when a high-pressure condition is detected by a pressure switch, and then the siren is supposed to be silenced when the "Alarm_silence" pushbutton is pressed. However, the siren continues to pulse (and so does the alarm lamp) despite repeated attempts by the operators to press the "Alarm_silence" switch:



You have the ability to remotely monitor the PLC program ("online") from the maintenance shop over a network cable, allowing you to view the working program without ever getting near the angry operators. What you see on your laptop computer screen is shown above.

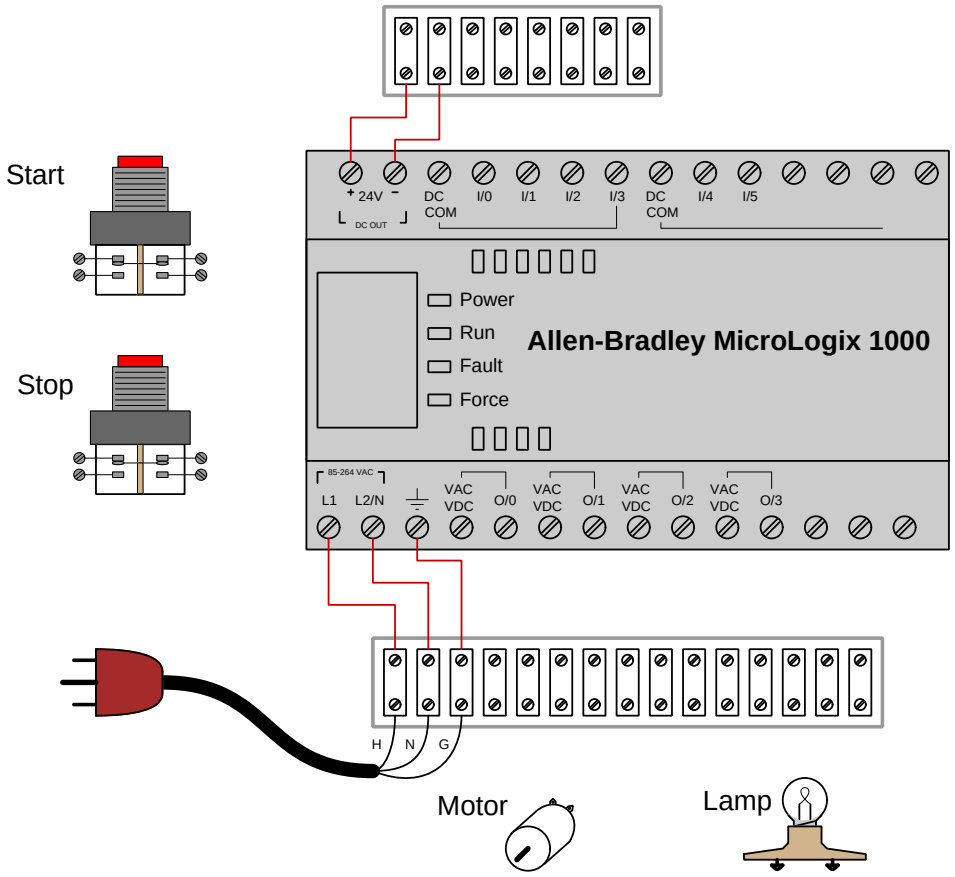
`Grading`

- ◯ [20%] Identify one possible reason the alarm refuses to silence
- ◯ [20%] Identify whether or not an actual high-pressure condition exists
- ◯ [20%] Explain the purpose of the Latch (`C1`) bit in this program
- ◯ [20%] Identify how the system would behave if _____ were failed (*open* / *shorted*) instead
- ◯ [20%] Identify the necessary contact wiring of the high-pressure switch, either NO or NC

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Problem #6

Sketch wires necessary to form a motor start/stop system using this Allen-Bradley (Rockwell) MicroLogix 1000 PLC:



The discrete inputs on this PLC can either source or sink current at 24 Volts DC. The discrete outputs are relay contacts, capable of switching AC or DC. Both the motor and the lamp are rated for 120 Volts AC. The three-conductor 120 VAC power plug and cord are already wired to the PLC, and the PLC's 24 Volt DC output is already wired to the other terminal block. The motor and the lamp must be connected to different discrete outputs, so that their functions may be independent of one another. Organize all your wiring so that all field-device conductors pass through terminal blocks and do not directly connect to any PLC I/O terminals, in a manner similar to how the 120 VAC power cord is wired through the terminal block to the PLC's AC power terminals.

`Grading`

- ◯ [20%] Start pushbutton properly wired
- ◯ [20%] Stop pushbutton properly wired
- ◯ [20%] Motor properly wired
- ◯ [20%] Lamp pushbutton properly wired
- ◯ [20%] Example ladder-diagram program for starting/stopping the motor, the lamp energizing when this condition is met: _____

Note: full credit given only for answers that are correct and logically supported by trusted principles.

Theory session 60

The written exam will consist of the following types of questions and their *related principles*:

- (Question #1 – REVIEW) Determine PLC I/O statutes, bit statuses, and color-highlighting from process switch stimuli, schematic diagrams, and PLC ladder-diagram code.
  PLC ladder-diagram programming, normally-open versus normally-closed switch behavior, color highlighting of PLC instructions, process switch (e.g. pressure, flow, temperature) operation

- (Question #2 – REVIEW) Edit an existing PLC system, either its programming or its wiring, to either correct an error or modify its behavior.
  PLC ladder-diagram programming, normally-open versus normally-closed switch behavior, color highlighting of PLC instructions, process switch (e.g. pressure, flow, temperature) operation, latching (start-stop) PLC programs, PLC counter instructions, PLC timer instructions, analog signal scaling, PLC program scan order, discrete PLC I/O wiring

- (Question #3 – REVIEW) Convert between different forms of digital numeration (e.g. binary, hexadecimal, decimal) for signed integer values.
  Unsigned binary integers, signed binary integers, hexadecimal notation

- (Question #4 – REVIEW) Determine possible faults in a PLC-controlled motor system given I/O wiring diagram and the ladder-diagram program running in the PLC.
  PLC ladder-diagram programming, normally-open versus normally-closed switch behavior, series versus parallel switching circuit properties

- (Question #5 – REVIEW) Determine possible faults in a relay ladder logic circuit.
  Properties of series and parallel networks, effects of opens vs. shorts, relay behavior, relay ladder diagram symbols and conventions

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