E/ET 221 COURSE

LANEY COLLEGE
ENVIRONMENTAL CONTROL TECHNOLOGY

Commercial HVAC Systems Program

Electrical & Electronics Technology
E/ET 221 Motors & Drives

Courtesy of National Science Foundation – BEST Center
www.BESTctr.org

MOTORS & DRIVES

Course Documentation

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"Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation."

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Table of Contents

Catalog description

Brief Catalog Description:

Introduction to the application of motors and drives used in commercial and industrial refrigeration, air conditioning, heating and ventilation: Different types of motors and drives and their applications, including electric and magnetic (VFD) variable frequency drives for improved efficiency control and energy savings.

Detailed Syllabus Description:

This course introduces students to electrical controls, motors, and motor drives used in commercial and industrial applications. Commonly used manual and automatic motor control circuits and components are presented and concepts of control logic are introduced and applied to practical control circuits. Theories of operation for electromagnetic devices ranging from electromagnets, solenoids, contactors and magnetic motor starters, to DC motors, and 1- and 3-phase AC induction motors are presented along with practical troubleshooting methods used to isolate and identify failed devices. Motor overload protection and compliance with requirements of Article 430 of the National Electric Code® are highlighted in this class to ensure students understand the requirements for safe motor and motor control circuit installation and operation. A brief overview of the theory of operation of variable-frequency drives (VFD) is presented and students are introduced to basic VFD installation situations, including the initial commissioning of a drive and motor, programming a variety of drive and motor performance parameters, and interfacing remote controls to a VFD and 3-phase motors.

Class hours

Lecture 26.25 Hours Lab 26.25 Hours

Units

Lecture 1.5 semester units Lab 0.5 semester units

Entry skills needed

- Reading level: College level English technical reading. Ability to decode new technical terminology with reference help.
- Writing level: Ability to express complex technical concepts in English.
- Math level: college technical math
  1. Perform mathematical operations using real numbers fractions, decimals and percentages.
  2. Solve simple linear equations.
  3. Demonstrate knowledge converting fractions to decimals and decimals to fractions.
  4. Solve basic math and geometry problems on area, angles, volume and percentages.
  5. Use algebraic equations to solve heating and cooling load calculation problems.
  6. Solve problems involving ratio and proportions.

7. Interpret data in graphs in rectangular coordinate systems.
8. Use and apply Imperial and Metric systems of measurement.
9. Solve problems involving area and perimeter.

- Mechanical and Electrical Devices skills:
  1. Identify, test, replace, repair and describe the functions of all electrical and electronic components.
  2. Demonstrate ability to work safely with high and low voltage.
  3. Demonstrate proper troubleshooting procedures and the use of basic instruments.
  4. Identify the different types of transformers and motors.
  5. Explain the basic concepts of electricity and Ohm's law.
  6. Describe the relevant sequence of operation of the system.
  7. Demonstrate the ability to interpret electrical diagrams.
  8. Exhibit familiarity with energy management and efficiency.
  9. Demonstrate a thorough understanding of electrical safety procedures.

Syllabus

See Appendix A for sample Syllabus, course schedule, and policies. For lessons to include in course, see below.

Student learning outcomes

The exit skills listed in the next section support these 4 outcomes:

Identification

Explain the function and the types of motors and drives.

Application

Demonstrate familiarity with different motor controls and applications.

Installation & Programming

Build motor control circuits and program the drives.

Troubleshooting

Develop safe and proper methods for troubleshooting motors and drives.

Exit skills

Course content to achieve 4 outcomes listed above:

Motor Identification

1. Identify the different types of motors and their applications.
   Course Content for this objective:
   a. Basic electricity and electrical instrumentation review
      Lesson Topics:
      - Basic Electrical Quantities, Components, Circuits.
      - Electrical Tools and Test Equipment.
      - Theory of operation of AC and DC Motors.
      - DC Generators, and DC Motors
      - AC Generators, and AC Motors
      - Lab: build and test a simple DC motor. Observe effects of direction of magnetic field and current flow on a simple DC motor.
      - Labs (application of entry skills): Capacitance & Inductance analysis, Capacitance & Inductance with AC current analysis, Frequency dependence of Capacitance & Inductance.

Drive Identification

2. Identify the different types of drives and their use.
   Lesson Topics:
   - Introduction to AC motor drives
   - Lab: Motor Drive Station intro and orientation

Control Components

3. Describe the various contactors, starters and relays.
   Course Content for this objective:
   a. Analyze simple motor control circuits and explain the sequence of operations and functions performed by the circuit components.
   b. Demonstrate knowledge and understanding of the use and selection of overload protection devices that prevent motors from overheating due to overload
      Lesson Topics:
      - Electrical Symbols and Diagrams.
      - Introduction to NEC Article 430.
      - Motor control circuits and devices, their application.
      - Solenoids
      - Transformers
      - Contactors and Motor Starters
      - Motor overload protection, selecting motor overloads.

- Control Devices and Reversing Circuits
- Lab: Relay circuit function analysis.
- Lab: build simple circuit and measure voltages and current and calculate power.
- Lab: build circuit using magnetic control to start a motor.
- Lab: measure primary and secondary voltages of transformer.
- Lab: build AC to DC converter using Diodes.

Troubleshooting

4. Troubleshoot motors using proper methods and instruments.
   Course Content for this objective:
   a. Tools and Test Equipment, instruments for troubleshooting motors.
   b. Control Logic
   c. Demonstrate an understanding of basic troubleshooting applied to basic motor and motor control circuits using standard troubleshooting techniques
      Lesson Topics:
      - What are the basic requirements of an overload relay?
      - Voltage imbalance

Three phase power

5. Explain the difference between single-phase and three-phase motors.
   Course Content for this objective:
   a. Be able to explain the theory of operation of 1-phase and 3-phase AC motors.
      Lesson Topics:
      - Power distribution systems

Variable Frequency Drive application

6. Describe the function of the (VFD) Variable Frequency Drive and its application.
   Course Content for this objective:
   a. Line diagram analysis
      Lesson Topics:
      - Lab: build simple electronic device to control the speed of motors.
      - Lab: Variable Frequency drive wiring and programming.

Programming

7. Demonstrate the ability to program the various parameters in a VFD.
   Course Content for this objective:
   a. Demonstrate that they can commission a Variable Frequency Drive (VFD) with a 3-phase motor, and program it to be operated with remote control.
      Lesson Topics:
      - Variable Frequency Drive (VFD) commissioning and programming.
      - Lab: commission & test a VFD with a three-phase motor.
      - Lab: program and operate a VFD and motor.

Safety

8. Demonstrate the necessary safety procedures when working with motors.
   Course Content for this objective:
   a. Demonstrate that they can identify and apply the requirements of the National Electric Code, Article 430, that are relevant to the safe installation and operation of motors and motor controls circuits.
      Lesson Topics:
      - Electrical Safety requirements
      - Electrical grounding and safety
      - Introduction to NEC Article 430

Course materials

Principal text

Gary Rockis and Glen A. Mazur, "**Electrical Motor Controls for Integrated Systems**" 4th ed., American Technical Publishers, Inc., 2009
ISBN-10: 0826912184
Chapter 1 thru 12.

Lecture materials and handouts

Presentation materials include PowerPoint slides to accompany lecture, as well as assorted cut sheets for equipment, animations, and illustrations. Slide show topics include:

- Electricity Basics, AC power concepts, circuits.
- Tools and test equipment
- Electrical safety
- Electrical symbols and diagrams
- Logic applied to line diagrams
- Solenoids, DC generators and DC motors
- AC generators, transformers and motors
- Power distribution systems
- Contactors and motor starters
- AC and DC motor drives

Other reference materials

Variable Frequency Drive User's Manuals will be provided by instructor and must be returned at end of semester.

Excerpts from the National Electric Code will be provided by instructor and must be returned at end of semester.

Software needed

Variable Frequency Drive embedded software used for programming the units.

Lab materials

Tools: digital multi-meter, combination wire cutter, stripper and crimper or diagonal cutter and long-nose pliers, and small flat blade and cross-point screwdrivers.

Simple DC Motor Laboratory supplies: Small, strong ceramic magnet (1 each), Large paper clips(2 each), Large rubber band (1 each), and D-cell Battery (1 each).

Equipment & instruments required

Hands-on implementation of concepts is key to successful learning of equipment function and relationships. Hand tools, bench space, Danfoss and ABB VFDs, common wiring devices and single and three phase motors are required. Students use lab stations for measurement, diagnosis, servicing, and commissioning practice.

Samples of weekly assignments

Reading assignments, answering questions based on reading and lecture content, and problem solving exercises:.

- Circuit Review Problems: Series & Parallel circuit analyis for voltages and currents.
- Control Circuit Problems: Operation of control components, Ladder diagram, Troubleshooting control circuit.
  - What is AND logic as applied to control circuits?
- AC Capacitance and Induction
  - What is the property of a circuit that causes it to oppose a change in current due to energy stored in a magnetic field?
  - What are the four basic rules followed when selecting a solenoid?
- Transformer Problems.
  - What are the considerations in choosing a transformer?
- Voltage Unbalance Problems for motor derating.
- Overload Selection, process, references and problems.
  - What are the basic requirements of an overload relay?
- NEC Article 430, text, reading assignment, problems.

Project

The lab work in this course cumulatively creates a programmed motor-drive installation. See the Project Rubric in Appendix B for outcomes and scoring applicable to the lab work project.

This course does not have a Problem Based Learning (PBL) project. However, the PBL process for identifying, researching, and solving a troubleshooting as well as assessing student success can be applied to

the lab work in this course. The basic level of this course is not a target location in the curriculum for including the synthesis and presentation skills components of the PBL process.

Assessment

Methods

- Tests
- Instructor verified Hands-on Lab work.

See Appendix B – Sample project rubric for project assessment.

Sample test questions

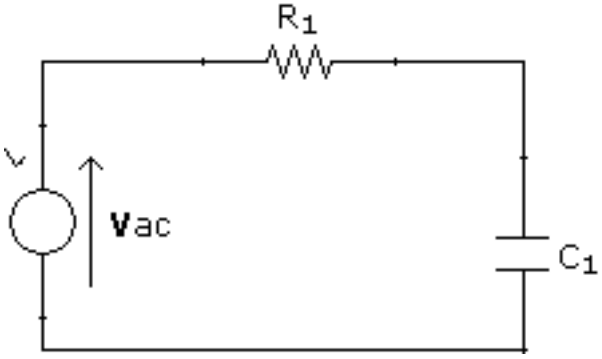
Quiz 1 - 25 multiple choice and calculation problems.

Covers: Basic electricity, AC power supply, ladder diagrams, logic, resistive, capacitance and inductive circuit analysis.

1. What type of diagram indicates the path and the components in a circuit without showing detail of the wire?

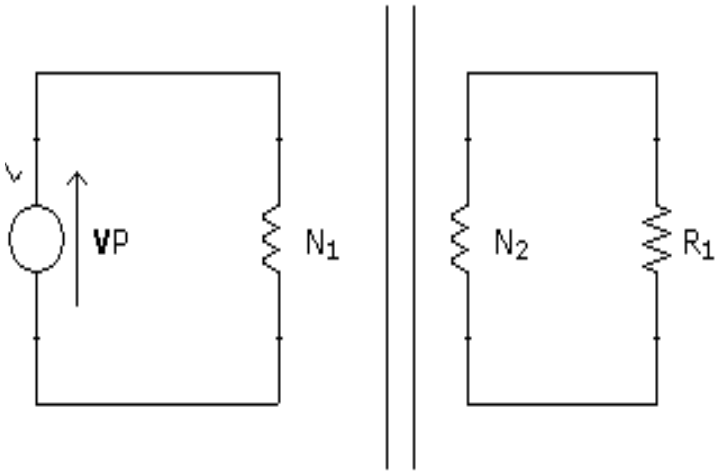
   a) Label diagram
   b) Circuit diagram
   c) Schematic diagram
   d) Safety diagram

2. Find the capacitive reactance (X_c), the impedance (Z) and the current (I_Z) of the following resistive and capacitive circuit. **V_{Supply} = 140** Vac, **f= 1000** Hz, **R=50Ω**, **C=3.1µF (micro Farad).**
   X_c = _____; Z = _____; I_Z =_____



Quiz 2: 31 multiple choice questions.
Covering: solenoids, DC motors/generators, AC motors, 3phase motor wiring.

1. Which of the following does not represent a solenoid configuration?
   a) Clapper
   b) Bell-Crank
   c) Diagonal-Action
   d) Horizontal-Action



For VP = 408 V, N1 = 1200 turns, N2=400 Turns, R1 = 30Ω

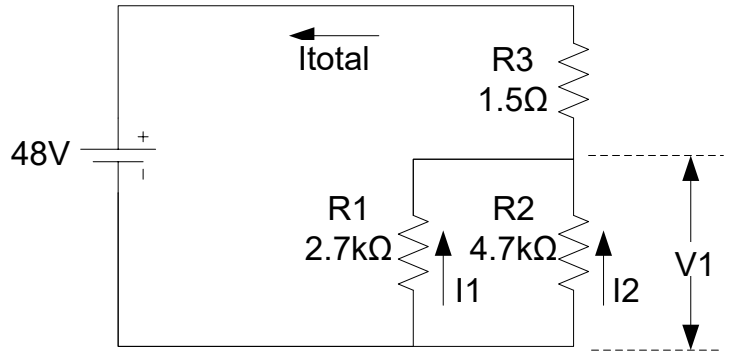
2. What will be the value of secondary voltage Vs?
   a) 408 Volts
   b) 204 Volts
   c) 136 Volts
   d) 102 Volts

Test 1: 8 multi-part calculation, short answer and MC questions.

Covering: Inductance, Capacitance, Power in circuits, Logic, Ladder diagrams and GFCI breakers.

1. In the circuit diagram below, calculate the following quantities using Ohm's law and the power formulas.

   a. The resistance (Rp) of the parallel resistors R1 and R2: Rp=_____
   b. Total load resistance (Rt) connected to the battery: Rt=_____
   c. Itotal, the power supply current: Itotal=_____
   d. V1, the voltage dropped across R1 and R2: V1=_____
   e. I2, the currents in R2: I2=_____
   f. What is the total power (PR2) consumed by R2? PR2=_____



2. In a GFCI, which circuit conductors are monitored for fault current?
   a. Neutral and Ground
   b. Hot and Ground
   c. Hot and Neutral
   d. None of the above

Midterm: 21 multi-part, short answer, calculation and MC questions.

Covering: Inductance, Solenoids, Transformers, DC generators, AC motors, 3phase power, and overload protection.

1. List three ways to change the strength of an electromagnet. *(3)*
   a. _____
   b. _____
   c. _____

2. Circle your responses (true or false) to the following statements related to causes of solenoid failure. Solenoids fail due the following causes:
   a. Incorrect operating voltage **True / False**
   b. Incorrect operating frequency **True / False**
   c. Exceeding duty cycle limits **True / False**
   d. High ambient temperature **True / False**

3. A 6-pole motor, running on 60 Hz power has a speed of 1138 rpm at full load. What is the slip (in percent) of the motor? Show your calculations in the space below and write your answer in the space provided.

   Synchronous speed, n_s = _____

   Slip % = _____%

Final: 51 MC questions.
Covering: Impedance, Reactance, AC power, 3phase power, safety, motors, motor protection, DC motors, and Logic.

1. If the load resistance of R=70Ω is connected to reactance of capacitor with C=47 μF, and supply frequency of f=60HZ. Find the total impedance.

   a) 69.3 Ω b) 89.9 Ω c) 109.3 Ω d) 139.4 Ω

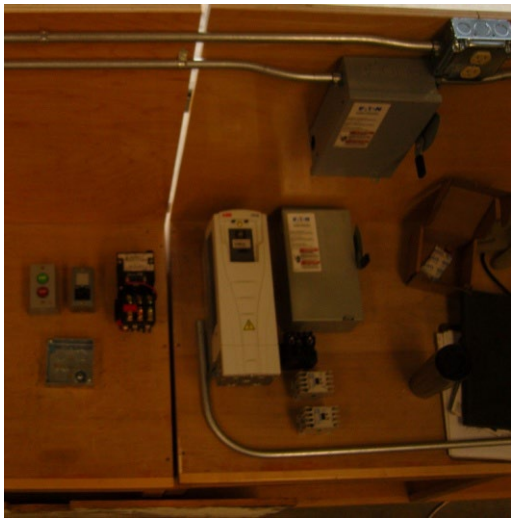
2. Which of the following is not true about added capacitor circuit in motor circuit?
   a) It improves the power factor of the motor.
   b) It is used as starter circuit for AC motor.
   c) Capacitor can be used as filter for ripple voltage.
   d) Capacitor started motor does not require centrifugal switch.

3. A solenoid with 120 volts of operation voltage has 2400 VA in Rush current, and 120 VA sealed VA. What will be the in rush current and sealed current respectively.
   a) 20 amp and 1.5 amp
   b) 20 amp and 1 amp
   c) 20 amp and 20 amp
   d) 1amp and 1amp

Images & other media

Lab equipment set-up

Lesson material on Motors and Variable Frequency drives benefit from access to the equipment below.




Figures 3 & 4: VFD wiring supplies in lab, and student-wired VFD set ups.

Adaptability to on-line format

Requirements: Adaptation of laboratory equipment to photographic presentation for web-based course. Search for/develop a VFD/Motor performance simulation software to apply to lab work.

Appendix A – Sample syllabus

- (See Exit Skills section for lesson topics.)

Course Name: Motors and Drives
Course Number/code: E/ET 221
Units: 2 units.
Time: Mon. and Wed, 5:30PM–6:45PM
Location
Start date:

Final Exam date:
Instructor
Office:
Office Hours: To be announced
Phone
email:

Course Description: This course introduces students to electrical controls, motors, and motor drives used in commercial and industrial applications. Commonly used manual and automatic motor control circuits and components are presented and concepts of control logic are introduced and applied to practical control circuits. Theories of operation for electromagnetic devices ranging from electromagnets, solenoids, contactors and magnetic motor starters, to DC motors, and 1- and 3-phase AC induction motors are presented along with practical troubleshooting methods used to isolate and identify failed devices. Motor overload protection and compliance with requirements of Article 430 of the National Electric Code® are highlighted in this class to ensure students understand the requirements for safe motor and motor control circuit installation and operation. A brief overview of the theory of operation of variable-frequency drives (VFD) is presented and students are introduced to basic VFD installation situations, including the initial commissioning of a drive and motor, programming a variety of drive and motor performance parameters, and interfacing remote controls to a VFD and 3-phase motors.

Enrollment Students must be enrolled by September 2nd or will be asked to leave class and no students will be added as per the Dean and "the computer."

Goals and Learning Outcomes: Students will:

1. Be able to explain the theory of operation of 1-phase and 3-phase AC motors.
2. Analyze simple motor control circuits and explain the sequence of operations and functions performed by the circuit components
3. Demonstrate that they can commission a Variable Frequency Drive (VFD) with a 3-phase motor, and program it to be operated with remote controls
4. Demonstrate that they can identify and apply the requirements of the National Electric Code, Article 430, that are relevant to the safe installation and operation of motors and motor controls circuits.
5. Demonstrate knowledge and understanding of the use and selection of overload protection devices that prevent motors from overheating due to overload
6. Demonstrate an understanding of basic troubleshooting applied to basic motor and motor control circuits using standard troubleshooting techniques

Prerequisites: ECT 11, Mechanical and Electrical Devices

Recommended preparation: Reading and writing in English, basic mathematics, knowledge of basic electricity is very helpful.

Text Book and other class material:

1. "**Electrical Motor Controls for Integrated Systems**" 4th edition, By Gary Rockis and Glen Mazur, American Technical Publishers, Inc. Students must purchase this book.
2. Variable Frequency Drive User's Manuals. Will be provided by instructor and must be returned at end of semester.
3. Excerpts from the National Electric Code. Will be provided by instructor and must be returned at end of semester.

Tools and Supplies Needed:

Classroom: Textbook and handout materials, pencils, pens, notepad, and scientific calculator

Laboratory: Textbook, handout material for the lab, notepad, pen, scientific calculator. Other tools, including digital multi-meter, combination wire cutter, stripper and crimper or diagonal cutter and long-nose pliers, and small flat blade and cross-point screwdrivers are provided. Students are encouraged to bring and use their own digital multi-meters and hand-tools if they have them.

Simple DC Motor Laboratory supplies: (required items for first lab assignment)

1. Small, strong ceramic magnet , 1 each
2. Large paper clips, 2 each
3. Large rubber band, 1 each
4. D-cell Battery, 1 each

Lecture: Chapter 1 thru 12 of the text book will be covered during the semester; material in all chapters but 11 and 12 will be covered in lectures. In addition, handout material including article 430 of the National Electric Code (NEC) and Variable Frequency Drives will be covered in Lectures. Lectures concentrate on the following areas:

1. Basic electricity and electrical instrumentation review
2. Electrical grounding and safety
3. Motor control circuits and devices, their application and troubleshooting
4. Theory of operation of AC and DC Motors
5. Motor overload protection
6. Introduction to AC motor drives
7. Introduction to NEC Article 430
8. Variable Frequency Drive (VFD) commissioning and programming

Laboratory: Students will: (1) build simple circuit and measure voltages and current and calculate power, (2) build circuit using magnetic control to start a motor, (3) measure primary and secondary voltages of transformer, (4) build AC to DC converter using Diodes, (5) build simple electronic device to control the speed of motors, (6) build and test a simple DC motor, (7) commission a VFD with a three-phase motor, and (8) program and operate a VFD and motor using remote controls. The VFD lab assignments (2 and 3) will be repeated by all students on two different VFDs.

1. Lab assignments (with the exception of lab 1) will be completed by teams of 3 to 5 students.
2. Each student is required to submit the written portion of lab 1 for grading. For Labs 2A, 2B, 3A, and 3B, which are completed by teams, only one completed lab handout will be submitted for each team.
3. Lab assignments are due for grading as indicated in the class schedule.
4. Due to limits on instructor time and facility use, it is very important that you are present to complete VFD lab work during scheduled lab times. It will be difficult to schedule time outside of class to make-up missed lab time.

Homework: Assignments are designed to support and broaden your understanding of lecture and laboratory material and include reading assignments, answering questions based on reading and lecture content, and problem-solving exercises.

1. Assignments are graded and included in your overall class grade.
2. Assignments are due as indicated in class schedule,
3. Assignments will be reviewed in the class session following the due date.

Grading Policy: Your grade for this class will be based on your performance on exams, homework, and laboratory projects as follows:

1. Exams: 55%. Exams must be taken on the scheduled date unless other arrangements are made with the instructor. Your exam grade will be reduced by 10% if you do not take an exam on the scheduled date and have not made arrangements, in advance, with the instructor to take it at another time. If you fail to take an exam on the scheduled date and have not made arrangements with the instructor, then you must take a make-up exam within 2 class sessions or receive an "F" for that exam. In addition, **Cheating will result in an "F" grade in the course and the student will be invited to leave the classroom or lead to expulsion from the Peralta Community College District.**

   a. First Exam: 15%
   b. Midterm Exam: 20%
   c. Final Exam: 20%

2. Homework: 20%

   a. A 5% reduction in grade will be made on assignments that are late by 2 class sessions
   b. A 10% reduction in grade on assignments that are late by 3 class sessions
   c. A 25% reduction in grade on assignments that are 4 class sessions late
   d. Assigned homework that is more than 4 class sessions late will not be accepted and will be graded "F"

3. Laboratory Projects: 25%. Each lab team member is required to complete and turn-in the lab worksheet provided for the assignment for grading. Lab projects are graded as follows:

   a. 80% of your lab project grade is based on the work you turn in for grading.

   b. 20% of your lab project grade is based on your participation. Participation grading includes both instructor observation of your work in the lab and recorded attendance in laboratory sessions. Factors that influence this part of your grade are your level of active participation in completing assigned work, teamwork with lab partners, and effective use of laboratory time.

Attendance: If you do not attend class regularly, you may be dropped by the instructor if:

1. You do not attend class during the first week of class (August 20 and 22, 2012)
2. You miss more than 4 class sessions and have not communicated with the instructor about the circumstances that prevent your attendance.

   Drops of this type can only be done on Census Day (September 4, 2012), and on Attendance Verification Day (November 17, 2012). Please communicate with me as soon as possible if you are having, or expect to have, problems attending class, laboratory, or an exam.

   If you will be absent for an exam, you must also make arrangements with the instructor to resolve any issues that arise as a result of your extended absence. These arrangements should be made, preferably, ahead of time, but if not, then as soon as possible following the initial absence.

Add/Drop Policy: See Laney College Spring 2012 Class Schedule for official Add/Drop policy.

Other Rules:

1. Be respectful of others.
2. No MP3 players or iPods in use in classroom or laboratory.
3. Cell phones turned OFF or to silent-mode during class times. If you must answer your phone, please leave the classroom before doing so.
4. Handheld devices (iPhones, smart phones, etc) that can access the internet are not allowed to be used as calculators during exams. Bring a conventional, dedicated calculator for exams.
5. Clean up after yourself at the end of each class or lab session. Put test equipment, cables, adapters, etc. in designated locations. Pick up any trash and dispose of in designated containers in the B120 area, reorganize furniture, etc.

Appendix B – Sample project rubric

Motor Control Project
Student Name: _____

CATEGORY	4	3	2	1
Information Gathering	Accurate information taken from several sources in a systematic manner.	Accurate information taken from a couple of sources in a systematic manner.	Accurate information taken from a couple of sources but not systematically.	Information taken from only one source and/or information not accurate.
Motor Control Knowledge	Explanations by all group members indicate a clear and accurate understanding of motor control component, VFD functions & programming.	Explanations by all group members indicate a relatively accurate understanding of motor control component, VFD functions & programming.	Explanations by most group members indicate relatively accurate understanding of motor control component, VFD functions & programming..	Explanations by several members of the group do not illustrate much understanding of motor control component, VFD functions & programming.
Plan	Plan is neat with clear measurements and labeling for all components.	Plan is neat with clear measurements and labeling for most components.	Plan provides clear measurements and labeling for most components.	Plan does not show measurements clearly or is otherwise inadequately labeled.
Assembly and programming - Care Taken	Great care taken in assembly & programming so that the wiring is neat, and program is accurate.	wiring is neat for the most part, but 1-2 details could have been refined for a better installation.	wiring accurately followed the plans, but 3-4 details could have been refined for a better installation.	Wiring appears careless or haphazard. Many details need refinement
Function at first try	Motor functions extraordinarily well, at all operating conditions.	Motor functions well, at most operating conditions.	Motor functions pretty well, but fails under several operating conditions.	Motor does not function.
Modification/ Testing	Clear evidence of troubleshooting, testing, and refinements based on data and control	Clear evidence of troubleshooting, testing and refinements.	Some evidence of troubleshooting, testing and refinements.	Little evidence of troubleshooting, testing or refinement.

Total score of all 6 rows: _____.
Scoring: Assign earned value (1 to 4) for each row. Multiply by 4.167. = Group Project Score_____

BEST Center Curricula, Resources & Recordings

Academic Programs
Georgia Piedmont Technical College - Building Automation Systems
Milwaukee Area Technical College - Sustainable Facilities Operations
Laney College - Commercial HVAC Systems
City College San Francisco - Commercial Building Energy Analysis & Audits

Professional Development Materials, Presentations & Videos
National Institutes
Building Automation Systems Instructor Workshops
Webinars (e.g., BEST Talks)

Faculty Profile Videos
Reports & Case Studies
Marketing Resources

BEST
Building Efficiency for a Sustainable Tomorrow

NSF National Science Foundation