AC 2007-1854: PROJECT-BASED APPROACH TO INTRODUCE BUILDING SYSTEM DESIGN IN AN ELECTRICAL ENGINEERING CURRICULUM

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Project Based Approach to Introduce Building System Design in an Electrical Engineering Curriculum

Abstract

The current demand for engineers with fundamental understanding of systems design in buildings is a growing niche in industry. Some universities are recognizing this need and are introducing new courses and/or new programs to provide students with this knowledge. Approximately sixteen universities across the USA are offering undergraduate and graduate degrees in Architectural Engineering (AE) with emphases on the electrical, lighting, acoustical, mechanical and structural building system design. In the electrical and lighting field, students are designing systems with emphases on efficiency, implementation of renewable resources and conservation of energy. A basic understanding and an overview of this material can be introduced into current electrical engineering curriculum courses at the junior level in universities without such programs. This introduction will serve as means to introduce one such critical and practical implementation of the fundamental theory covered in the classroom. This approach has been implemented in a current junior electrical course at the University of Idaho and will be the subject of this paper. The practical implementation of fundamental engineering theory, the National Electrical Code and its application and methods to conserve energy are covered in the lectures and are explored by students in two separate projects. Student participation, learning and engagement in the material have made a difference in their approach to electrical machinery, power calculations and perspective on their roles as future engineers. Work samples from the student's projects will be presented and an assessment and observation of these samples and the student involvement will be discussed.

I - Introduction

Engineering programs within colleges and universities are adapting to technological advances and society needs by introducing new courses, new programs and concurrently implementing innovative methods to complement the class room teaching. Fundamental engineering theory concepts are still the core material in introductory courses, however, implementation and applications of this theory is becoming more and more specialized. Specialized fields in engineering disciplines continue to grow in order to meet this demand. As a result engineering curricula must provide relevant examples for students, be based on the needs of society, and develop methods used by real world engineers[1].

One such specialized field is the current demand for engineers with fundamental understanding of building system design. This specialization is a growing niche in industry. Approximately sixteen universities across the USA are offering undergraduate and graduate degrees in Architectural Engineering (AE) with emphases on electrical, lighting, acoustical, mechanical, and structure systems[2]. These systems constitute a building system design. In the electrical and lighting field, students are learning the fundamental theory of electrical circuits, single and three phase systems, power calculations, basic machinery and transformers. This material is then applied to the electrical building design via an introduction to the National electrical Code (NEC)[3]. An emphasis is focused on designing practical electrical systems with efficiency,

implementation of renewable resources, where applicable, and conservation of energy as essential components of each system.
A basic understanding and an overview of this material can be introduced into current electrical engineering curriculum courses at the junior level in universities without such programs. This approach has been implemented in a current junior electrical machinery course, at the University of Idaho, through the use of two separate projects. Theory and practical designs are explored by students in group collaborative efforts. The first project focuses on the elements of an electrical system design for building systems as set forth by local, state and national codes. The second project focuses on engineering roles in society to protect and conserve the environment and its resources. Students learn about and explore how utilization and design alternatives are shaping and affecting our environment and energy awareness.

This paper will discuss this project approach and material covered in more details. Section II will discuss one specific Architectural Engineering program with emphases on learning styles and structure layout to teach students electrical system design. Section III will provide a brief description of the junior level electrical engineering course and discuss the project based approach in more details. Section IV will provide project outcome and samples detailing student participation, learning and engagement in the course material. Section V will discuss observation and assessment of how this project made a difference in students approach to understanding of fundamental electrical systems and perspective on their role as future engineers. Finally, section VI will provide a summary and conclusion.

II – An Overview of Building System Design in AE Programs

The introduction of the NEC code and an overview of electrical system design in buildings as a project at the junior level at the University of Idaho are proposed as a method to introduce students to this field. It is also to provide them with the basic understanding of applications of theory covered in the classroom as is being taught at universities with Architectural Engineering programs (at a more extensive level.) To provide a measure of the project conducted by the students, an overview of a specific Architectural Engineering program proves to be helpful. The program at the University of Nebraska-Lincoln is selected and will be discussed next.

The Peter Kiewit Institute (PKI) at the University of Nebraska-Lincoln is one of leading institutions that offer undergraduate and graduate degrees in Architectural Engineering[4]. Similar to the ITL (Integrated Teaching and Learning) program[1], the PKI provides living examples of functional engineering components with which students and faculty can interact. Exposure to the systems and sensors that are integrated into and visible throughout the building stimulates the visualization aspects involved in the design process. Program-specific laboratories with state-of-the-art equipment and technology keep students on the cutting edge in their fields. Rooms designed for the purpose of displaying building system components allow these cutting edge students to see how their designs will be integrated into the designs of other professions.

Students in the electrical option are introduced to the fundamentals of building system design with emphasis on electrical circuit analysis, machinery principles, fundamental of lighting theory, and building communication systems. Students also enroll in interdisciplinary design courses with projects that lead to a better understanding of the equipment and tools used in the building industry. Specifically, in the junior and senior year, students are introduced to two courses in electrical system design and its integration into building systems. Inside the classroom, a variety of visual aids are present to assist both the instructor and students in presenting and understanding the application of single and three phase electrical systems analysis, calculations and associated practical applications. One such visual aid is a complete off-line replica of an actual 480V three phase electrical distribution system, including a main distribution panel, motor control center, step-down transformer, branch circuit lighting and power panels along with actual circuit breakers, disconnect switches, fuses and conduit and conductors to interconnect the entire system. Fig. 1, shows a picture of this layout. This replica system allows students to see the physical connections and sizes of equipment to facilitate practical and rational design methods. The classroom is also equipped with actual inductive loads, power factor correction capacitors and demand meters. These components allow the student to visually inspect the difference between real and displacement power factors and power factor correction design alternatives. In addition, the lab is equipped with various types of lighting systems and exposed mechanical equipment to provide further insight into the built environment and the student's role in this development.

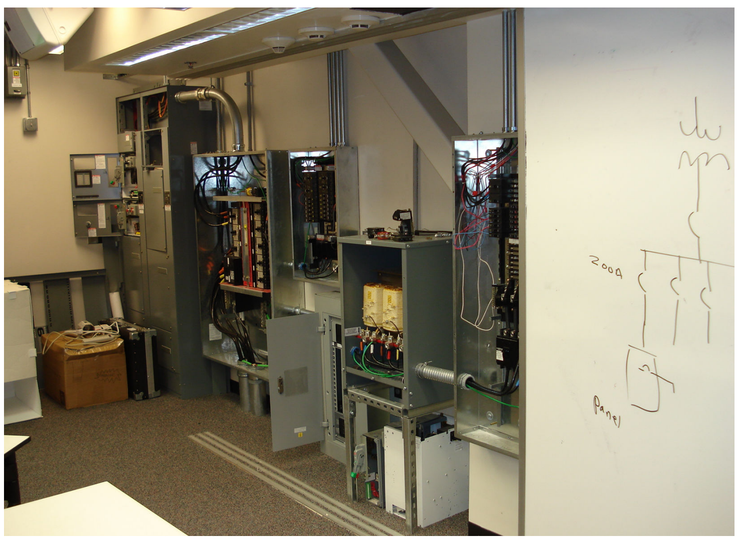


Fig. 1, Complete replica of an electrical distribution system in a classroom.

III – Project Based Approach to Introducing Electrical Building System Design

While the focus of the AE program is on graduating students with full understanding of the built environment with emphasis on building electrical system design for students in the lighting and power option, a basic understanding and an overview of such systems can be introduced in electrical engineering programs. This approach is implemented in a current mandatory course at the University of Idaho. The purpose is to provide students with practical applications of engineered systems and to give them the opportunity to explore this field in more details if they decide to pursue it as a career field. The following subsections describe the implemented approach.

A- Energy System Course Overview

Energy System I (ECE 320) is the first mandatory course in the junior year for students enrolled in electrical engineering field. The course provide students with fundamental concepts in DC and AC circuit analysis with emphasis on single and three phase power system design. System parameters including Real, Reactive, Apparent and Complex Power and their relationships are presented extensively. The course then covers electromagnetic theory as it relates to machinery principles. Transformers and DC and AC machines are introduced and their operation is explored. Practical applications of these devices are discussed to reinforce their role in the generation, transmission and distribution of electrical energy[5]. The course also covers power electronics with emphasis on buck and boost converter circuits. Students also enroll in a mandatory laboratory one credit course to provide them with hands on experience on topics covered in the Energy System I course.

The introduction to single-and three-phase power calculations and transformer theory and application provides comprehension of electrical circuits that apply to everyday life. Single phase and three phase transformers are used in many applications to convert and regulate voltages into more useful and manageable forms of power. Commercial buildings are one such example where many types of transformers are being utilized to supply different power and voltage level requirements. Typical loads in a building that will require different voltage levels include but not limited to lighting systems, receptacles, mechanical loads, motor load, building automation systems and sensors. This setting with multiple loads and voltage level calculations and analysis becomes a next step in understanding how the material covered in the lectures is used in a real world engineering problem.

B- Electrical Building System Design

The method used to introduce the topic is a combination of classroom instruction followed by a project assignment. The instruction builds on single-and three-phase power systems with transformers and motors. This is followed by introduction to the NEC, its history and purpose in practical safeguarding equipment and fire prevention. Examples of provisions of the code, such as voltage drop calculations, fault current, grounding and over current protection of electrical equipment are explained. The instruction then introduces electrical system design for residential and commercial facilities. The systems that are addressed are lighting, power, fire alarm, communications, audio/visual, building automation systems, control, and emergency systems. Components in these systems include transformers, switchboards and panel boards, protection equipment, conductors and conduit, motors, power electronics, lighting, HVAC, etc. are also discussed. Design of such electrical systems are then discussed with emphasis on proper selection and sizing of equipment, location, layout design considerations, single and three phase load calculations, fault current and voltage drop calculations. The instruction concludes with a design example illustrating the electrical system design in a typical educational building. An electrical one-line diagram for a specific building is discussed in the class and the major components are highlighted. A tour of that building is then used to show students how the one-line diagram is being transformed into actual physical components of the electrical system in the building design. Fig. 2, show various pictures taken during the tour that highlight various electrical system components.

Fig. 2, Pictures from tour of electrical system in an educational facility.

To solidify the instruction, students are teamed up in a group environment and are assigned two projects. The first project is in the NEC code implementation. In this project students are involved in the design development of a hypothetical building with pre-specified electrical and mechanical loads. In the second project, the student research and present findings on energy conservation and current industry standards.   The following subsections describe each project in more details.

1- Project I – NEC Code Implementation

The purpose of the first project is to apply knowledge of contemporary issues to identify, formulate and solve engineering problems using the National Electrical Code and understand the impact of engineering solutions in a global and social context. It requires the students to develop a simple electrical system design for a typical three story office building with a set of system requirements. Step by step procedures are used to guide students in their approach to the design process, as follow:

- Students explore the NEC and develop standard design recommendations.
- Electrical load for each floor is calculated.
- Step-down transformer applications are identifies and their sizes are determined.
- Electrical lighting and power panels are selected and sized to meet the load demand.
- Calculations of the entire system are determined and used to size the overall electrical system, including the Main Distribution Switchboard and the building service transformer.
- Consideration is taken in designing the system for future expansion.
- Overcurrent protection devices for service entrance, feeders and branch circuit panels are sized and selected.
- Service entrance, feeder and branch circuit conductors are then selected and sized for proper installation on each floor and to the building as a whole.
- Routing means (conduit, bus bars) are then evaluated and selected.
- Short circuit and voltage drop calculations are required to ensure proper circuit protection and performance.
- Finally complete one line diagram is developed for the building by each design team.

2- Project II – Power Quality and Energy Conservation.

The purpose of the second project is to identify, formulate and solve engineering problems and understand the impact of engineering solutions in a global and social context with emphasis on power quality and energy saving products and solutions. The students are required to:

- Investigate and analyze technology advances in common fields such as video monitors, computers, ballasts, variable frequency drives, and power factor correction capacitors.
- Investigate the impact of these advances in technology to improve utilization at home, in the workplace, and in commercial and industrial applications.
- Discuss the broader impact of these devices on the environment and the steps taken to conserve energy.
- Provide specific examples to support their conclusions.

IV – Project Outcome

The outcome of the project based approach is described in the following subsections.

A. Project I outcome

The outcome of this project provided student with practical applications of electrical energy systems discussed in the classroom. It also, broadened their engineering knowledge and understanding of electrical building system design. The project focused on the development of a partial one-line diagram based on single and three phase power calculations of system components. Interpretation of this data and development of a physical system has strengthened the fundamental theory discussed in the classroom. It also exposed the students to potential specialization field to pursue in the area of electrical power systems.

Sample Results

The following summary is submitted by one of the groups, the associated partial one-line diagram is shown in Fig. 3. Fig. 4, shows the developed partial one-line diagram from another group in the class.

"In order to calculate the load for each piece of equipment in the building, many resources were taken into consideration. We began our calculations using the National Electric Code in order to determine proper rating for specific things like receptacles and lighting and motors. The Internet and examples given during lecture were also used for calculation.
After determining how much current and the apparent power rating of each of the pieces of equipment in the building, we determined how many and what size breakers would be needed. We then used this information to determine the size and number of panels needed per floor. Each panel was left room for expansion and the bus-ways which they were fed from were also designed for future expansion. Our design shows the air handling unit, elevator and high voltage equipment coming directly out of the MSB so that fewer panels may be used. After adding all of the bus-ways and other connected equipment, we were able to determine the size of the MSB with at least 20% future expansion room. After finding the size of the MSB, the size of the transformer was found and the fault current was calculated. This information was enough to develop a one-line diagram so that each conductor size could be easily referenced."

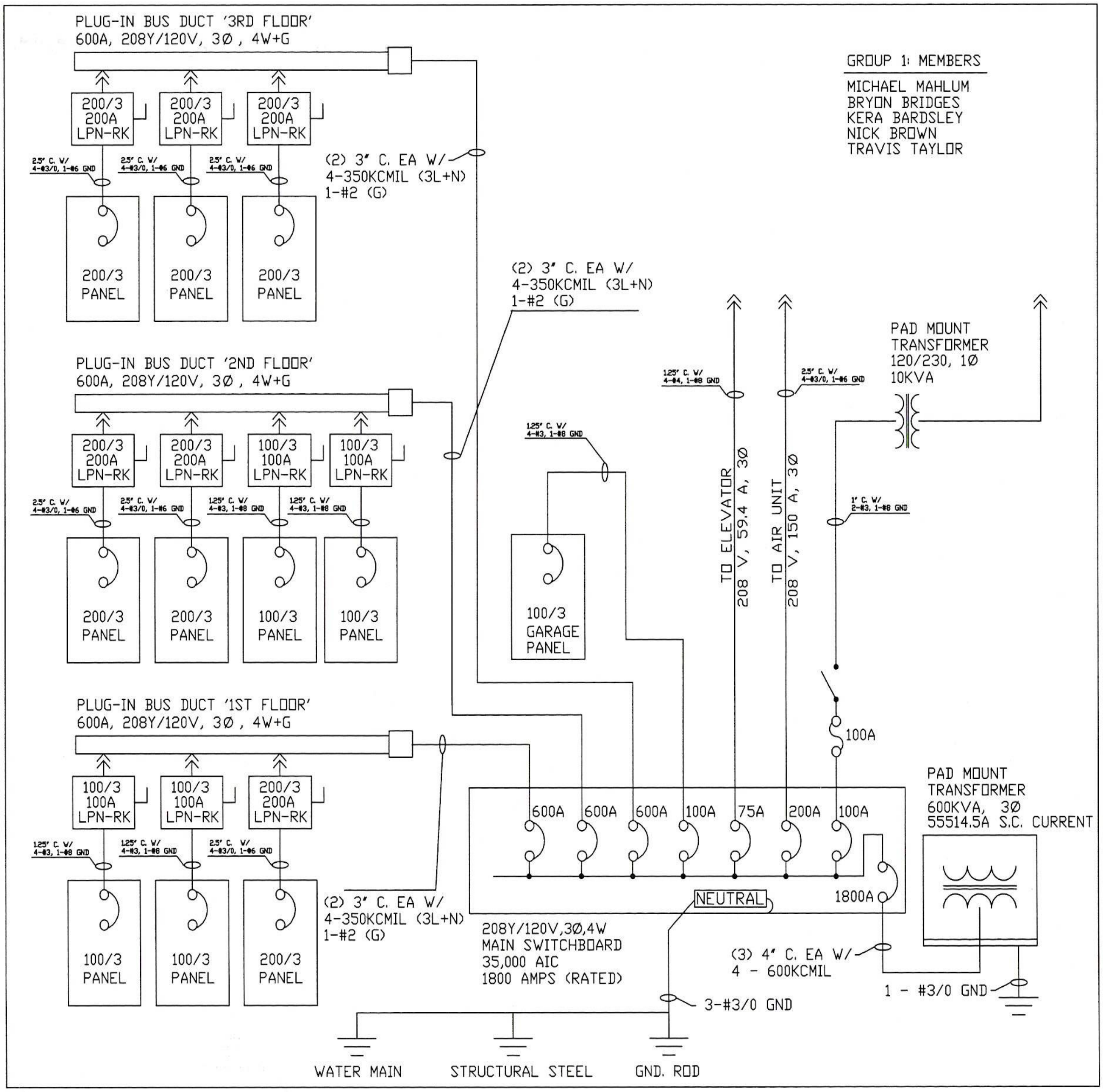


Fig. 3, Partial one-line diagram system developed by one of the groups.

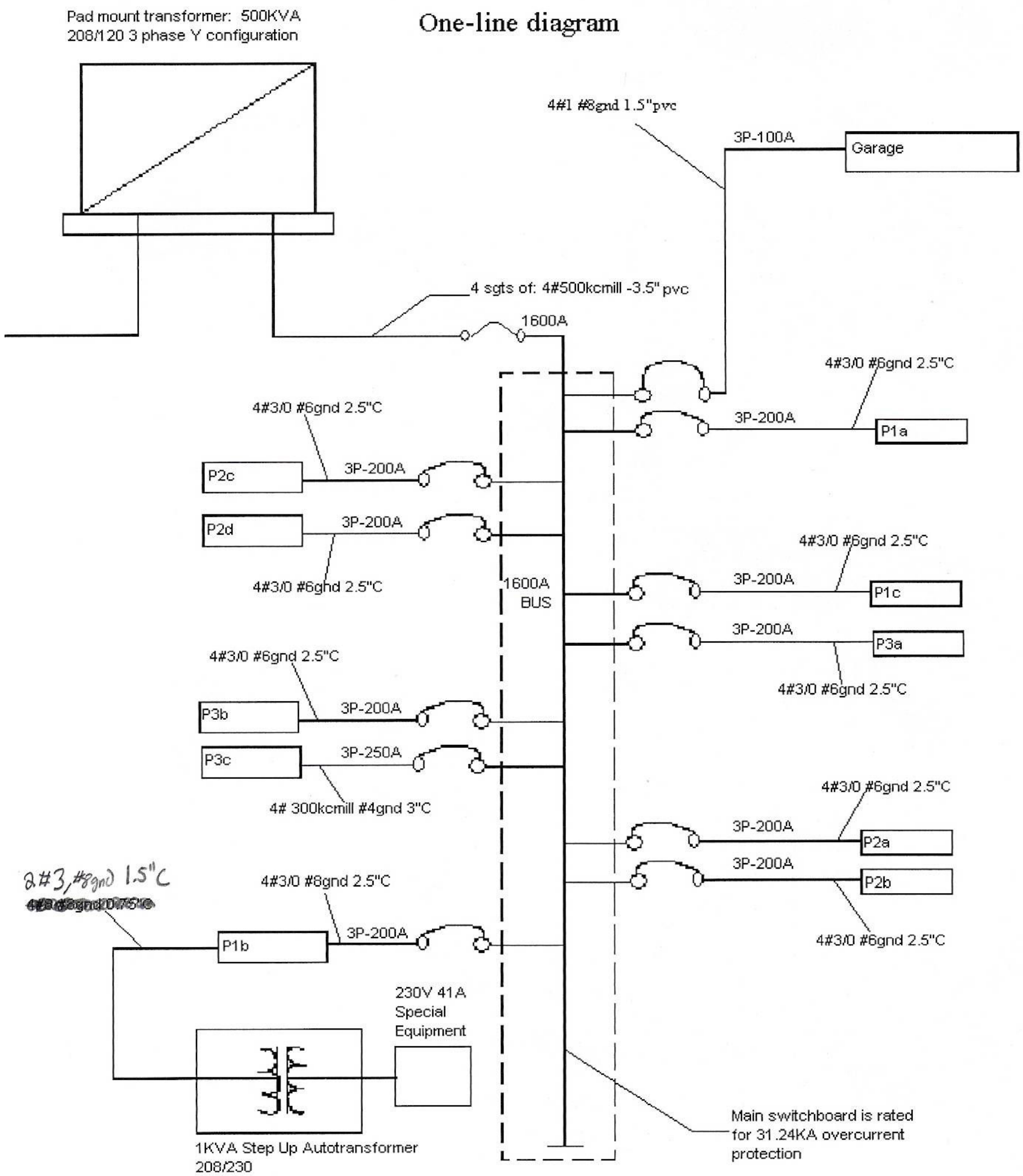


Fig. 4, Partial one-line diagram developed by another group.

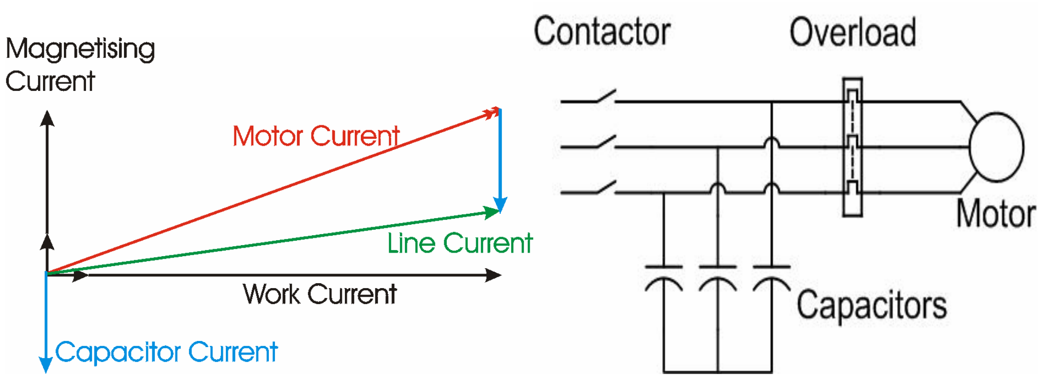
B. Project Two Outcome

The outcome of the second project provided students with knowledge related to practical application and implementation of systems and products. This in turn generated questions on why and how each component affects the environment in which they live in. Energy conservation and current issues in power systems are explored.

Sample Results

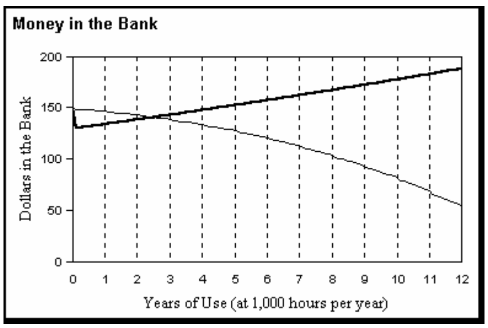
The following is a summary submitted by one of the groups. This summary serves as the results of the reasoning behind this project.

"Power factor correction capacitors are used when the total load of a system is shifted towards inductive. This is fairly common in industrial settings as almost all motors used are inductive to the grid and an inductively shifted power factor away from unity leads to voltage droops from the supply transformer and increased losses across supply lines. Power correction capacitors do NOT have an impact on power quality and so an active power factor correction unit (ac/ac converter) or a harmonic mitigating transformer is required to clean up a poor power quality. Power factor correction capacitors use must be carefully planned when used in conjunction with variable frequency drives.



Flat panel monitors use 33% less energy than a CRT of the same size display. However the cost of a flat panel display is higher, according to Microsoft, a 17 inch CRT costs 60-100$ whereas a 17 inch flat panel display can cost 200-250$. A simple online search using Google's Froogle shows prices up to 400$ for quality flat panel displays. The reasons for this are decreases in weight and materials as well as the electronics behind the operation. CRT monitors require very large voltages (25.6KV for a 15 inch monitor) at rather high currents (~1.2 mA for the same size) as well as the somewhat smaller though still quite large, 300 – 900 voltages needed for the guns, focus, and deflection controls. Flat panel monitors also require a high voltage for the backlighting, however this voltage is 700v, is DC, and does not have significant current requirements.

Current compact fluorescent lights (the "screw-in" type that are designed to replace incandescent bulbs) output more light, consume less power, and last longer than incandescent bulbs. A 75 watt incandescent light bulb lasts for 750 hours, and outputs 1170 lumens. The advertised equivalent compact fluorescent bulb to this 75 watt bulb consumes only 20 watts, outputs 1200 lumens, and will last for 8000 hours. The cost for the incandescent is 50 cents per bulb while the compact fluorescent costs $6.50. This cost is actually less when bought in bulk packaging and could be as low as $2.50. Most office buildings do not use these kinds of lights (they use the more common dedicated tube fluorescent lighting fixtures) while most homes do. The initial cost of installing a house full of fluorescent lights will be much higher than it would using incandescent lights, however, since the fluorescent bulbs last ten times longer, and consume almost four times less energy the savings over time is quite apparent. The use of these bulbs does have a negative impact on the power quality as the switching converters used are nonlinear in nature, however, in a household setting this is rarely an issue. These types of lights are generally not used in commercial or industrial settings. The figure below shows a comparison in saving between CFL and an Incandescent lamp.



Power savings in commercial buildings can be gained by using electronic ballasts instead of the older magnetic ballasts. Electronic ballasts have the advantage of increasing the switching frequency of the lights which reduces flicker and stress of personal working under the lights. Efficiency increases of 10% (at 10KHz) can be expected, as high as 20% according to the Berkley Applications Team (above 20KHz). Magnetic ballasts tend to be heavier as they rely on large iron inductors to operate. Electronic ballasts are lightweight as they operate at an increased frequency using switching power converter topologies and can therefore use ferrite based transformers which are significantly smaller for the same power rating.

Variable frequency drives are becoming more and more popular as a way to gain the control over cheap and robust induction motors that used to be only available to DC or synchronous machines, both of which require a DC field and therefore bulky and special power supplies or generators nearby. The VFD is an AC/AC switching converter that provides the required frequency signal to keep or change the speed of an induction motor as the speed is directly related to the frequency of the applied signal. Due to the nonlinear nature of the VFD controls, power factor can be negatively influenced and power correction capacitors CANNOT be used on the output of a VFD. PFCs cannot be used within 75 meters of the input as well so this imposes quite a drawback to the implementation, and more specifically conversion of older systems where PFC's may be already located nearby."

V – Observation and Assessment

The engineering solution to the electrical system in the built environment and the impact of current technologies and engineering practices are valuable outcomes from the approach adapted by the University of Idaho. This is measured via positive feedback and quest for learning by the students to design such systems and apply theory of single and three phase power calculations and implementation to actual engineering system in the built environment. The effectiveness of this approach is also measured by the by the project outcomes as seen in the previous section.

The assessment of students' learning can be measured by the level of understanding of real engineering problems and applying the theory learned in the classroom. This understanding is obvious in the developed summary and partial one-line diagrams each group presented. The first project has made students think about the physical environment and answer their curiosity as to why and how the electrical system in buildings is developed. Their design shows attention to how the placement of loads affects the size and design of appropriate protection circuitry with significant cost advantages, a strong indication of understanding above what students normally have at this level. The exposure to the NEC and research methods to develop a practical electrical system is a valuable knowledge that can be extended if students decide to pursue careers in this filed. Similarly, the second project outcome provides similar results and observation to students understands of the impact of engineering solutions in a global and social context with emphasis on power quality and energy saving products. Their insight into the engineering tradeoffs of power factor correction, for example, the placement of capacitors for effectiveness, for power quality, and for safe operation of power electronics is a strong and insightful design. Their attention to safety, even for a VFD, is remarkable at this level. The research approach in this project has made students understand and think about how the decisions they will make, will shape our future and impact the energy resources and quality of the utilized power system.

Student engagement and participation proved to be very effective and recommended for an ongoing bases with a more structured course material and supporting laboratory experiments. Inclusion of renewable energy alternatives can support this addition with the recent emphasis on green buildings and Leadership in Energy and Environmental Design (LEED). This material can be incorporated as part of a well defined course that explores energy systems, renewable energy alternatives and integrating renewable energy into the electrical system building design.

VI – Summary

This paper presented a project based approach to introduce electrical system building design into junior electrical engineering course. This approach is used to reinforce practical implementation of engineering theory covered in the course and discuss methods used to conserve energy and improve power quality. It also provided students with introductory knowledge about building system design, NEC code and potential specialization in this field. This approach is implemented due to the current demand for engineers with this knowledge. The outcome of this approach is measured by the positive and professional results presented by each group as discussed in this paper. Potential advantages to this addition include the recent focus to the renewable alternative energy and its implementation into the built environment.

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