AC 2008-103: ENHANCING ONE STUDENTS' DESIGN SKILLS IN AN ELECTRICAL ENGINEERING CAPSTONE SENIOR DESIGN PROJECT BY LEARNING FROM THE DESIGN AND HARDWARE CONSTRUCTION OF AN ANNUNCIATOR

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Enhancing One Students' Design Skills in an Electrical Engineering Capstone Senior Design Project by Learning from the Design and Hardware Construction of an Annunciator

Abstract

This paper reports on the use of the design and hardware building of an annunciator (a temperature monitor device) in a capstone senior design project course to provide an introduction to innovative instrumentation design, development and hardware construction techniques to an electrical engineering undergraduate student. The annunciator system is an excellent student learning tool because its design and implementation develops and enhances students' knowledge of several interesting and challenging aspects of analog and digital system engineering and signal processing.

Only one student (the co-author of this paper) enrolled in the capstone senior design project course offered in fall semester 2007. For her project, the student applied various hardware design techniques to develop and implement an annunciator for a unit of the State of California Department of Water Resources Harvey O. Banks Water Pumping Plant. Since the water pumping unit already exists, the new student-designed annunciator system is designed to operate in compliance with the current setup of the plant. The student-designed annunciator system is designed to be completely compatible with the 13.8 KV switchgear, and to meet other specific requirements. For example, it is suitable for normal operation at 125 V DC and continuous operation over a range of 100–150 V DC. The annunciator system is programmable and expandable to accept up to four different inputs. It also consists of output signals, such as pushbuttons for testing, acknowledging, and resetting the device.

The dual-alarm annunciator is wired to terminal blocks at the rear of the annunciator, and uses a flashing light device as well as audible alarm horn to make notifications and provide warnings when the monitored oil level and oil temperature in each water pump deviate from a preset range. These warnings are visible in the window display of the annunciator, and are heard by sounding a loud alarm/buzzer. The student installed the new system into the existing electrical prints, which date back to the 1960s. The design was retested and verified by plant engineers before the installation. The annunciator system project provided the student with in-depth knowledge and hands-on experience with designing, developing and testing a sophisticated working system that meets practical real-world engineering requirements, constraints and specifications. The instructor for the capstone design course has suggested similar annunciator design projects to electrical and computer engineering and engineering physics students taking the current (spring semester) offering of the capstone senior design project course, and plans to continue to suggest the project to students in future offerings of the course.

Introduction

The purpose of the project is to design an annunciator system for one of the units of the Harvey O. Banks Pumping Plant, a facility of the Department of Water Resources (a State of California agency). The requirements call for the annunciator system to be installed in Unit 3 of the plant. There are eleven units total. Unit 3 is one of the older existing and fully functional units in the pumping plant, and a less modern annunciator system is already installed and fully functional. Therefore, the design needs to operate in compliance with the current setup and serve as a full and functional replacement. The annunciator system design for Unit 3 consists of a window display, lights, and horn alarms that are activated by set points of oil pressure, temperature, and other characteristics.

This paper focuses primarily on the temperature monitoring device and its alarm. A new, digital temperature monitor device is implemented, replacing the original system that was installed decades ago. In order to proceed with this implementation, electrical prints that date back to the 1960s are updated, that is, the existing system will be replaced with a new temperature monitor system. Based on the requirements and specifications provided, the new temperature monitor equipment is designed and incorporated into the existing prints. Because installation of a fully functional temperature monitor device and completion of Unit 3's annunciator system will most likely not occur until mid-2008, a scaled down example of a temperature monitor is used in this project for demonstration purposes. The scaled down example successfully demonstrates the operation of the temperature monitoring process and activation of the alarm and unit trip at set temperature points.

Theoretical Background

California's State Water Project is the largest state-built multipurpose water project in the country. With construction beginning in 1957 and continuing indefinitely, it is comprised of 29 storage facilities, 18 pumping plants, four pumping-generating plants, five hydroelectric power plants, and spans a distance of over 600 miles in canals and pipelines from Lake Oroville in Butte County to lakes in Los Angeles County and Riverside County. Water supplied through the California Water Project may be found throughout Northern California, Central Valley, Central Coast, and Southern California, with about 60% going to urban users and 40% to agriculture. The Harvey O. Banks Pumping Plant is a crucial part of the State Water Project, as it is the beginning of the California Aqueduct, one of the most significant waterways found in the state of California, as well as the United States. Built in the 1960s, Banks Pumping Plant is located in Byron, California and is a part of the Delta Field Division. It consists of eleven pumping units – seven from the original construction of the plant, and four added during the 1986 expansion.

This design project focuses on Unit 3 of the Banks Pumping Plant. Unit 3 consists of a 34,500 horsepower, 225 RPM motor and a centrifugal pump that pumps 1130 CFS (cubic feet per second). The motor/pump has a working voltage of 13.8 kV and working amperage of 1,200 A, and is separately excited. Upon start, Unit 3 runs as an induction motor but becomes a synchronous motor after it has synched. Additionally, Unit 3's motor has a DC generator as a part of the excitation system. As mentioned in the introduction, Unit 3 has an existing annunciator system as part of the switchgear. Photographs of the switchgear and existing annunciator display window may be found in Figures 1-3. (An AutoCAD drawing of the annunciator display may be obtained from the authors of this paper via email.)

Figure 1. Harvey O. Banks Unit 3 Switchgear

Figure 2. Unit 3 Switchgear

Figure 3. Unit 3 Annunciator Window Display

Specifications

The annunciator system design must follow very specific requirements in order to comply with National Electrical Code as well as function properly and effectively with the existing unit design, connections, and specifications. For example, the design must be completely compatible with the existing 13.8 KV switchgear. It must also be suitable for normal operation at 125 VDC and continuous operation over a range of 100-150 VDC. (The actual connection and schematic diagrams of the existing system, as well as the system designed in this project may be obtained from the authors of this paper by email.) In these drawings, it is clear what components are removed and which components are added as a replacement.

The annunciator system accepts up to four alarm input signals per cell, with signals in either normally open or closed relay contacts. The system must also have 'test', 'acknowledge', and 'reset' pushbuttons. The 'test' buttons are used to simulate alarms, the 'acknowledge' buttons are used as a signal of the operator's recognition of the notification and to ultimately silence the alarm, and the 'reset' buttons will put the annunciator back in normal state. These pushbuttons are used for each monitoring device in the annunciator system (pressure, temperature, etc.).
At least two alarm output relays are wired to the annunciator. One relay is used to operate an audible alarm horn, while another is used to operate a flashing beacon. These relays must supply a normally open contact with minimum rating of 5 amps at 120 VAC and 0.1 amps at 125 VDC. The audible alarm horn is rated for 125 VDC, 0.1 amps DC maximum, 97 dB minimum at 10 feet, and is surface mountable. The annunciator system also includes a window display (Figure 3) that is made up of backlit window cells that are 2.75"x2.75" in size. These windows are engraved with their respective indications and/or alarms. All input and output wiring is connected to terminal blocks at the rear of the annunciator.

The annunciator operational sequence consists of seven states, tabulated below:

Normal condition	Lamps off, audible alarm relays de-energized, horn off
Alarm condition	Lamps flashing fast, horn on
Acknowledge alarm	Steady lamps, horn off
Return to normal	Lamps flashing slow, horn off
Return to normal before acknowledge	Lamps flashing slow, horn on
Reset alarm	Lamps off, horn off
Annunciator test	Alarm condition simulation for all points

Table 1. Annunciator Operational States

In terms of environmental requirements, the annunciator system is designed to be mounted in a control switchboard and switchgear with a rating of 13.8 KV. The system is required to withstand the vibrations caused by the start, stop, and run of large hydro pump motors.
As previously mentioned, the temperature monitor device is one of the most significant components of the annunciator system. The temperature monitor device monitors the temperatures of the pump's oil and pump bearing using three-wire temperature probes. The monitoring devices are assigned three temperature set points: an ambient value, an alarm value, and a unit trip value. The ambient value is a temperature lower than the alarm value. The alarm set point, "set point A" indicates the heating of the bearing (or oil) past the ambient temperature, while the pump bearing's "set point B" temperature value causes the entire unit to trip. Oil temperature does not cause a trip in the unit to occur. The temperature monitor device has corresponding windows in the annunciator system window display, and it corresponds to the annunciator system sequence.

Design

AutoCAD and Raster Design software were used in the design and updating of connection and schematic diagrams to include the alarm system and temperature monitor. Revisions were made primarily on switchgear and panel-board drawings. The Department of Water Resources Operations and Maintenance division maintains an extensive number of drawing files, and each of the drawings that pertain to the design project had to be retrieved. Additionally, a new drawing of the temperature monitor connection terminals had to be created. (The most updated drawings can be obtained from the authors of this paper via email. The drawings use a different color for the parts added to the updated system, and a different color for the parts that are removed.)

In terms of actual equipment used in the project, it has been decided to use a Ronan annunciator system. For the sake of uniformity with the newer units in Banks Pumping Plant, the X11SN annunciator system is implemented in unit 3. Documentation relating to the X11SN can be found on the Ronan website[1]. A Ronan High-Density Process Monitoring System, model X87, is used as well. The X87 device is shown in Figure 4, and a user manual complete with specifications can be found in the Ronan Website[1].

Figure 4. Ronan X87 Monitoring System

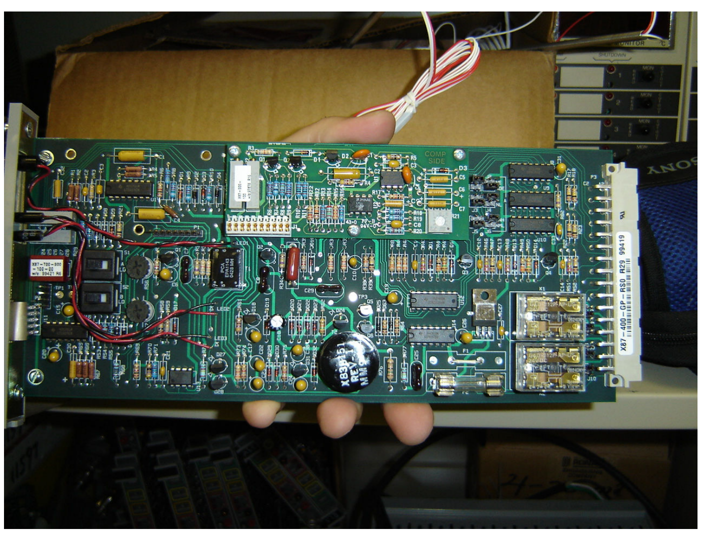

Figure 5. Ronan Temperature Monitoring Card

Ronan temperature monitor cards like the one shown in Figure 5 are installed within the monitoring system, replacing the existing Omniguard temperature monitoring device. A photograph of the Omniguard device is shown in Figure 6. Much research had to be conducted on the Omniguard device and hand-over -hand wire tracing had to be used. The original drawings had to first be updated due to the extensive amount of time that has passed between installations. Wiring of the actual device had to be traced in the plant, to match the drawings, as well. Complete verification was needed in order to proceed with the new design.

Figure 6. Edison Omniguard Temperature Monitor

In completing all research and verification, all existing drawings that pertain to the temperature monitor and annunciator were modified. Drawings that included wiring for the existing Omniguard were updated to show removal of the system and addition of the Ronan device. The drawings are completely up to date and ready to be implemented in the scheduled March 2008 installation. Each of these drawings may be obtained from the authors of this paper via email. As far as the cost of the system, at the time of this writing, it is not certain what the entire cost, including labor, will be.

Design and Demonstration of Small-Scale Replica

A scaled-down replica of a temperature monitor was connected in the electrical/mechanical shop to simulate the functions of the temperature monitor to be installed at Banks Pumping Plant. This replica consisted of a Ronan X87 Monitoring System, two Ronan temperature cards: one to signify oil bearing temperature and one to signify oil temperature, a temperature calibrator/heater, two three-wire temperature probes, and heated water in a container. Photographs of the equipment used can be found in Figures 4 and 5 (Ronan equipment), and Figures 7 and 8.

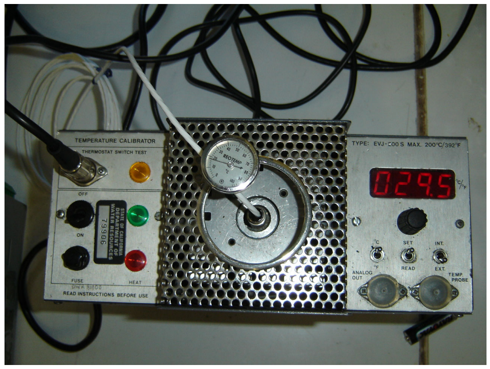

Figure 7. Temperature Calibrator

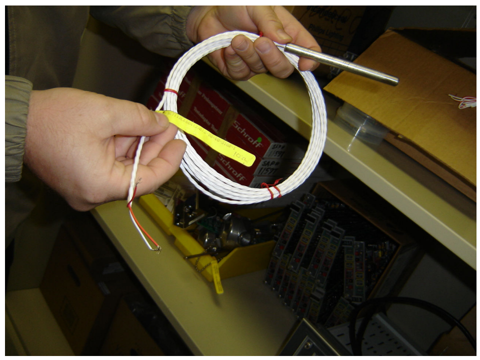

Figure 8. Three-Wire Temperature Probe

The temperature monitor cards were installed into the X87 monitoring device, as shown in Figure 9.

Figure 9. Ronan X87 device with two temperature monitor cards installed

With the two cards installed, temperature probes were wired to the back of the cabinet, at the cards' corresponding terminals. The white wire serves as common, while the two red wires are active. This wiring configuration can be found in Figure 10.

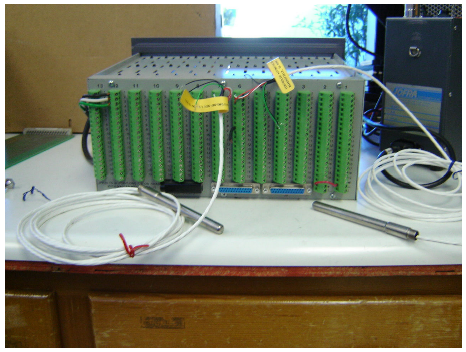

Figure 10. Wiring of Temperature Probes to Monitoring Device

A complete block diagram of the setup, as well as a photograph of the setup can be found in Figures 11 and 12.

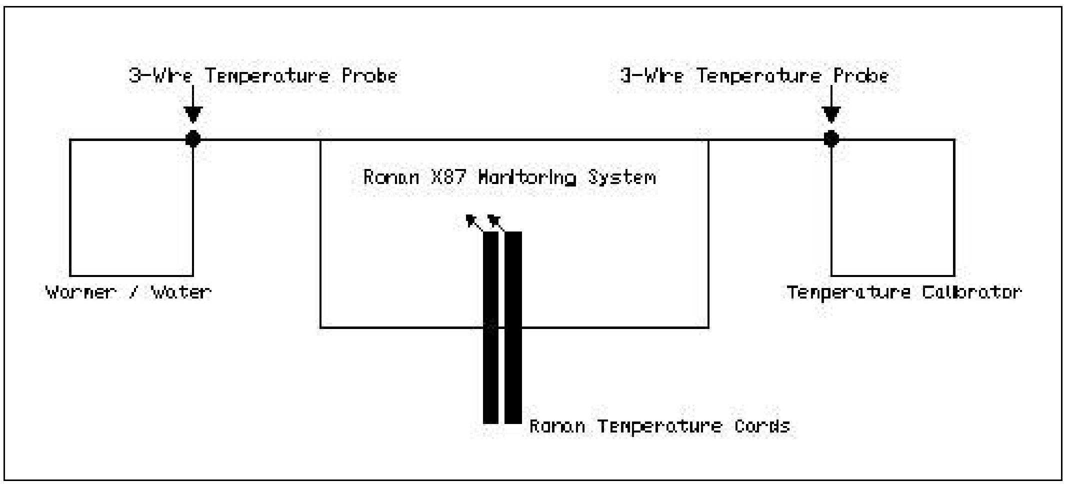

Figure 11. Block Diagram of Demonstration Setup

Figure 12. Complete Setup of Demonstration

To perform the demonstration, the temperature calibrator was implemented as a heating device, and one of the temperature probes was to be inserted into the apparatus. The calibrator was set to a chosen temperature of 29.5°C. In order to demonstrate the functionality of the entire monitoring system, it was decided that the set points of the temperature card corresponding to the designated probe would be adjusted to 27°C for "Set Point A" and 28°C for "Set Point B." These adjustments were made by pressing the corresponding buttons and using a precision screwdriver to decrease or increase the temperature points accordingly. Setting the points with only a difference of 1°C would facilitate the process of triggering each alarm. Before any alarm is activated, the temperature monitor is found at rest at an ambient temperature, which is any temperature below the first set point. This is known as the normal condition, at which neither alarm light is on and no horn sounds.

As the calibrator heated, the "Input" button on the temperature card was pressed. This button allows the display of the temperature the probe detects. The temperature increase was monitored, and as expected, at a temperature of 27°C, the "Set Point A" alarm was triggered on, and the "Set Point A" light on the temperature card was turned on and flashed. In the actual design for the plant, an alarm horn would sound as well, but for the demonstration, no horn was connected. Generally, when an alarm is activated at the first set point, it serves as a warning or notification within the plant of potential overheating. This can be seen in Figure 13.

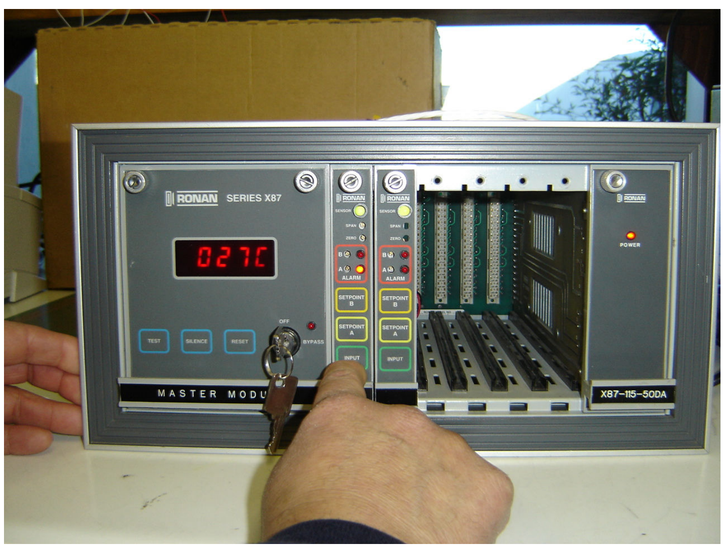

Figure 13. Temperature Point "A" Alarm Light at 27°C

Likewise, at a temperature of 28°C, the "Set Point B" alarm was triggered on, and the "Set Point B" light on the temperature card was turned on and flashed. In the actual plant, for oil bearing temperature monitoring, this point would indicate a trip of the unit. The indicator light flashing of "Set Point B" is shown in Figure 12.

Figure 14. Temperature Point “B” Alarm Light at 28°C

For the second card, a similar test was performed, with the probe submerged in water (used as a substitute for oil). For this card, however, both set points would only activate an alarm, and would not trip the unit.

Generally, the demonstration was a brief and simple way of explaining the main function and purpose of the temperature monitor system. The demo also shows how important the actual design is to the pumping plant and the maintenance of pump functionality. A temperature monitoring system is crucial in preventing serious damage to the pumps caused by excessive heating, and its installation is therefore necessary for all pumps in the plant.

Assessment and Concluding Remarks

In this section the costs and benefits of the project are assessed.

This was the first time the annunciator project was available to students; only a single student was enrolled in the senior capstone design project course in the fall semester, and the student is a graduating senior (the student needs to take only one more university course to graduate at the end of the current spring semester). Due to these factors, there is no control group data and hence it is not possible at the time of this writing to asses quantifiably whether and how the project led to tangible improvements in the success of the student at the university. Given these factors, the project was run as an experiment. Considering the success of this project, the instructor for the capstone design course has suggested some variations of this annunciator design project to electrical and computer engineering and engineering physics students taking the current (spring semester) offering of the capstone senior design project course, and plans to continue to suggest other variants of annunciator projects to students in future offerings of the course.

The university has incurred no direct financial cost for this project, since the Dept. of Water Resources has assumed the full cost, including all labor, materials and other expenses.

The following is quoted directly from the student co-author who worked on the capstone design project:

"After having spent such a great amount of time on the design of the temperature monitor and annunciator system for Unit 3 of Banks Pumping Plant, I can say that this has been a very valuable experience in which I learned a great deal. The opportunity to play a key role in the design of a project that will ultimately affect millions of lives in the long run has been a truly rewarding experience, and I am glad that my employer, as well as the university, have allowed me to utilize this experience for my senior project.

Working on this hands-on real-life project was very challenging and time consuming, particularly in terms of research conducted and constant plan checking and verification, but provided me with the kind of trials that I can expect from a full-time, professional employment position. I began to think in the type of mindset in which only my best effort was satisfactory in the completion of the project, and that someone out there was actually depending on me to provide the best functional design possible. Although this mindset was accompanied by a significant amount of stress, it was also the source of my enthusiasm and drive.

Working in the shop to design and construct the small-scale replica was also exciting. Because I was not permitted to physically touch any wiring of the actual switchgear, it was good to be able to put together the equipment necessary for the replica on my own, wire it, and test it. I believe that this experience also helped me to gain more knowledge and understanding of the entire system.

The installation of the full annunciator system is scheduled to take place in March 2008. It is unfortunate that at the time of the paper submission the installation has not yet occurred, as it would have been a wonderful finale to my senior project. However, it is anticipated that by the time the paper is presented at the conference, the new system will be installed and fully operational. I intend to participate in the installation and in the initial testing after installation and I plan to present up-to-date information on the installation and testing during the paper presentation at the conference."

Acknowledgments

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Bibliography

1. Ronan Website: http://www.ronan.com/