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Low Voltage Power Distribution System Provides Incubator for Energy-Related Student Projects

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Abstract

An emerging technology in building power distribution involves the use of a room ceiling tile support grid to create a low voltage "microgrid" network. With this network, 24VDC power is routed throughout the room via conductors embedded in the drop-ceiling support structure. Users can then tap into the low voltage supply from any location in the room. The microgrid effort is organized by a consortium of industry and university partners exploring the use of low voltage DC indoor power distribution for a variety of commercial, industrial and residential applications. An example of applications on the load side includes lighting and ventilation devices. Input power for the microgrid can be derived from many sources including standard building AC power and alternative sources such as solar. A 24VDC ceiling system was installed in one room of the engineering building at Penn State - Berks. The room serves as both laboratory and classroom space. Students in the engineering technology programs have been involved with designing and fabricating devices to use and/or control power derived from the 24VDC microgrid system. Devices include room lighting control and portable device charging stations. The low voltage microgrid provides a relatively safe environment in which to experiment with new devices for occupied space environmental control. Students are very motivated to create devices that positively influence their learning environment. This paper presents details of student projects which interface with the microgrid system. Details of the microgrid infrastructure are also presented and discussed.

Introduction

Engineering technology students at Penn State - Berks are involved with an innovative and emerging technology in the area of indoor building energy distribution. With the help of industry partners of the Emerge Alliance® consortium, an engineering laboratory/classroom has been converted to use a 24VDC system to power its lighting needs.[1] The 24VDC power is distributed throughout the room via conductors embedded in the support grid of the suspending ceiling system. The ceiling system used in the room is manufactured by Armstrong World Industries.[2] Other members of the Emerge Alliance consortium manufacturer equipment to support the low-voltage DC power distribution, control, and use of the microgrid.[3] End users can obtain power for their devices by simply connecting to the suspended ceiling grid, either below or above the ceiling tiles, at the point of use in the room. The ease of use and inherent safety of the low-voltage system make it very useful for engineering student projects.

Figure 1 shows photographs of the ceiling grid structure. Also shown in Figure 1 are some of the power connectors through which the 24VDC power is supplied to and taken from the microgrid.[4] There is also a version that provides access to the 24VDC power through a slot on the bottom side of the support member. The ceiling system members are the same size as standard, non-powered, versions therefore no special suspended ceiling tiles are required.

Figure 1. Ceiling Grid Structure and Connectors

Regulated 24VDC power for the microgrid is provided by a Power Server Module (PSM) manufactured by Nextek Power Systems.[5] PSM input power is provided by the AC mains (208/240VAC). There is also an option for an auxiliary DC input. The PSM provides sixteen 24VDC output channels with each channel providing a maximum of 95W (3.96A). The room ceiling grid is partitioned into sixteen electrical zones with one channel of the PSM providing power for each zone. The PSM is lightweight and mounts on the ceiling grid above the tiles as shown in Figure 2.

Figure 2. Nextek Power Server Module

The campus took advantage of the opportunity to install the Armstrong DC Flexzone suspended ceiling grid in one classroom/laboratory space when a new engineering building was being constructed. Due to building contracts and timing, the 24VDC microgrid power components, however, were not installed until after the building was completed.

System Integration – Phase 1

The first phase of implementing the 24VDC microgrid in the room was to convert the existing ceiling fluorescent lighting fixtures from 277VAC to 24VDC operation. The bulk of this work was performed by volunteers from Armstrong, Nextek and campus maintenance. The first step in this phase was to install the Power Server Module, connect the sixteen zones, and energize the ceiling grid. The AC input ballast of each fluorescent light fixture was removed and replaced with a 24VDC ballast manufactured by Nextek Power Systems.[6] Figure 3 shows the type of Nextek ballast that was installed.

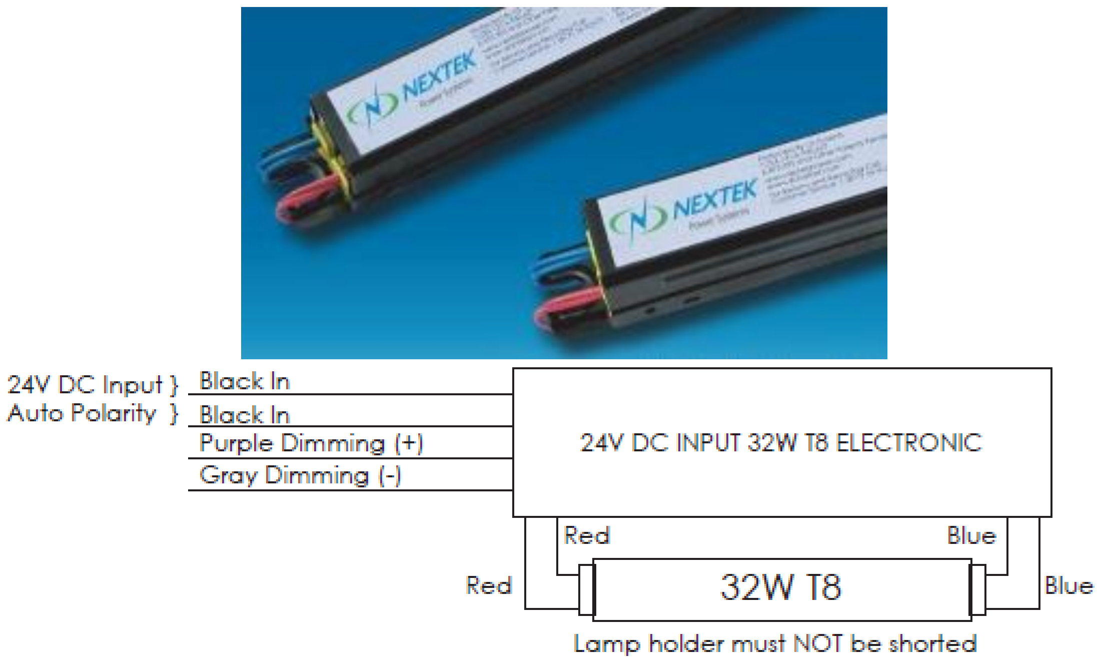


Figure 3. Nextek 24VDC Input Fluorescent Lamp Ballast

The 24VDC input power for the ballasts is provided through connection to the microgrid above the ceiling tiles. As shown in Figure 3, the 24VDC fluorescent lamp ballasts provide a dimming input. Dimming is accomplished by applying a 0 – 10VDC signal between the dimming inputs. If a dimming voltage less than 1VDC is applied to the dimming input, the lamp is extinguished. If the dimming inputs are left open, an internal pull-up circuit causes the lamp to operate at full brightness. Therefore, the dimming inputs can be wired to the existing room light switches via the existing room wiring to provide simple on/off lamp operation. Thus, the original room lighting function is maintained.

System Integration – Phase 2

With the infrastructure in place, there were now opportunities for students to get involved with creating devices to modify and enhance the function of the room. While many commercially available devices exist for use with the microgrid, the main purpose of installing the low-voltage system was to provide students with an area to experiment with their own ideas and designs for the type of devices that should be used in this environment.

Student Project 1 - Fluorescent Lamp Dimming

One obvious enhancement to the room was to add the ability to dim the overhead fluorescent lamps. This feature is very useful when the room is used for presentations. As previously discussed, the 24VDC ballasts that were installed in the room lighting fixtures provide dimming inputs. The project then became one of designing a scheme to provide the user with a convenient way to dim the lights. After some student brainstorming, it was decided to design a device to allow the user to dim the lights using a handheld, TV-style, remote control unit.

Implementing the desired lamp dimming functions and performance comprised many areas of analog, digital, and signal processing technology. Some of which were unfamiliar to the students. This situation provided an excellent opportunity to learn new concepts and how to integrate them into one device. Figure 4 shows a block diagram of the remote control lamp dimmer unit.

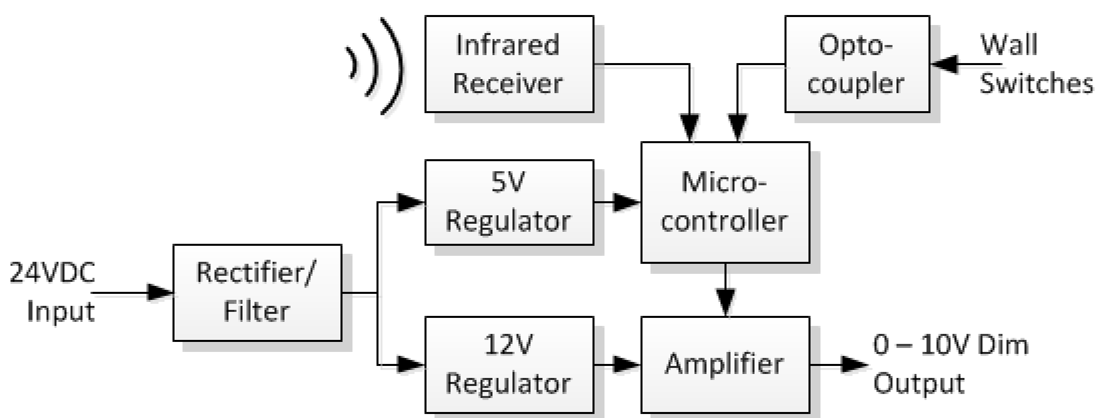
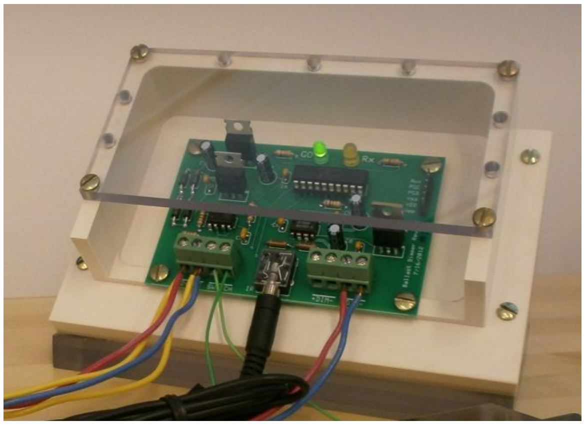


Figure 4. Remote Control Lamp Dimmer Unit Block Diagram

The student team worked to design the circuits, the printed circuit board, and the enclosure. Software for the microcontroller was also developed. A breadboard circuit was built and tested. CAD files to control a CNC milling machine were generated and the final assembly was fabricated, tested and installed. A user manual was also written and published. Figure 5 shows some photographs of the finished unit. The photo on the right shows the unit installed above the ceiling tiles. The tiny infrared receiver (not shown) is located beneath the ceiling tiles. Three units were built and installed to control the three sections of lighting. Operation of each section of lighting is controlled by a different button of the TV-style universal remote control unit.



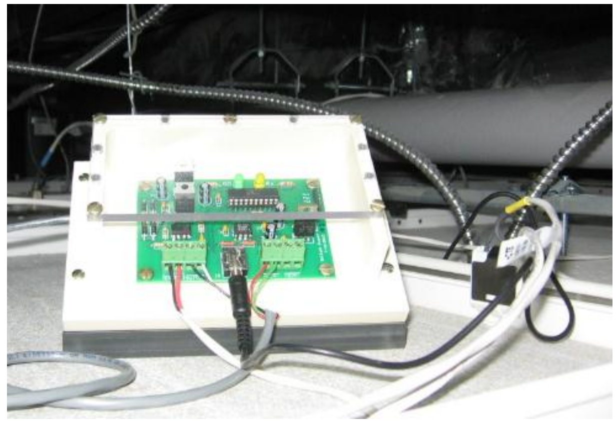


Figure 5. Fluorescent Dimmer Unit Assembled (left) and Installed (right)

Student Project 2 – LED Spotlight

The second student project was part of an independent study course to explore microcontroller applications beyond the introductory course level. Here the student was given a set of specifications for an LED spotlight that would be controlled by a TV-style remote control (the same remote control as the first project) and could be mounted to the ceiling grid above various workstation locations in the laboratory. As before, the project involved electrical and mechanical hardware design as well as microcontroller software design.

The LED spotlight is a commercially available unit (now discontinued) manufactured by LedEngin, Inc.[7] The spotlight is dimmable by applying a low frequency (~300Hz) PWM signal to the PWM input. The PWM signal is generated by the microcontroller on the student-designed printed circuit board. The microcontroller also decodes the TV remote control signal that is received by the infrared receiver device. Commands from the remote control are used to vary the PWM signal pulse width and thus dim the LED spotlight. Figure 6 shows the LED spotlight system breadboard and final assembly installed in the microgrid using a bottom-side connector. The lid of the control unit has been removed to show the enclosed PCB.

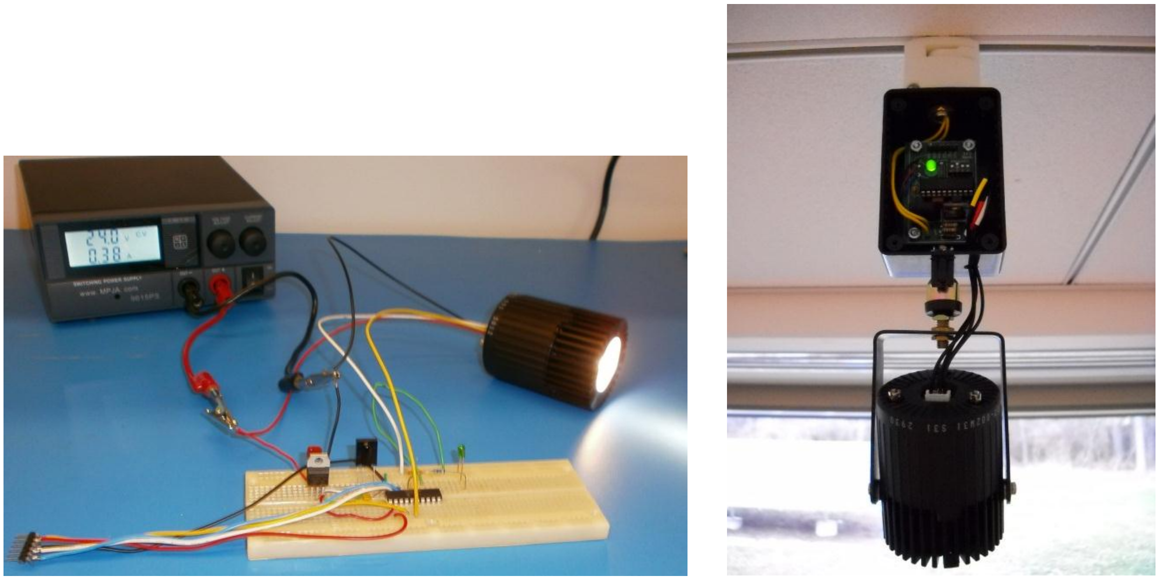


Figure 6. LED Spotlight System Breadboard and Final Assembly

Student Project 3 – Occupancy Sensor

When the classroom/laboratory space fluorescent lighting was converted from 277VAC to 24VDC, the room occupancy sensor that controlled the lights could not be included in the system without modification. Originally, all of the 277VAC power for the room lighting passed through a solid state relay that was controlled by the occupancy sensor. Power for the occupancy sensor electronics was also provided by a power supply contained within the solid state relay unit. The 24VDC power system module was not compatible with this type of power switching arrangement. Therefore, a new scheme needed to be designed to restore the energy saving function of an occupancy sensor in the room. The plan was to try to use the original occupancy sensor device in some way. The next student project opportunity became apparent.

The occupancy sensor used in this project is the DT-300 manufactured by WattStopper® [8]. The DT-300 requires 24VDC power, which is usually provided by the internal power supply of the accompanying solid-state relay module. Now, however, the DT-300 could be powered from the 24VDC microgrid. The problem remained how to control the room lighting from the occupancy sensor output signal. The answer was to create infrared signals to send to the lighting control units that were already installed (and presented here as projects 1 and 2).

The technical challenge with the infrared transmitter was to design a device that, 1) would easily attach to the existing occupancy sensor in the original location and, 2) could reliably send infrared signals to all of the infrared receivers already positioned around the room. The second challenge became the most formidable due to the myriad of obstacles already suspended from the ceiling (four rows of fluorescent light fixtures, a video projector, and six industrial retractable power cord reels).

To reliably transmit the infrared signal around the entire room with the available individual infrared LED device transmitting pattern, an array of twelve LEDs was constructed. The LEDs were arranged in a planar, equally-spaced, radial pattern (a dodecagon). A prototype array was constructed and tests were conducted to determine the distance beneath the ceiling at which the array must be located to reliably transmit to all receivers in the room. Figure 8 shows the final design which positioned the dodecagon LED array about eight inches below the ceiling tiles.

A small control unit was also designed and fabricated to generate the infrared signals to be transmitted by the LED array. The control unit PCB contains the 24VDC polarity correction rectifier bridge, 5V regulator for the microcontroller, microcontroller, occupancy sensor output signal conditioning circuit, and the infrared LED driver circuit. The control unit is located above the ceiling tile where the occupancy sensor is located. Figure 8 shows the control unit with the lid removed prior to installation.

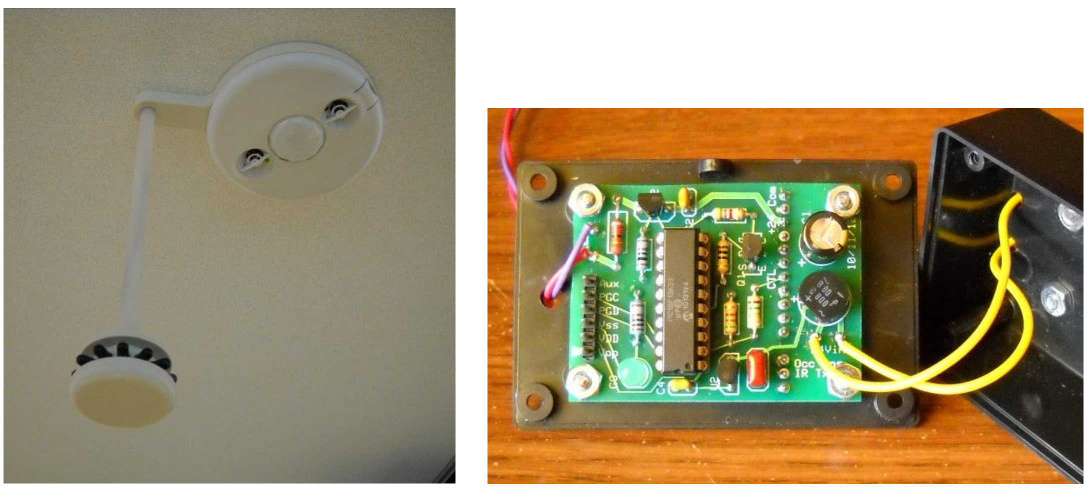


Figure 8. Occupancy Sensor and Transmitter (left), De-lidded Control Unit (right)

Student Project 4 – Mobile Device Charger

While brainstorming with a few students, they came up with the idea to use the microgrid as a source of power for charging their cell phones and other mobile devices while in class. Each laboratory bench in the room already has a desktop computer with ample USB ports that could be used for charging and standard 120V receptacles are everywhere in the room. However, as will be seen in the next section, “Future Work – Phase 3,” the microgrid will soon be at least partially powered from rooftop mounted solar panels. Therefore, the idea of using solar energy to charge their mobile devices was very attractive to the students. Their enthusiasm about green energy is common among engineering technology students.[9]

The mobile device charger project is still underway. The students have decided upon a design and several components have been purchased for the prototype. Their idea is to build the system around an existing, commercially available 24VDC charger. The students will then add the required input polarity correction and package the device such that it can be secured to the laboratory bench to reduce theft and provide strain relief for the input power harness. Input power will be obtained from a bottom-side DC Flexzone connector. The input power harness will be discretely routed down the wall to the bench-mounted charger. Figure 9 shows the collection of components and a CAD drawing of the enclosure to hold the charger unit.

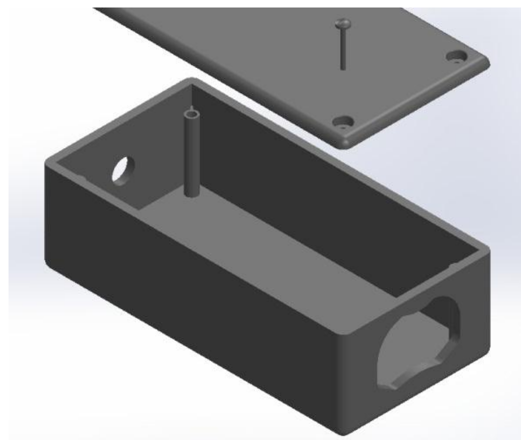


Figure 9. Mobile Device Charger Prototype Parts and Enclosure Design Concept

Future Work – Phase 3

As previously mentioned, the microgrid will be partially powered via roof-mounted solar panels. Five 230W solar panels have been donated by Canadian Solar, Inc. These solar panels will be installed in an array to be mounted on the roof of the new engineering building. Conduit was installed from the roof to the room containing the microgrid at the time the building was constructed in anticipation of this project.

Nextek has also provided a Maximum Power Point Tracking (MPPT) regulator to condition the solar array output power prior to being applied to the microgrid via the Power Server Module auxiliary input. The Power Server Module will provide the additional energy from the AC mains input if the microgrid load exceeds the energy available from the solar array. The status of the PSM power flow can be monitored via a Zigbee link and the accompanying software.

Also in Phase 3 of the project, energy storage via batteries will be incorporated into the system. The capacity of the battery array is still being determined by the manufacturer and corporate partner, East Penn Manufacturing, Inc., manufacturer of Deka® batteries. A charge controller for the batteries is also being developed by Ecoult, Inc., a subsidiary of East Penn Manufacturing.[10,11]

Faculty and students will work together on the energy storage phase of the project. Hardware and software will be developed to schedule and control the flow of energy from the solar array to the batteries and the room load. Various load/charge management profiles will be investigated to better understand how battery storage can be most efficiently utilized in microgrid installations.

Conclusions

Through these design experiences, the students have been required to consider many practical aspects of their products. Each device had to be designed such that it could be installed by the consumer or an electrician using standard practices. A user and installation manual was also developed and published for each device to provide assistance to users after the designing students have moved on. These topics are more easily understood by the students through project-based learning such as this.

The low-voltage power distribution system has and will continue to provide an excellent environment for students to experiment with devices to shape their learning environment. The 24VDC microgrid represents an emerging technology in energy distribution. Exposing engineering technology students to this type of new idea serves to widen their appreciation for the evolution of the energy field. The experience of seeing the devices that they helped to create being utilized to modify the environment in which they learn is also very valuable. The microgrid laboratory space will continue to evolve as each new class of students has an opportunity to provide input and ideas for its use.

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- East Penn Manufacturing, Deka Batteries
- Ecoult
- Canadian Solar

- Parker
- ONExia
- Off-Grid Technologies

Their contributions of material and/or time has made possible these students projects utilizing the microgrid.

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