Arnold Schwarzenegger
Governor

NEW POWERLINE CONTROL TECHNOLOGY FOR LIGHTING AND HVAC

INDEPENDENT ASSESSMENT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program
Energy Innovations Small Grants Program

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PREFACE

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

PIER funding efforts focus on the following research, development, and demonstration (RD&D) program areas:

- Building End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Environmentally Preferred Advanced Generation
- Energy-Related Environmental Research
- Energy Systems Integration
- Transportation
- Energy Innovations Small Grant Program

The PIER Program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million, five percent of which is allocated to the Energy Innovation Small Grant (EISG) Program. The EISG Program is administered by the San Diego State University Foundation through the California State University, under contract with the California Energy Commission.

The EISG Program conducts up to six solicitations a year and awards grants for promising proof-of-concept energy research.

The EISG Program Administrator prepares an Independent Assessment Report (IAR) on all completed grant projects. The IAR provides a concise summary and independent assessment of the grant project to provide the California Energy Commission and the general public with information that would assist in making subsequent funding decisions. The IAR is organized into the following sections:

- Introduction
- Project Objectives
- Project Outcomes (relative to objectives)
- Conclusions
- Recommendations
- Benefits to California
- Overall Technology Assessment
- Appendices
    - Appendix A: Final Report (under separate cover)

- Appendix B: Awardee Rebuttal to Independent Assessment (awardee option)

For more information on the EISG Program or to download a copy of the IAR, please visit the EISG program page on the California Energy Commission's website at: http://www.energy.ca.gov/research/innovations or contact the EISG Program Administrator at (619) 594-1049, or e-mail at: eisgp@energy.state.ca.us.

For more information on the overall PIER Program, please visit the California Energy Commission's website at http://www.energy.ca.gov/research/index.html.

Introduction

Power systems in existing, electrically complex buildings, such as commercial, industrial, and institutional facilities, could save energy if they were fitted out to communicate with individual load-control devices. In new construction, cost-effective control circuits can be incorporated into the original wiring. The cost of additional hard wiring for an energy-management system (EMS) in existing buildings generally is prohibitive. Typical solutions that use either existing building electrical wiring or wireless communications have been costly or unable to function accurately in an electrically complex environment. The development of a cost-effective, reliable communications system for existing buildings would produce energy savings.

The environmental benefits and associated cost-effectiveness of reducing energy usage with EMS in new commercial and industrial environments are well established. Assuming the communications problem can be solved for existing buildings, retrofitting them should produce similar benefits. As an example, if the retrofit enabled only savings in lighting (assumed to represent 30 percent of the building's total load), a typical reduction in energy for lighting of 20 percent to 45 percent from an energy management system would yield an overall building energy savings of 6 percent to 13 percent. Given the California Energy Commission's estimate that the commercial and industrial sectors accounted for more than half of total electricity consumption in California between 1990 and 2001, the potential energy savings from such retrofits could be substantial.

The researcher demonstrated that it is feasible to provide highly reliable communications through existing building wiring in electrically complex (3-phase, 120/208-volt and 277/480-volt) environments. This was done by using modules developed and built for the project to send and receive a series of precisely timed and relatively large (tens of volts) electrical pulses superimposed on top of the standard AC power sine wave over the AC line. One pulse per half-cycle of the AC sine wave is sent in a time position that is relative to its data value (Figure 1). The position corresponds to a value of: 0, 1, 2, or 3 (a Pulse Position Modulation scheme.)

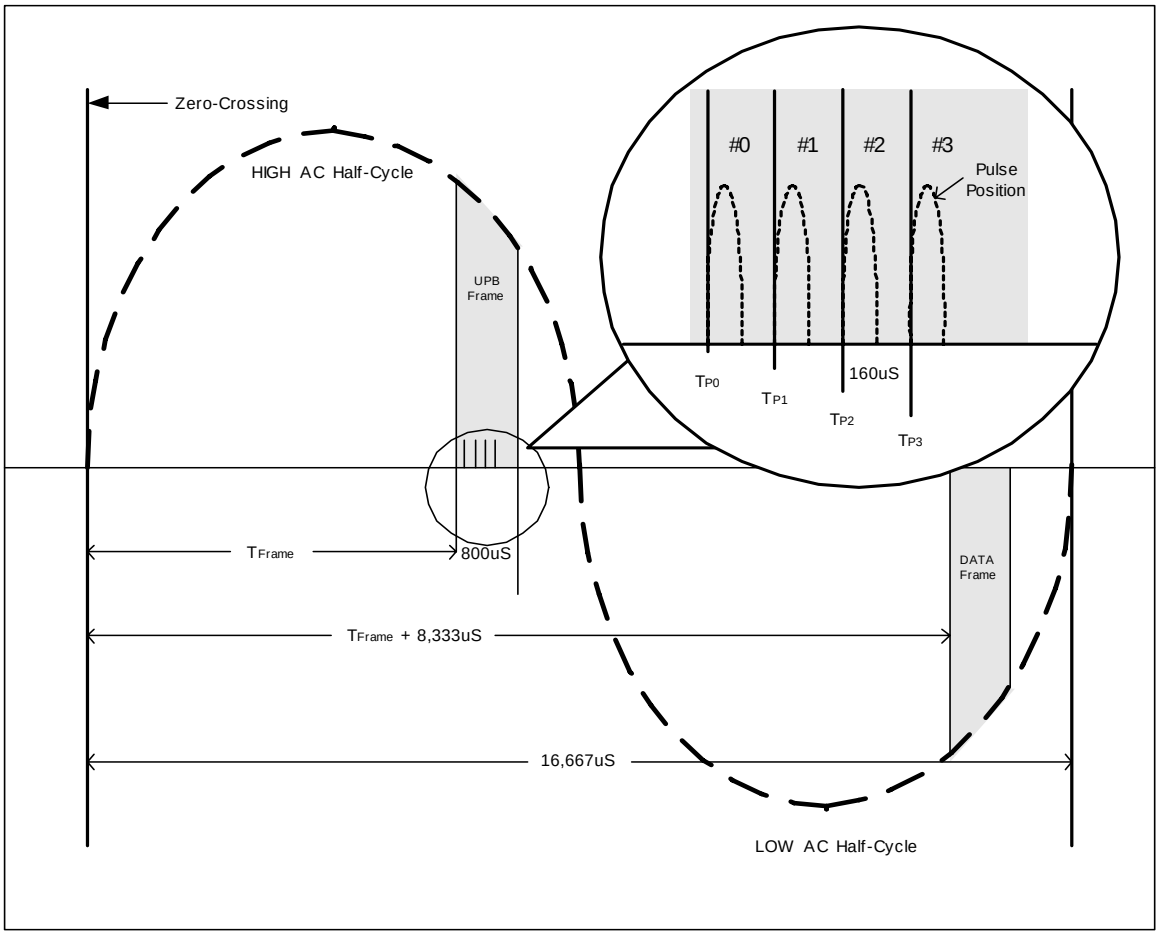

Figure 1: Communication Method Timing

Objectives

This project was to determine the feasibility of technology to provide highly reliable and low-cost communications suitable for EMS control of lighting and HVAC over existing electrical circuits in electrically complex commercial, industrial, and institutional buildings. The researchers established the following project objectives:

1. Fabricate at least 20 wired-in, powerline, communication-analysis modules designed to capture the data required to assess the feasibility of using this technology in the targeted electrical environments.
2. Place the analysis modules in a variety of locations (10-20 buildings) that represent the target environment, and capture the noise, signal level, and communications reliability data for a statistically valid sample.
3. Demonstrate that the technology communicates with a reliability level of at least 99 percent in the targeted electrical environments and in a manner transparent to connected electrical/electronic equipment.

4. Show that the communication efficiency target can be attained with two-way transmission/receiving circuitry that is in the projected cost range of $3 to $5 per communication node.

Outcomes

1. Twenty-four 120/208V and 24 277/480V powerline communication analysis modules were fabricated. The hardware and firmware required for these modules were also developed. In addition, three 12/208V and two 277/480V three-phase, powerline interface devices were created, along with the necessary data-acquisition and recording software.

2. Analysis modules were placed at 15 random test locations on the California State University, Northridge, campus. Test data was collected 4 times every 30 minutes for one week, and the associated level and number of retry attempts was logged.

Table 1: Summarizes the locations and characteristics of the 15 test locations

Location	Equipment
1 CSUN Electric Shop	Repair equipment, offices, florescent lighting
2 CSUN Rm. 160	High bay multi-ballast florescent lightign
3 CSUN Receiving	Warehousing, offices, florescent lighting, battery chargers
4 CSUN Parking Structure	HID lighting fixtures
5 CSUN PPM Offices	Florescent lights, office equipment
6 High Quality	PCB production machines
7 Prototype Sheet Metal	Metal working machines, offices
8 All Sale Electric	Warehousing, offices, florescent lighting
9 CSUN Post Office	Warehousing, offices, florescent lighting
10 CSUN Receiving	Warehousing, offices, florescent lighting
11 CSUN Electric Shop	Repair equipment, offices, florescent lighting
12 CTL Emergency Lighting	Production machinery, offices, florescent lighting
13 CSUN Physical Plant	Chillers, heaters, boilers, HID lighting, pumps, motors
14 PCS Warehouse	Production machinery, offices, florescent lighting
15 Sysco Foods	Chargers, refrigeration equipment, HID lighting, offices

Reliability, noise, signal-level, and communications-reliability data were collected. Signal-level and communications-reliability data are presented in the final report. The final report does not present the noise data; however, it does represent that "…the signal strength at the receiver is generally much greater than the strength of any noise that is on the powerline."

3. Overall communications reliability for the 15 test sites was 98.9 percent for the first attempt, increasing to 99.7 percent for the second, further increasing to 99.8 percent for

the third, and achieving 99.9 percent after the fourth. These results indicate the importance of a retry or multiple transmission mechanism in the communication protocol.

The existing electrical/electronic equipment at each location was monitored for proper operation during testing to determine whether any interference was caused by the communication technology. No problems were noted.

4. No cost data was presented in the report, leaving no basis to support researcher's original proposition, that reliable, two-way communication can be achieved for a cost of $3 to $5 per communication node.

Conclusions

1. The researcher's powerline, communications analysis modules, powerline interface modules, and associated hardware, firmware, and data-acquisition and recording software were developed and fabricated as proposed.

2. The locations and associated electrical/electronic equipment used for the test provided a reasonable sample of typical, small-to-medium-scale processes that may interact with or be affected by a communications protocol.

3. The test data confirmed that this method of communication can provide greater than 99 percent communications reliability under field test conditions for at least one week (overall reliability was 99.9 percent). There was no observed interference with any of the electrical/electronic equipment in the test locations, although it is not clear whether examples of especially sensitive electronic devices requiring very high power quality were present in the test sites.

4. Cost for this technology is at least as important as its communications reliability. Without cost data in the report, it is not possible to assess this or compare it to other competing communications technologies.

In summary, the researcher demonstrated that it is feasible to provide highly reliable data communications through existing building wiring in electrically complex (3 phase, 120/208-volt and 277/480-volt) non-residential environments without interfering with typical connected equipment.

Recommendations

Additional research should be conducted in the following areas:

1. The objective of demonstrating the ability to provide communications at a cost of $3 to $5 per module was not addressed in the final report. It is important to test this premise, since one of the technology's potential competitive advantages is its combination of high communications reliability with low cost.

2. Evaluate the technology's ability to communicate between multiple sub-panels, which is a common configuration in commercial/industrial applications.

3. Develop interfaces to recognized EMS devices and test operation of the technology in a representative number of operating EMS systems.

4. Explore noise/interference potential in more detail and establish whether there are power-quality effects for a wider range of installed equipment.

After considering: (a) research findings in the grant project, (b) overall development status, and (c) relevance of the technology to California and the PIER program, the program administrator has determined that the proposed technology should be considered for subsequent funding within the PIER Program.

Receiving funding ultimately depends upon (a) availability of funds, (b) submission of a proposal in response to an invitation or solicitation, and (c) successful evaluation of the proposal.

Benefits to California

Public benefits derived from PIER research and development are assessed within the following context:

- Reduced environmental impacts of the California electricity supply or transmission or distribution system.
- Increased public safety of the California electricity system.
- Increased reliability of the California electricity system.
- Increased affordability of electricity in California.

The primary benefit to the ratepayer from this research would be increased affordability of electricity in California. This would occur through a reducing the energy used by commercial/industrial buildings, with corresponding savings in energy costs that would potentially flow through to customers of the enterprises using these buildings. This conclusion depends on successfully bringing this concept to market in a product that delivers the communications reliability found in this research, at a price that helps make the EMS system cost-effective in existing buildings.

Overall Technology Transition Assessment

As the basis for this assessment, the program administrator reviewed the researcher's overall development effort, which includes all activities related to a coordinated development effort, not just the work performed with EISG grant funds.

Marketing/Connection to the Market

The initial grant application included letters of interest in a proven, cost-effective technology such as that proposed by the researcher from five diverse manufacturers of commercial equipment. No further market research was presented in the final report. The grant application also presented a table comparing the proposed technology to existing, residential, powerline-communication technologies. The table represented that the proposed technology offered superior reliability in residential environments, far fewer transmission errors, and a low cost per node. While the report presented no further comparisons or competitive analysis focused on applications intended for electrically complex commercial and residential environments, the researcher states that the proposed technology does not face competition in this marketplace.

Engineering/Technical

The researcher demonstrated that it is feasible to provide highly reliable communications through existing building wiring in electrically complex (3-phase, 120/208-volt and 277/480-volt) non-residential environments without interfering with typical connected equipment. This was accomplished through testing the proposed technology in 15 locations over one week and resulted in an overall communications reliability of 99.9 percent.

Legal/Contractual

The researcher indicated that a professional search determined the technology does not infringe on any other active or expired patents. Two patents have been issued for the technology (09/656.160 and 09/879.874).

Environmental, Safety, Risk Assessments/ Quality Plans

The original grant application states that the original, residential-level technology meets the requirements of the Federal Communications Commission for conducted emissions, and it includes a letter from an independent testing laboratory with confirming test results. Unless the emissions of the commercial/industrial level devices differ from the tested residential devices, there should be a similar result for this technology. Other plans need to be developed as part of a commercialization process.

Production Readiness/Commercialization

No information was provided in the final report for these considerations. The researcher is encouraged to develop a commercialization plan.

Appendix A: Final Report (under separate cover)

Attachment A – Grantee Report

NEW POWERLINE CONTROL TECHNOLOGY FOR LIGHTING AND HVAC

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IAR 02-26 Appendix A

ENERGY INNOVATIONS SMALL GRANT (EISG) PROGRAM

EISG FINAL REPORT

New Powerline Control Technology for Lighting and HVAC

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PIER Subject Area: Energy Systems Integration

Legal Notice

Inquires related to this final report should be directed to the Awardee (see contact information on cover page) or the EISG Program Administrator at (619) 594-1049 or email eisgp@energy.state.ca.us.

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Table of Contents

List of Figures

List of Tables

Abstract

No cost effective and reliable technology currently exists to provide building owners/managers with the ability to remotely or automatically control specific electricity loads/circuits without installing dedicated control wiring to each load. The purpose of this project is to determine whether technology can be developed that will provide a highly reliable and low cost method of controlling lighting and HVAC electrical loads in existing commercial and industrial buildings. This project has 4 specific objectives: fabricate 20 communication analysis modules designed to capture characteristic data of three-phase power lines; to capture the noise, signal level, and communication reliability data from 10 – 20 locations; to demonstrate that the technology communicates with at least 99% reliability in the targeted electrical environment in a manner transparent to connected electrical/electronic equipment; and to show that the communication efficiency target can be attained with two-way transmission/receiving circuitry that is in the projected cost range of $3 - $5 per communication node. The primary outcomes from this project are the development of three-phase powerline communication technology that can be used to control electrical loads and the analytical confirmation that the technology can work in a variety of commercial and industrial environments. The project outcomes provide evidence that the technology is valid as a foundation on which to build a commercial three-phase powerline control system. We conclude that this technology is a viable solution for commercial three-phase powerline control systems. We recommend that the technology be extended to include communication between electrical sub-panels and then be integrated with existing energy management systems.

This report details the development and testing of a highly reliable powerline communication technology for commercial and industrial buildings.

Key Words: buildings, lighting, energy, efficiency, retrofit, power

Executive Summary

Introduction: No cost effective and reliable technology currently exists to provide building owners/managers with the ability to remotely or automatically control specific electricity loads/circuits without installing dedicated control wiring to each load. Several technologies and products exist that provide high bandwidth communication via hard-wired, powerline, and wireless approaches, but these are far too expensive to be used for energy efficiency or conservation applications. A number of companies have developed power line based communication technologies, but these are limited to operating within the electrically simplistic environment of residential structures.

According to California Energy Commission data, the commercial and industrial sectors consumed approximately 56% of all electricity in California from 1990 to 2001. For the year 2001, the amount of energy consumed was nearly 150,000 GWh, which equates to approximately $9 billion based upon an average cost of $0.06/kW/hr. Although it is cost effective to install dedicated control wiring during the construction of new buildings, it is prohibitively expensive to do so for existing buildings. Data derived from the construction of new buildings with lighting control options such as occupant sensors, light sensors, and dimming, shows actual electricity savings between 20% and 45%. Given the retrofit capability of the proposed system and assuming that 30% of the commercial and industrial sector load is related to lighting and that 80% of existing commercial and industrial buildings do not have any form of intelligent lighting controls, the potential benefit in terms of energy and cost savings to the state of California due to the successful deployment of this technology in lighting control alone could be as high as 15,000 GWh ($900 million).

Purpose: The purpose of this project is to determine whether technology can be developed that will provide a highly reliable and low cost method of controlling lighting and HVAC electrical loads in existing commercial and industrial buildings. Targeting the end use efficiency and conservation of electricity in commercial, industrial, and institutional buildings, we sought to demonstrate the feasibility of a reliable and cost effective powerline communications technology to control lighting and HVAC electrical loads in existing buildings.

Due to the fact that the actual environment in which any powerline communication method is deployed becomes part of the transmission/receiving circuit, there is no substitute for communication/powerline circuit analysis to determine whether the proposed technology would meet the performance and reliability demands of the energy management marketplace. To prove the feasibility of the proposed technology within the three-phase, high voltage, high noise, and complex electrical circuit environment, we conducted research-level analysis, testing and evaluation utilizing the actual environment as an on-site laboratory.

The project's PIER subject area is Energy Systems Integration.

Project Objectives: This project has 4 specific objectives:

1. Fabricate at least 20 wired-in three phase powerline communication analysis modules designed to capture the data required to assess the feasibility of utilizing the this technology in the targeted electrical environments of industrial, commercial, and institutional buildings.

2. Place the analysis modules in a variety of locations (10 – 20 buildings) that are representative of the target environment, and capture the noise, signal level and communications reliability data for a statistically valid sample.

3. Demonstrate that the technology communicates with a reliability level of at least 99% in the targeted electrical environments in a manner transparent to connected electrical/electronic equipment.

4. Show that the communication efficiency target can be attained with two-way transmission/receiving circuitry that is in the projected cost range of $3 - $5 per communication node.

Project Outcomes: The primary outcomes from this project are:

1. The development of three-phase powerline communication technology that can be used to control electrical loads.

2. The analytical confirmation that the technology can work in a variety of commercial/industrial environments by capturing sufficient data to establish a reasonably accurate model of the electrical environment. The overall communications reliability during test data acquisition was 99.9%.

In addition, we have made significant advances in understanding the accuracy and usability of diagnostics for three-phase commercial and industrial environments.

Conclusions: The project outcomes provide evidence that the technology is valid as a foundation on which to build a commercial three-phase powerline control system. We conclude that this technology is a viable solution for commercial three-phase powerline control systems.

Many existing commercial, industrial and institutional buildings have installed energy management systems (EMS) as a first step towards greater energy efficiency. One problem related to adding intelligent EMS control to an existing building is communication between the EMS equipment and the various energy consuming load devices, which consist primarily of lighting, HVAC and various industrial process equipment. The proposed technology will allow energy management systems to extend control throughout the entire building, instead of being limited to only a few major loads. We expect that a significant effort will be necessary to integrate this technology with existing energy management systems and to demonstrate its use in the field.

IAR 02-26 Appendix A

Recommendations: Based on the project outcomes, our recommendations for further development of this technology are:

- Develop the ability to communicate between electrical sub-panels.
- Develop interfaces to existing energy management systems.

Public Benefits to California: The successful deployment of this technology in commercial and industrial buildings would result in a significant impact on energy consumption in California. This would save businesses within the state, as well as the state itself, a considerable amount of money.

Introduction

Background and Overview

No cost effective and reliable technology currently exists to provide building owners/managers with the ability to remotely or automatically control specific electricity loads/circuits without installing dedicated control wiring to each load. Several technologies and products exist that provide high bandwidth communication via hard-wired, powerline, and wireless approaches, but these are far too expensive to be used for energy efficiency or conservation applications. A number of companies have developed powerline based communication technologies, but these are limited to operating within the electrically simplistic environment of residential structures.

According to Energy Commission data (Table 1), approximately 56% of all electricity consumed in California is by the commercial and industrial sectors[1]. For the year 2001, the amount was approximately 150,000 GWh which equates to $9 billion based upon an average cost of $0.06/kW/hr. Although it is cost effective to install dedicated control wiring during the construction of new buildings, it is prohibitively expensive to do so for existing buildings. Data derived from the construction of new buildings with lighting control options such as occupant sensors, light sensors, and dimming, shows actual electricity savings between 20% and 45%. Given the retrofit capability of the proposed system and assuming that 30% of the commercial and industrial sector load is related to lighting and that 80% of existing commercial and industrial buildings do not have any form of intelligent lighting controls, the potential benefit in terms of energy and cost savings to the state of California due to the successful deployment of this technology in lighting control alone could be as high as 15,000 GWh ($900 million).

The goal of this project is to determine whether technology can be developed that will provide a highly reliable and low cost method of controlling lighting and HVAC electrical loads in existing commercial and industrial buildings. Targeting the end use efficiency and conservation of electricity in commercial, industrial, and institutional buildings, we sought to demonstrate the feasibility of a reliable and cost effective powerline communications technology to control lighting and HVAC electrical loads in existing buildings.

Year	Residential	Commercial	Industrial	Agricultural & Water Pumping	Other	Total Consumption
1990	67,669	73,486	52,465	20,849	13,280	227,748
1991	67,144	73,379	51,526	16,345	13,575	221,968
1992	69,227	76,696	51,378	15,483	13,914	226,698
1993	68,426	77,776	51,088	15,918	14,415	227,624
1994	69,781	77,609	50,622	16,957	15,128	230,097
1995	69,767	79,366	51,954	14,321	15,583	230,990
1996	72,166	81,743	53,677	16,898	15,152	239,636
1997	73,549	85,776	55,188	17,733	15,231	247,476
1998	75,389	85,909	53,972	14,624	14,790	244,685
1999	76,484	90,837	54,190	17,694	14,480	253,684
2000	80,615	95,561	54,720	17,652	14,946	263,493
2001	76,233	91,593	52,190	18,659	14,940	253,614

Table 1: California Electricity Consumption by Sector (million kWh)[1]

Powerline Communication Method

The powerline communication method consists of generating a series of precisely timed and relatively large electrical pulses (tens of volts) that are superimposed on top of the standard AC power sine wave to communicate digitally encoded information to receiving devices on the powerline. A simple circuit that discharges a small capacitor into the powerline is used to produce a pulse similar to the pulse produced by a lamp dimmer. The transmitting device generates one pulse per half-cycle of the AC sine wave in a time position that is relative to its data value. The position of each pulse determines its value. The generation of each pulse is precisely timed to occur within one of four predefined positions of the AC powerline half cycle. Figure 1 shows the relative timing of the four pulse positions in relation to the AC half cycle.

Receiving devices can easily detect and analyze these pulses and pull out the encoded information. Each pulse position represents a 2-bit encoded data value where the position of each pulse determines its value as 0, 1, 2, or 3. This method of encoding data as the relative position of a pulse is a well established and recognized method of digital communication known as Pulse Position Modulation (PPM). Variable length messages are constructed by stringing multiple pulses together over numerous half-cycles. Each pulse can encode two bits of data for each AC half-cycle for a communication speed of 240 bits per second. Although this speed isn't sufficient for high bandwidth applications, it is certainly adequate for control applications.

Signal Attenuation

As the pulse travels along the powerline the natural impedances that exist attenuate its strength (voltage) such that it may be relatively weak (less than a volt) by the time it gets to a receiving device. The amount of powerline attenuation that exists at an individual installation is an impossible thing to precisely predict. It is predicated on such factors as: the type of devices connected, the number of devices connected, what the devices are doing at the time, the length of the powerline, the size of the powerline, the temperature, etc. Although attenuation was not explicitly measured, an attempt was made in this study to capture the strengths of all of the received pulses to help statistically determine if signal attenuation would be a problem to the communication method. It is not expected that signal attenuation will be a problem. The digital pulse has a broad frequency spectrum (about 4 to 40 kHz) which travels better on the powerline. Attenuation of the signal level on the powerline is lower at these frequencies and less susceptible to noise. This enables the pulse to travel large distances over the powerline and even couple through the power transformer.

Noise

In addition to attenuation, small, unwanted noise pulses occasionally occur on the powerline that may confuse the receiving devices and cause them to incorrectly receive the actual signal. The amount of powerline noise that exists at an individual installation is also an impossible thing to precisely predict. It is predicated on such factors as: the type of devices connected, the number of devices connected, what the devices are doing at the time, the frequency content of the noise, weather, EMI, the temperature, etc. An attempt was made in this study to periodically capture the strength of the powerline noise to help statistically determine if it would be a problem to the communication method. What makes the communication method work so well is the fact that, in most cases, the signal strength at the receiver is generally much greater than the strength of any noise that is on the powerline.

How Signal Strength Is Measured

The devices used in this study are capable of measuring and reporting the signal strength of the pulses they receive. They are also capable of measuring the strength of any noise pulses that occur. This signal strength and noise level information can give a better understanding into how well the communication is working. Rather than just telling if a message was received correctly or not, we can also tell how strongly it was received. We can also tell if it was received in the presence of powerline noise or not. The strength of a pulse is a product of its magnitude (energy) and its duration (time). In other words, it is the area under the pulse curve (power). In a perfect world the devices would be able to measure the exact power of each pulse and report it in known units such as watts.

The devices used in this study are relatively simple devices. The pulse strength measurements that they make are therefore relatively crude but still based on the relative area under the pulse curve. The pulse is not a simple singular pulse waveform but it is actually made up of a series

of ringing waves that go above and below zero volts. The devices only measure the area under the positive going waves and add them together to form the total strength of the pulse. Furthermore, the receive circuit clips each wave at 6 volts maximum. The devices use analog comparators to sample the pulse's voltage at regular time intervals and perform an analog-to-digital conversion on each sample. The samples are then scaled down to fit in an 8-bit register.

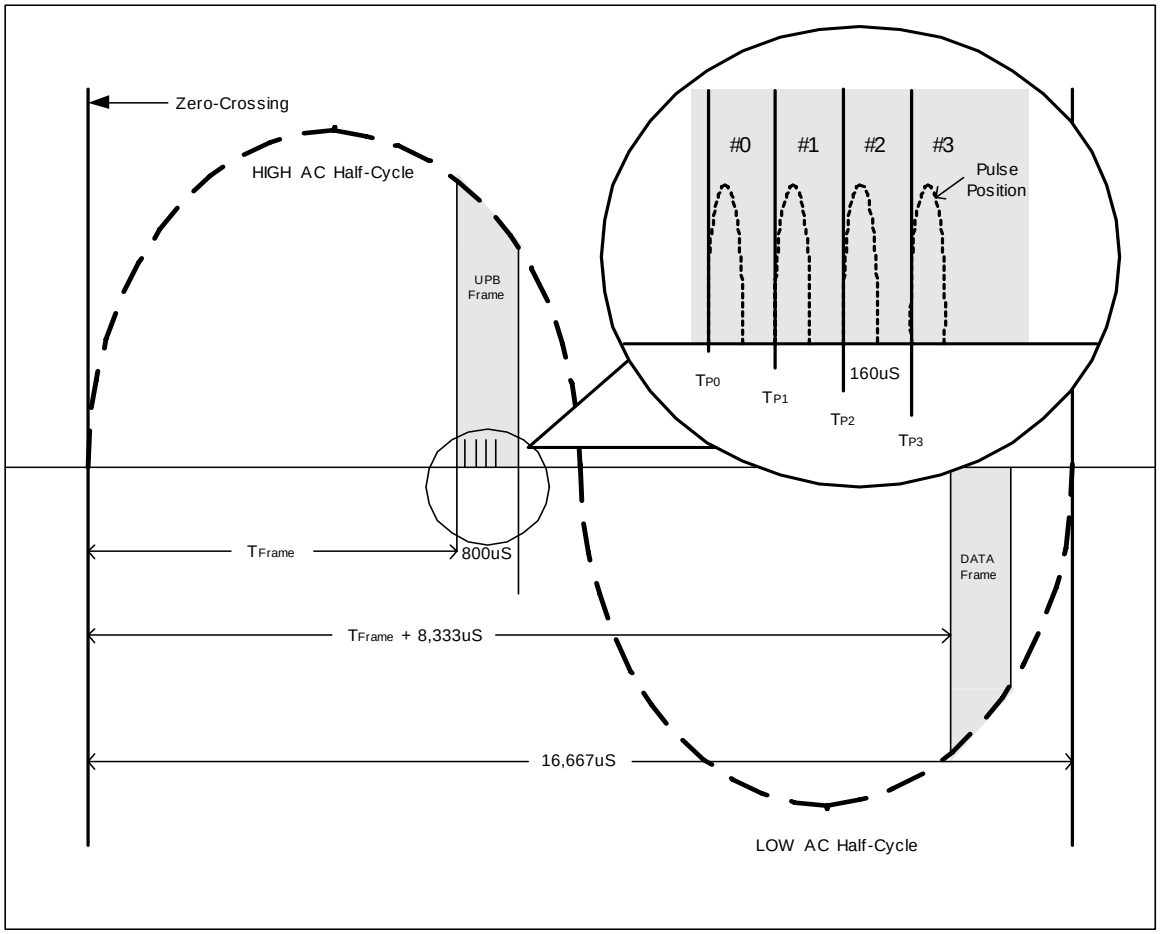

Figure 1: Communication Method Timing

Powerline Communication Packets

The communication method uses pulses to convey two bits of information each AC half-cycle. A typical series of pulses is shown in Figure 2, which is taken directly from an oscilloscope output. Four pulses are grouped together to form one byte of data. Each powerline communication is packaged into a variable length structure containing a 5 byte packet header, up to 18 bytes of data, and a 1 byte checksum. The packet header is used to indicate the packet size, network address, source unit address, and destination unit address.

The network address field of the packet header is used to indicate the intended network for the packet. This field allows separate virtual networks to be formed on the same physical interface (AC powerline). The unit address is used to indicate which individual device on a network that the packet is intended for. Each device is assigned an 8 bit network address and an 8 bit unit address. Devices ignore packets with a network address or unit address different from its assigned addresses.

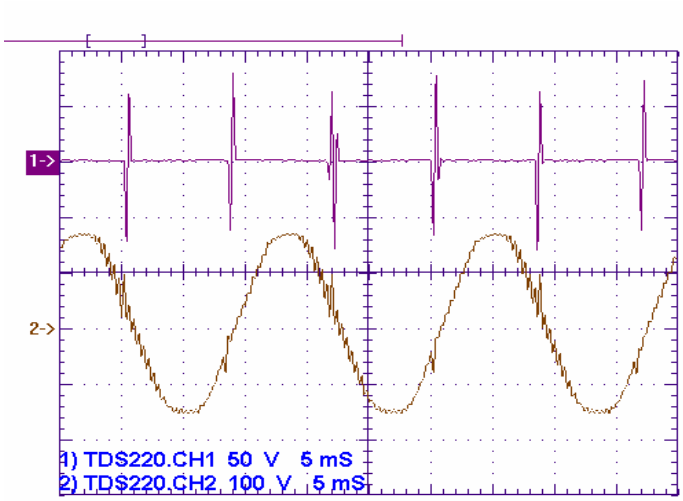

Figure 2: Communication Pulses vs. AC Sine Wave

Testing Methodology

Due to the fact that the actual environment in which any powerline communication method is deployed becomes part of the transmission/receiving circuit, there is no substitute for communication/powerline circuit analysis to determine whether the proposed technology would meet the performance and reliability demands of the energy management marketplace. To prove the feasibility of the proposed technology within the three-phase, high voltage, high noise, and complex electrical circuit environment, we conducted research-level analysis, testing and evaluation utilizing the actual environment as an on-site laboratory.

Report Organization

This report presents our findings and recommendations that have resulted from investigating the feasibility and merit of a new powerline control technology for lighting and HVAC in the commercial environment. This report is organized as follows:

Section 1.0 Introduction

Section 2.0 Project Objectives

Section 3.0 Project Approach

Section 4.0 Project Outcomes

Section 5.0 Conclusions

Section 6.0 Recommendations

Section 7.0 Public Benefits to California

Project Objectives

The specific technical objectives for the project are:

1. Fabricate at least 20 wired-in powerline communication analysis modules designed to capture the data required to assess the feasibility of utilizing this technology in the targeted electrical environments of industrial, commercial, and institutional buildings.

2. Place the analysis modules in a variety of locations (10 – 20 buildings) that are representative of the target environment, and capture the noise, signal level and communications reliability data for a statistically valid sample.

3. Demonstrate that the technology communicates with a reliability level of at least 99% in the targeted electrical environments in a manner transparent to connected electrical/electronic equipment.

4. Show that the communication efficiency target can be attained with two-way transmission/receiving circuitry that is in the projected cost range of $3 - $5 per communication node.

Project Approach

Development of Powerline Communication Analysis Modules

A substantial portion of the project effort was dedicated to developing the hardware and firmware needed to facilitate the powerline communication analysis modules. Forty-eight communication analysis modules, twenty-four 120/208V modules and twenty-four 277/480V modules were created and used to obtain the reliability, noise, and signal level data at 15 random test locations. Table 2 provides a list of the test locations.

	Location	Voltage	Phases	Type
1	**CSUN Electric Shop**	120/208	3	Repair Shop
2	**CSUN Rm. 160**	277/480	3	Gymnasium
3	**CSUN Receiving**	277/480	3	Warehouse
4	**CSUN Parking Structure**	277/480	3	Multi-level Parking Structure
5	**CSUN PPM Offices**	120/208	3	Office Building
6	**High Quality**	120/208	3	Circuit Board Assembly
7	**Prototype Sheet Metal**	120/208	3	Metal Fabrication
8	**All Sale Electric**	120/208	2	Electrical Equip Distributor
9	**CSUN Post Office**	277/480	3	Offices
10	**CSUN Receiving**	120/208	3	Warehouse
11	**CSUN Electric Shop**	277/480	3	Repair Shop
12	**CTL Emergency Lighting**	120/208	3	Lighting Fixture Manufacturer
13	**CSUN Physical Plant**	120/208	3	University Heating/Air conditioning
14	**PCS Warehouse**	120/208	3	Light Manufacturing
15	**Sysco Foods**	277/480	3	Food Storage/Distribution Center

Table 2 – Powerline Communication Test Locations

Three 120/208V and two 277/480V three-phase powerline interface devices (see Figure 3) were created. Finally, data aquistion software was created to capture and record the test data. The three-phase powerline interface device uses RS-232 serial communications to both receive commands from the data acquisition software to transmit information onto the powerline and to relay responses received from the powerline to the data acquisition software.

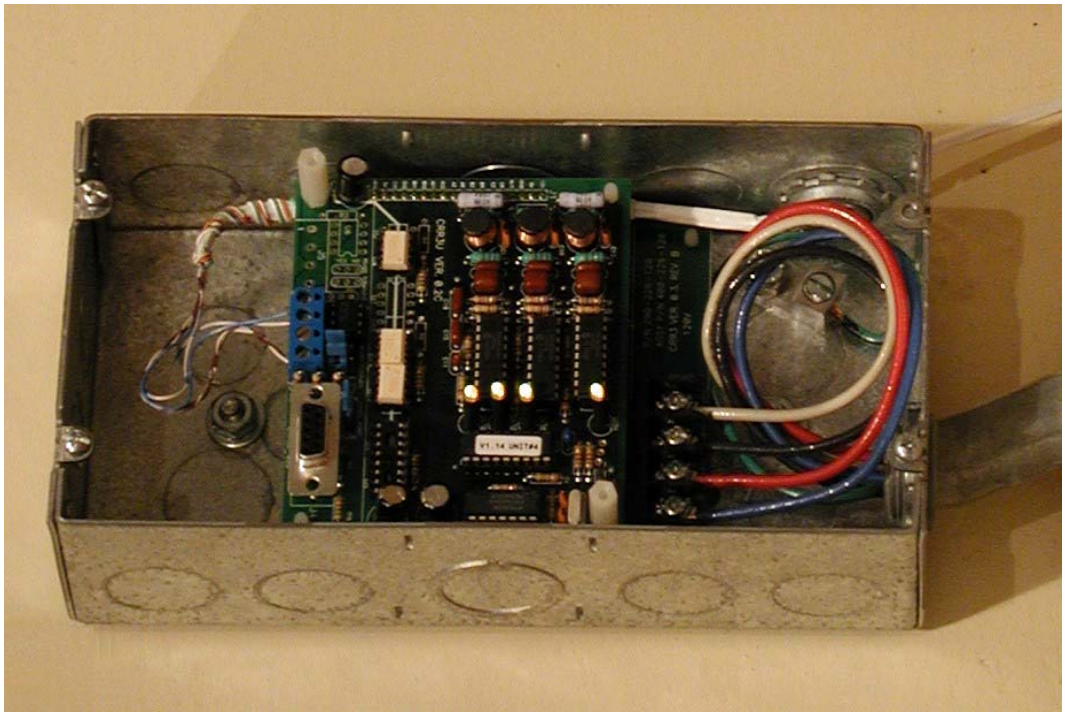

Figure 3: Three Phase Powerline Interface Device

Capture Reliability Data

PCS has defined communication reliability as the probability of successful two-way communication upon initial installation between two devices installed at random locations in a commercial/industrial environment. To measure reliability using this definition, analysis modules capable of reporting successful and unsuccessful communications attempts were designed. A communication failure was defined as the communication failure of four successive attempts. The selection of four retries was made because the communication protocol implements a method of packet repeating based on a maximum of four attempts.

Data acquisition software was created to capture communication test data for the New Powerline Control Technology for Lighting and HVAC project. The data acquisition software is a Windows® based software program intended to run on a PC or laptop. The personal computer interfaces to the 3-phase powerline interface through a RS-232 serial communications port. The data acquisition software communicates through the 3-phase powerline interface device with twelve communication/power line circuit analysis modules that are connected to the power line at random locations.

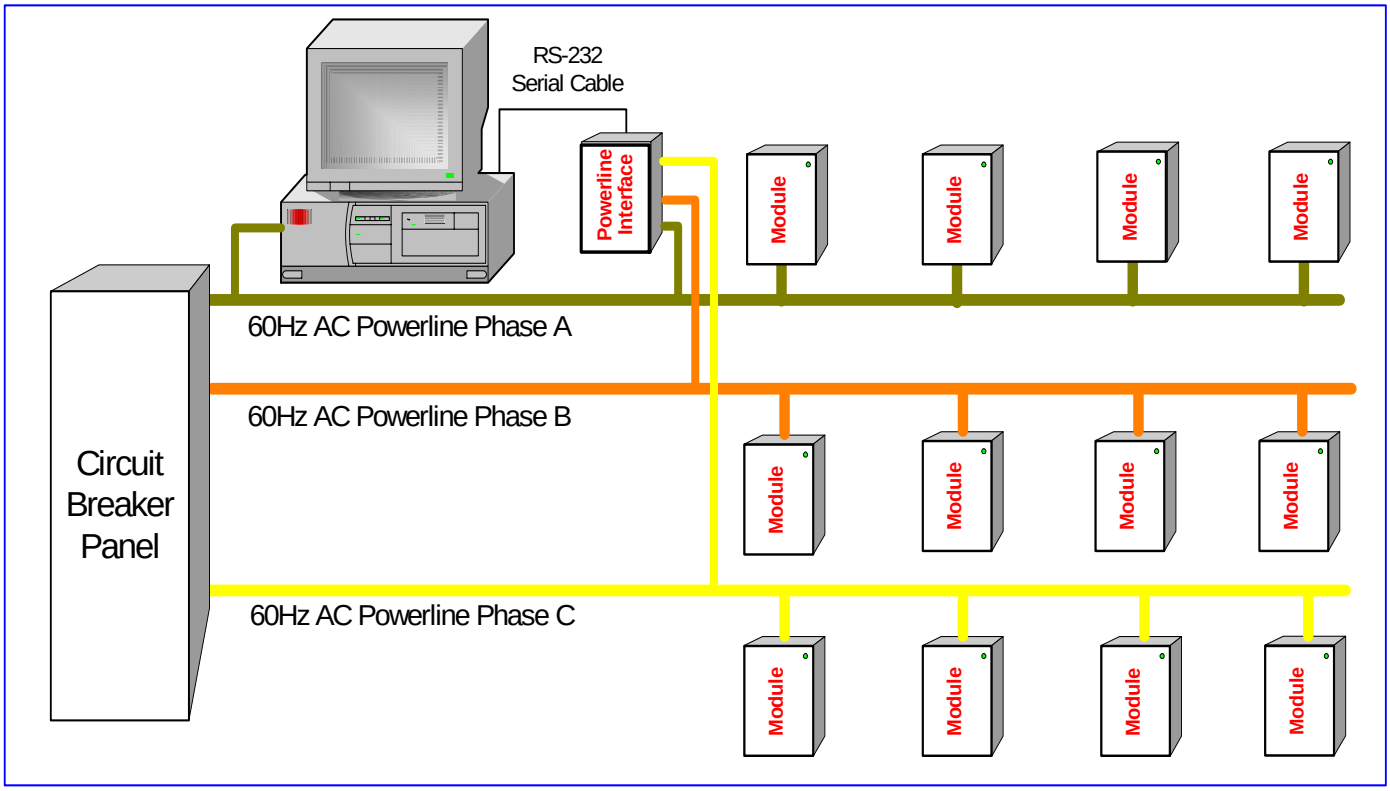

Figure 4: Powerline Control Communication Diagram

Noise, signal level, and communications reliability data were acquired at 15 random test locations in Southern California using at least 12 circuit analysis modules at each location. The test sites used ranged in size from 10,000 square feet up to 200,000 square feet and involved either 120/208V or 277/480V three phase panels. Circuit analysis modules were connected to the powerline at random locations throughout each test site. There was no attempt to choose optimum test device locations at any of the test locations.

The data acquisition software performed a series of two-way power line communications between the 3-phase powerline interface device and the circuit analysis modules over a one-week period. Each run of the communications test performs a typical two-way communication sequence with each of the circuit analysis test modules. The entire two-way transaction must be successful in order for a communication exchange to be successful. After each attempted communication exchange, the test software monitors for success. Each test cycle repeats this communication sequence four times per test module followed by a 30-minute idle period before starting the next cycle.

Here is a typical communication exchange:

a) The data acquisition software initiates a two-way communication transaction, prepares the packet and sends it to the three-phase powerline interface device using an RS232 serial port.

b) The three-phase powerline interface device sends an immediate acknowledgement to the data acquisition software to confirm that the serial packet request was received properly.

c) The three-phase powerline interface device sends the packet onto the powerline and sends a confirmation to the data acquisition software to indicate that the packet was sent on the powerline successfully.

d) The three-phase powerline interface device forwards an acknowledgement to the data acquisition software to indicate that the packet was correctly received by the destination circuit analysis module if the three-phase powerline interface device receives an acknowledgement pulse from that analysis module.

e) The data acquisition software sets a timeout and waits for a complete correct response message from the destination circuit analysis module via the three-phase powerline interface device.

f) The entire transaction is deemed successful if a correct message detected by the data acquisition software within the allotted time. Any other outcome is a failure for that attempt.

After each attempted two-way communication exchange, the test software monitors for success and records the result. If the communication exchange is successful, the test software records the successful event and continues on to the next scheduled communication exchange. If the communication exchange is unsuccessful, the test software records the failure event and then retries the communication exchange up to three more times. The data acquisition software measures the success/failure rate of 1, 2, 3, and 4 retries as part of the basic test algorithm.

During execution, the data acquisition software creates four log files on the PC which are used to record the results of the test. These log files are used for evaluation and comprise the source of all of the results included in this report. The following text describes the information recorded in each file.

Log #1 – Records the results of each individual run on each individual circuit analysis module. This includes such information as:

1) Analysis Module Identification Information
2) Timestamp
3) Signal Level at the Powerline Interface
4) Noise Level at the Powerline Interface
5) Signal Level at the Analysis Module
6) Noise Level at the Analysis Module
7) Read Data Values
8) Communications results

Log #2 – Records a summary line for each Circuit Analysis Module and a total test summary line. This includes such information as:

1) Test Date and Time

2) Software Version Number
3) Analysis Module Name and ID
4) Analysis Module Firmware Version Number
5) Powerline Interface Firmware Version Number
6) Electrical Phase of Analysis Module
7) Number of Successful Communications
8) Number of Bad (Failed) Communications
9) Signal Level at the Powerline Interface
10) Signal Level at the Analysis Modules
11) Noise Level at the Powerline Interface
12) Noise Level at the Analysis Modules
13) Communication Results

Log #3 – Records the raw serial communications traffic between the test software and the powerline interface module.

Log #4 – Records the significant test site parameters entered by the test administrator. These include:

1) Contact Name
2) Building Name
3) Address
4) Email address
5) Phone Numbers
6) Building Square Footage
7) Main-panel Volt/Capacity
8) Number of Sub-panels
9) Sub-panel Volt/Cap
10) Number of transformers
11) Transformer Type/Size
12) Phases Used
13) Fixture Types and Bulb Types of all luminaries
14) Circuit Breaker Panel Type and configuration
15) Main Panel Type, Distance from Lighting Panel, Wire Size

Demonstrate Non-Interference with Other Equipment

Due to the fact that the environment in which any powerline communication device is installed becomes part of the transmission/receiving circuit, the proposed technology must not effect the operation of existing electrical/electronic equipment connected to the electrical powerline. To demonstrate that the technology communicates with a reliability level of at least 99% in the targeted electrical environments in a manner transparent to connected electrical/electronic equipment, we conducted research-level testing and analysis utilizing the actual environment as an on-site laboratory. Existing electrical/electronic equipment was monitored at each location for proper operation during testing to ensure that no interference was caused by the proposed technology. Table 3 shows the types of equipment at each test location.

Location	Equipment
1 **CSUN Electric Shop**	Repair equipment, offices, florescent lighting
2 **CSUN Rm. 160**	High bay multi-ballast florescent lightign
3 **CSUN Receiving**	Warehousing, offices, florescent lighting, battery chargers
4 **CSUN Parking Structure**	HID lighting fixtures
5 **CSUN PPM Offices**	Florescent lights, office equipment
6 **High Quality**	PCB production machines
7 **Prototype Sheet Metal**	Metal working machines, offices
8 **All Sale Electric**	Warehousing, offices, florescent lighting
9 **CSUN Post Office**	Warehousing, offices, florescent lighting
10 **CSUN Receiving**	Warehousing, offices, florescent lighting
11 **CSUN Electric Shop**	Repair equipment, offices, florescent lighting
12 **CTL Emergency Lighting**	Production machinery, offices, florescent lighting
13 **CSUN Physical Plant**	Chillers, heaters, boilers, HID lighting, pumps, motors
14 **PCS Warehouse**	Production machinery, offices, florescent lighting
15 **Sysco Foods**	Chargers, refrigeration equipment, HID lighting, offices

Table 3 – Test Location Equipment

Project Outcomes

The project outcomes for the project are:

1. The development of three-phase powerline communication technology that can be used to control electrical loads.

2. The analytical confirmation that the technology can work in a variety of commercial/industrial environments by capturing sufficient data to establish a reasonably accurate model of the electrical environment. The overall communications reliability during test data acquisition was 99.9% (Table 4).

We have tested the reliability, noise, and signal level,in 15 commercial and industrial environments at both 120/208V and 277/480V three phase systems. PCS has defined communication reliability for this technology as the probability of successful two-way communications between devices upon initial installation at random locations within a three-phase commercial environment. Communication reliability was tested 4 times every 30 minutes for 7 days using 12 test modules at each commercial location. The data acquisition software recorded the level and number of retry attempts so that it could be seen how often a communication exchange failed one, two, three, or four times in a row.

Table 4 provides a communication results summary captured at the 15 test locations. The following text describes the information recorded in the table:

1. Location – Testing location description.
2. ATS – Number of successful two-way communication packet attempts.
3. ATT – Total number of two-way communication packet attempts.
4. AT1 – Number of successful two-way communications on the first packet attempt.
5. AT2 – Number of successful two-way communications on the second packet attempt.
6. AT3 – Number of successful two-way communications on the third packet attempt.
7. AT4 – Number of successful two-way communications on the fourth packet attempt.
8. ATF – Number of failed two-way communication packet attempts.

	Location	Voltage	ATS	ATT	AT1	AT2	AT3	AT4	ATF
1	**CSUN Electric Shop**	120/208	16128	16128	16097	27	3	1	0
2	**CSUN Rm. 160**	277/480	26855	26880	26538	283	22	12	25
3	**CSUN Receiving**	277/480	16041	16128	15661	246	92	42	87
4	**CSUN Parking Structure**	277/480	16128	16128	15766	349	11	2	0
5	**CSUN PPM Offices**	120/208	16127	16128	15756	316	51	4	1
6	**High Quality**	120/208	16127	16128	16039	83	4	1	1
7	**Prototype Sheet Metal**	120/208	16128	16128	16123	5	0	0	0
8	**All Sale Electric**	120/208	16128	16128	15983	145	0	0	0
9	**CSUN Post Office**	277/480	15754	15792	15582	111	40	21	38
10	**CSUN Receiving**	120/208	16021	16032	15885	100	26	10	11
11	**CSUN Electric Shop**	277/480	16127	16128	15897	180	44	6	1
12	**CTL Emergency Lighting**	120/208	16127	16128	15939	175	11	2	1
13	**CSUN Physical Plant**	120/208	16128	16128	16093	34	1	0	0
14	**PCS Warehouse**	120/208	13159	13160	13157	2	0	0	1
15	**Sysco Foods**	277/480	15959	16128	15956	2	0	1	169
	Totals		**248937**	**249272**	**246472**	**2058**	**305**	**102**	**335**
	Overall Reliability				**98.9%**	**99.7%**	**99.8%**	**99.9%**	

Table 4 – Powerline Communication Test Results

As seen in Table 4, the results demonstrated that the technology communicated with a 99.9% level of reliability at the three-phase commercial/industrial locations. As shown in Figure 5 and Figure 6, the total number of errors out of a total of 249,272 two-way communication attempts was reduced from 2800 (1.1%) for one transmission attempt to 335 (0.1%) with 4 transmission attempts. In 9 out of 190 communication paths (Figure 7) there was sufficient attenuation of the signal level to cause some or all of the communication packets to be corrupted. In 137 of 190 communication paths there was sufficient noise to cause some of the communication packets to be corrupted. Due to the possibility of intermittent powerline noise interfering with a communication packet in a 3-phase powerline environment, we believe that it is extremely important to have a retry or multiple transmission mechanism built into the communication protocol. This can be automatic multiple transmissions for broadcast messages with no acknowledgement or retries can be based on acknowledgement.

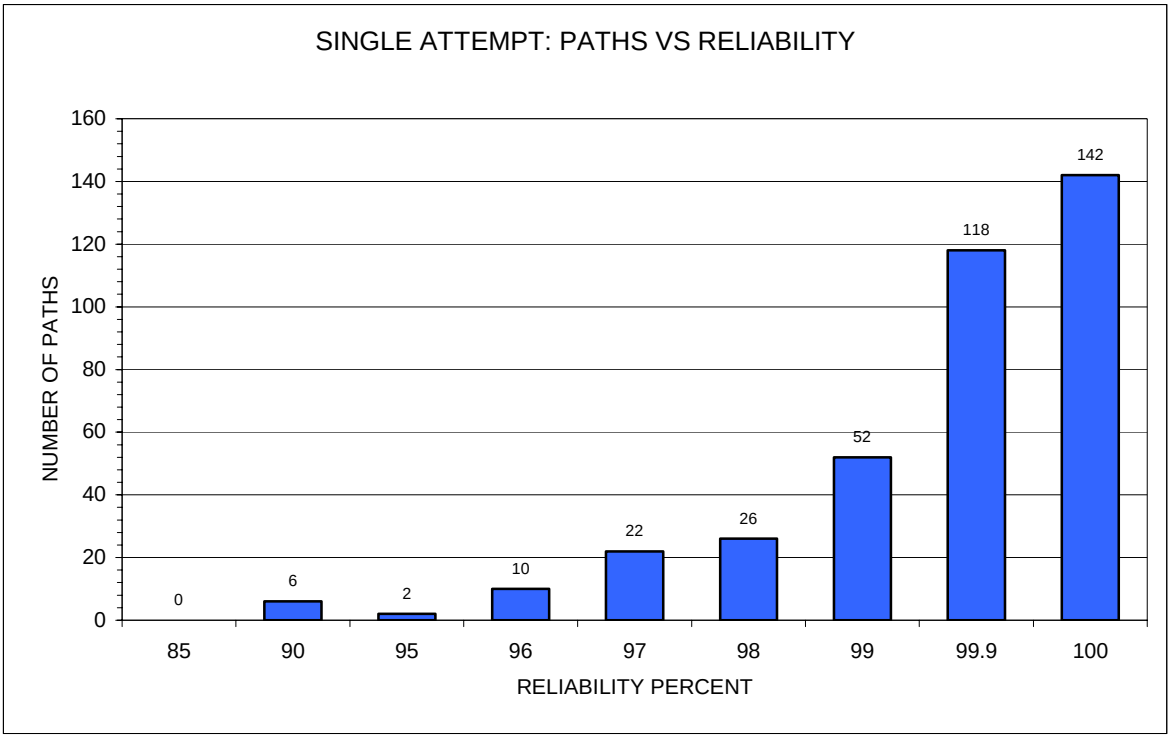

Figure 5 – Paths vs. Reliability: Single Attempt

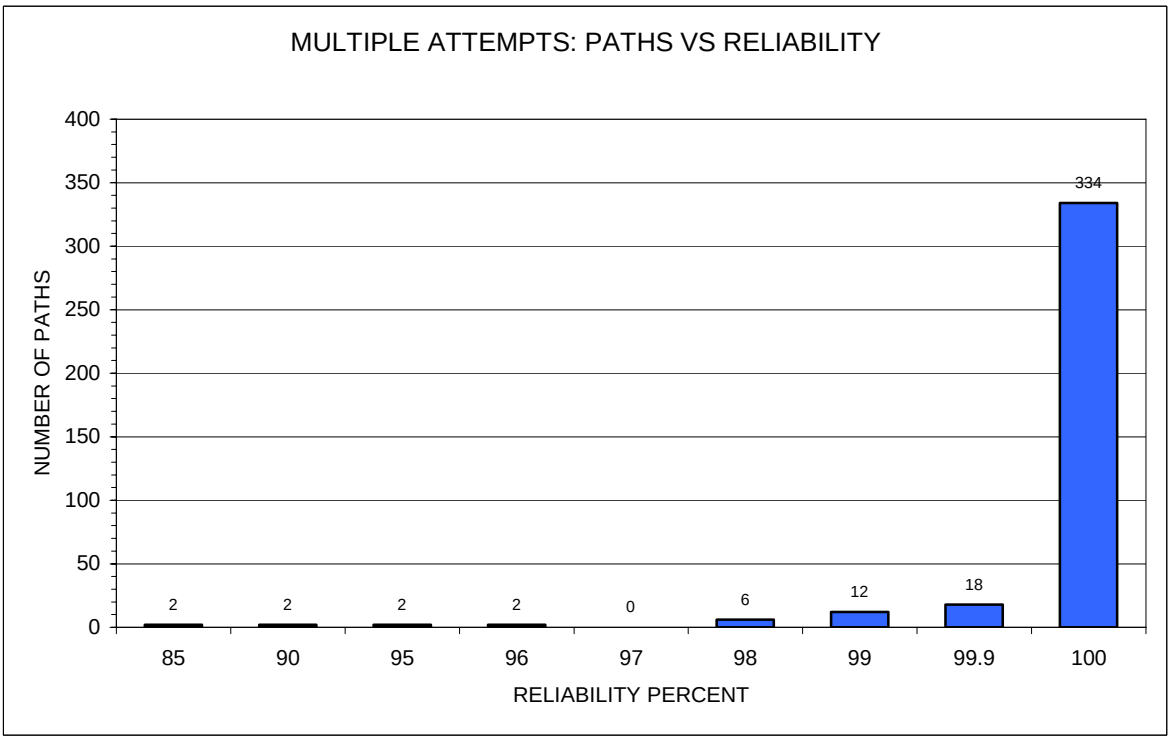

Figure 6 – Paths vs. Reliability: Multiple Attempts

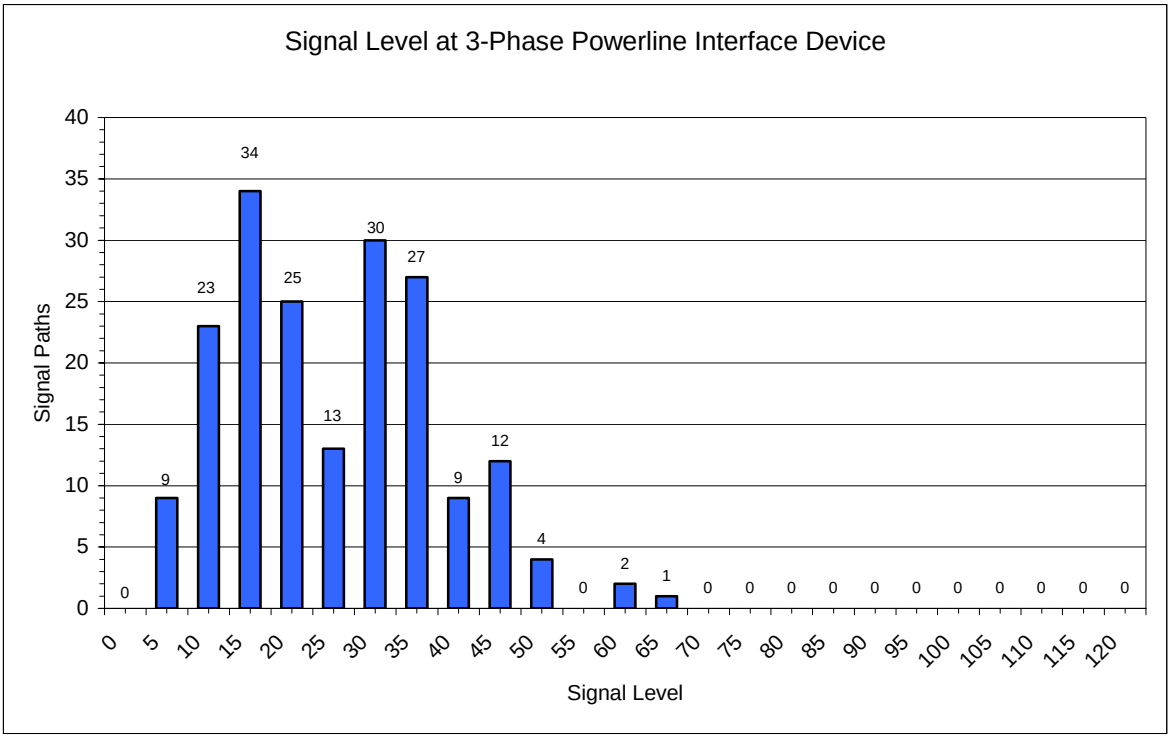

Figure 7 – Signal Level at the 3-Phase Powerline Interface Device

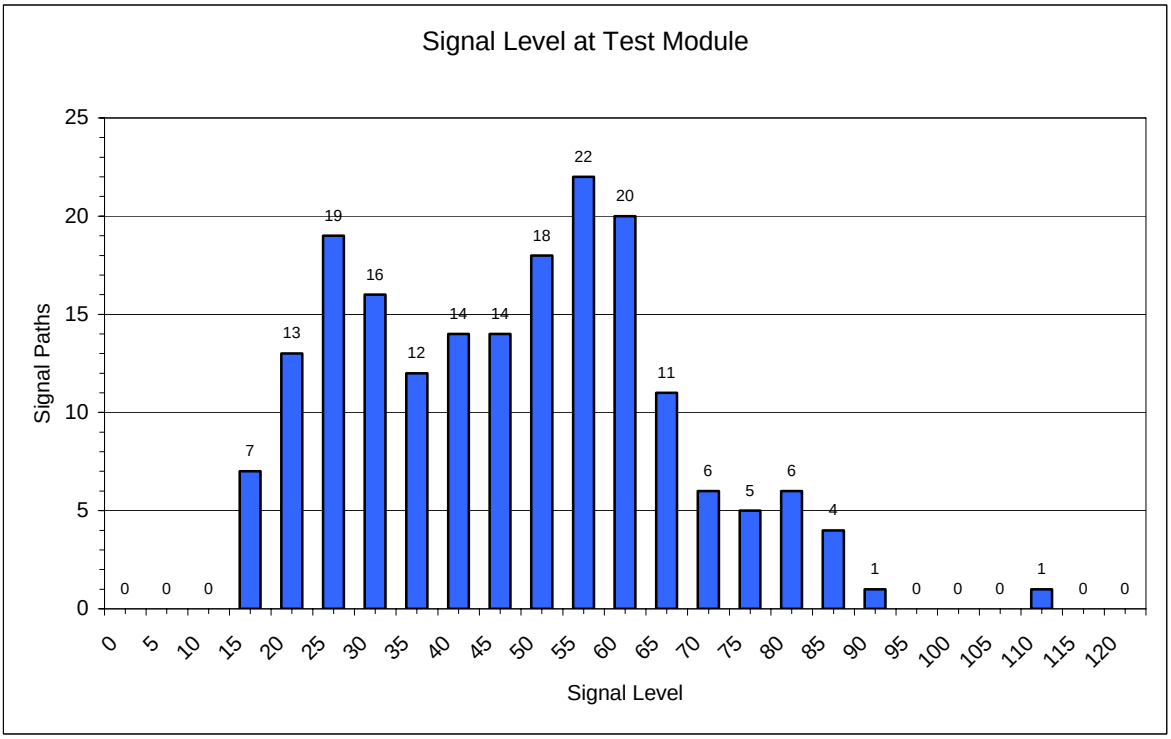

Figure 8 – Signal Level at the Test Module

Conclusions

The project tested two-way communication exchanges which are typical to the message activity that would take place in a commercial lighting system installation. The project outcomes clearly demonstrate the feasibility of using the proposed powerline communication technology in the three-phase commercial/industrial environment. We have tested the reliability, noise, and signal level in 15 commercial and industrial environments at both 120/208V and 277/480V three phase systems. PCS has defined communication reliability for this technology as the probability of successful two-way communications between devices upon initial installation at random locations within a three-phase commercial environment. Communication reliability was tested 4 times every 30 minutes for 7 days using 12 test modules at each commercial location. The results demonstrated that the technology communicated with a 99.9% level of reliability, with 99.9% of all two-way communication packets successfully received within 4 tries, at the 15 three-phase commercial/industrial test locations. We therefore conclude that this technology is a viable solution for commercial three-phase powerline control systems.

Many existing commercial, industrial and institutional buildings have installed EMS systems as a first step towards greater energy efficiency. One problem related to adding intelligent EMS control to an existing building is communication between the EMS equipment and the various energy consuming load devices, which consist primarily of lighting, HVAC and various industrial process equipment. The proposed technology will allow energy management systems to extend control throughout the entire building, instead of being limited to only a few major loads. We expect that a significant effort will be necessary to integrate this technology with existing energy management systems and to demonstrate its use in the field.

Recommendations

Based on the project outcomes, our recommendations for further development of this technology are:

Recommendation #1: Develop the ability to communicate between multiple electrical sub-panels. We believe this ability is essential because many commercial/industrial applications consist of more that one panel or sub-panel.

Recommendation #2: Develop one or more interfaces to recognized EMS systems. Many existing commercial, industrial and institutional buildings have installed EMS systems as a first step towards greater energy efficiency. One problem related to adding intelligent EMS control to an existing building is communication between the EMS equipment and the various energy consuming load devices. The proposed technology will allow energy management systems to extend control throughout the entire building, instead of being limited to only a few major loads.

Public Benefits to California

We have identified the following benefits that result directly from this study or that could develop over time:

Electricity consumption benefits. The principal benefit from the control of lighting and electrical loads in existing buildings using this powerline communications technology is significant energy savings. Given that all electrical loads are connected to the building's power grid via power lines, it seems apparent that significant electricity cost savings could be derived by utilizing those same power lines to transmit load control signals.

The importance of finding an economical retrofitable solution that will work reliably in the commercial/industrial environment is becoming increasingly important. Factors such as rising energy costs, lack of new power plant construction, and new state and federal energy management regulations all make the availability of a retrofitable control solution particularly important. The availability of an inexpensive and reliable method to control the existing install base of energy consuming devices in the commercial, institutional, and industrial retrofit environment could have a significant impact on energy consumption in California. We believe that implementing powerline load control could achieve significant savings in electricity consumption. This could save the state government and businesses within the state a considerable amount of money. As this technology is installed in California, data from these installations will provide a statistical profile that can be used to make precise estimates.

Glossary

AC	Alternating Current
CSUN	California State University, Northridge
EMS	Energy Management System
GWh	Giga-watt Hours
HVAC	Heating, Ventilating and Air Conditioning
PC	Personal Computer
PCS	Powerline Control Systems
PIER	Public Interest Energy Research

References

1. QFER, California Energy Commission. September 2002.

Appendix A and B

Please contact the awardee for a copy of these appendices.