

Power Distribution System for Data Centers

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Introduction

- IT and business process outsourcing are one of the key driving forces of the Philippine economy
- Data center – important technology supporting some IT and BPO services

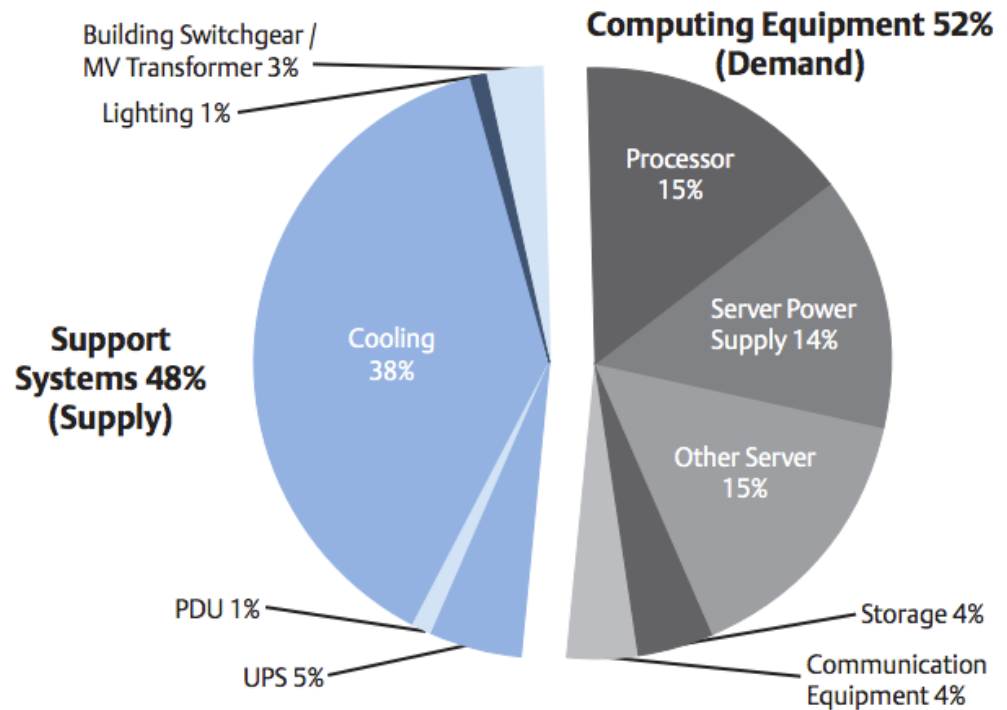


Introduction

- Some recent news:
 - “Manila overtakes Mumbai as no. 2 on Tholons top 100 BPO cities list.” – GMA News, January 2014
 - “PLDT allots P3B for 2 data centers.” – Philippine Star, March 2014
 - “IT-BPO sector seen to drive Philippine economy into a \$-trillion economy.” – Philippine Star, May 2014

Data Center Operation

- Energy intensive



- Data center operators also lease space for server and network equipment to third-party service providers
 - Need for a reliable and accurate tool that would determine the energy consumption of the lessee's equipment

Power Distribution Units (PDUs)



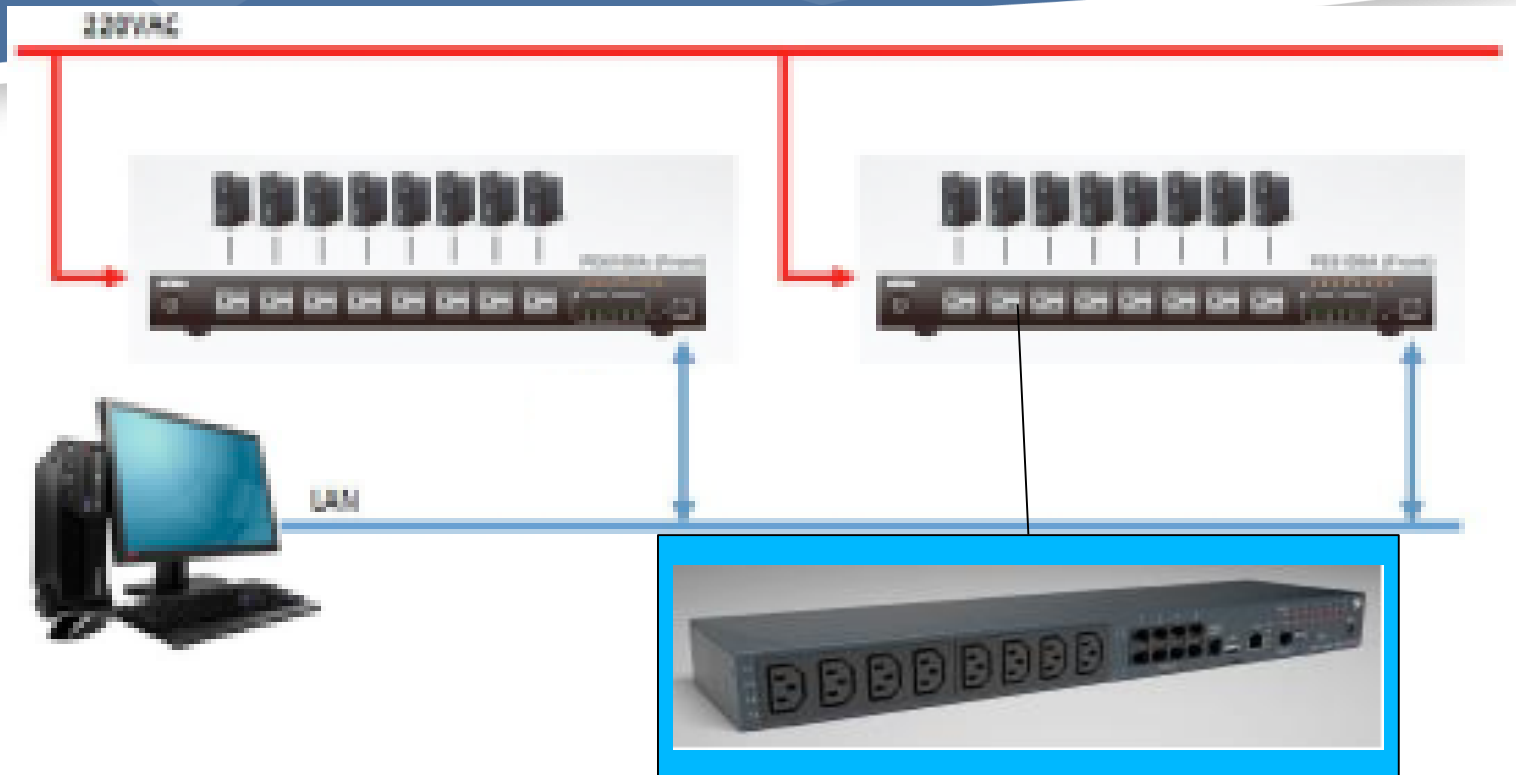
- Similar to power strips
- Range of functionalities
 - Basic PDU: Power protection
 - Metered PDU: Measures voltage, current, power, temperature
 - Switched PDU: Remote on /off of individual sockets
- Expensive
 - Basic metered: USD 400 / unit
 - Switch metered: USD 1,100 / unit
 - Software need to be bought separately

Project Objectives

Design and implement a cost-effective centralized power management system for data centers consisting of

- **Power Distribution Units** that can measure the energy consumption of several electric sockets and send these information to a central computer
- A **Energy Monitoring Software** that would receive, archive, and organize the data sent by the PDUs

Project Architecture

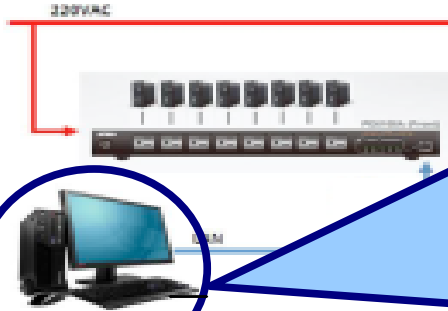


PDU

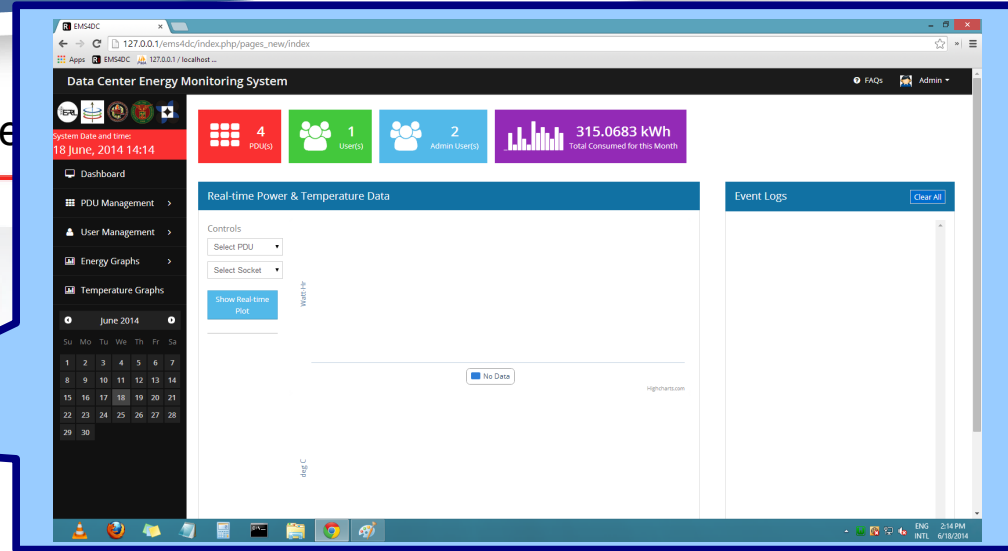
- Measures power consumption
- Sends measurements to monitoring software

Project Architecture

Simplified energy management

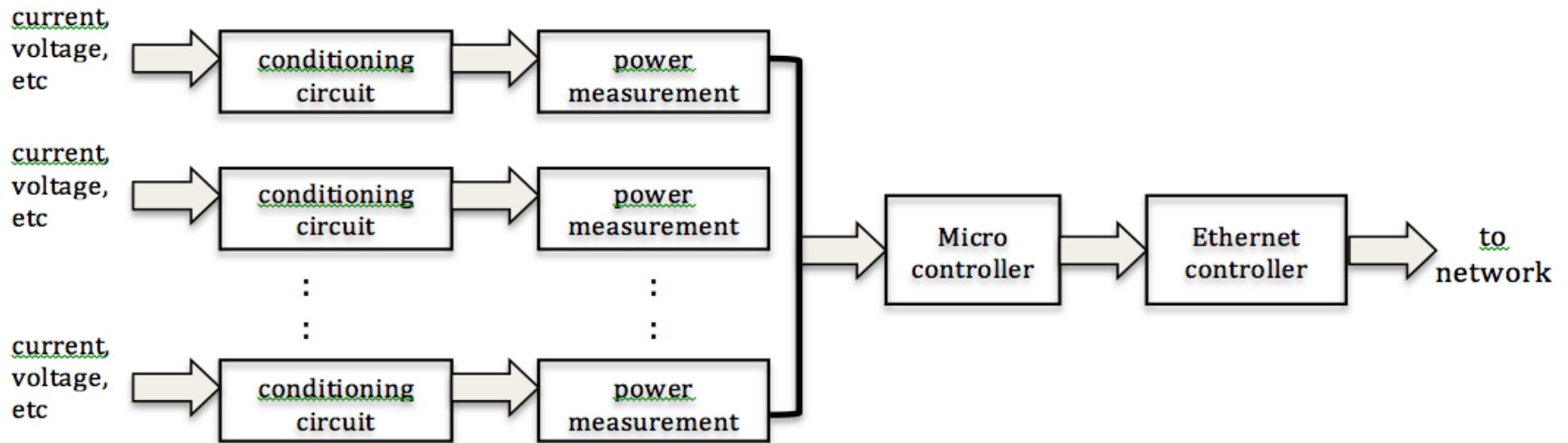


Energy
Monitoring
Software



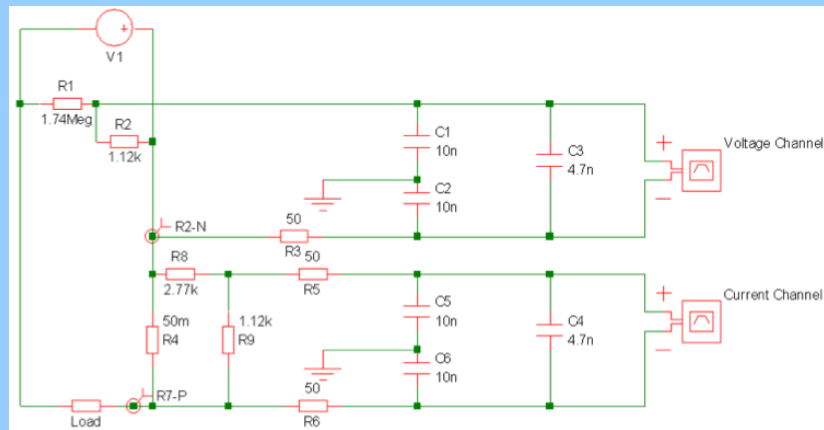
- Collects measured data from PDUs
- Computes energy consumption of attached equipment
- Archives the measured information
- Presents information meaningfully to data center operators and tenants

Power Distribution Unit

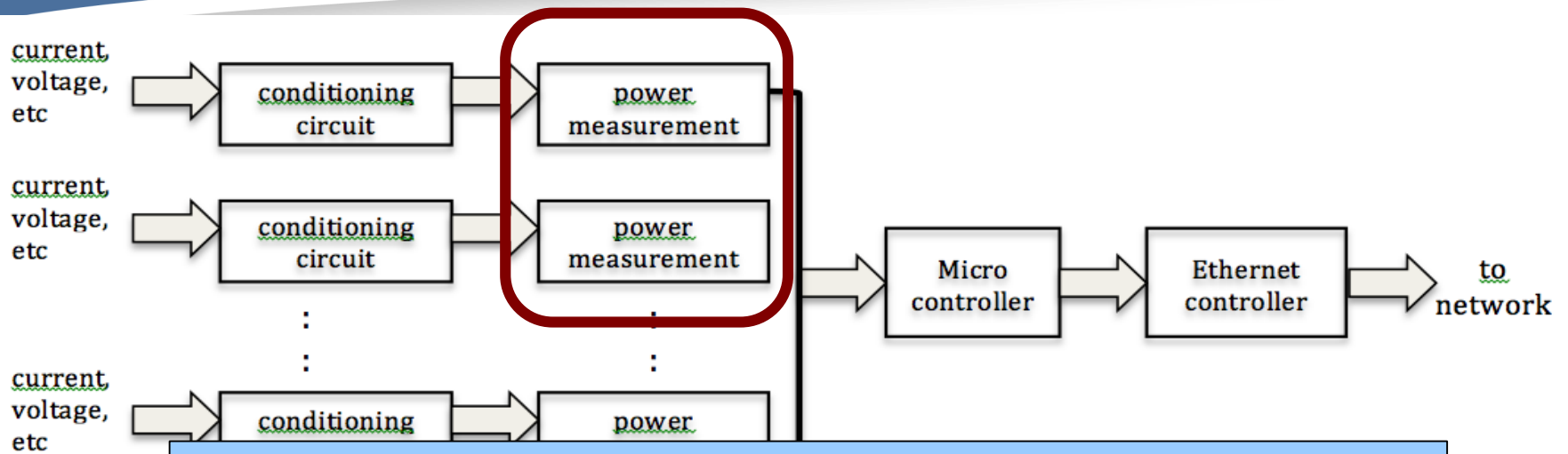


Conditioning Circuit:

Brings current and voltage measurements down to acceptable levels

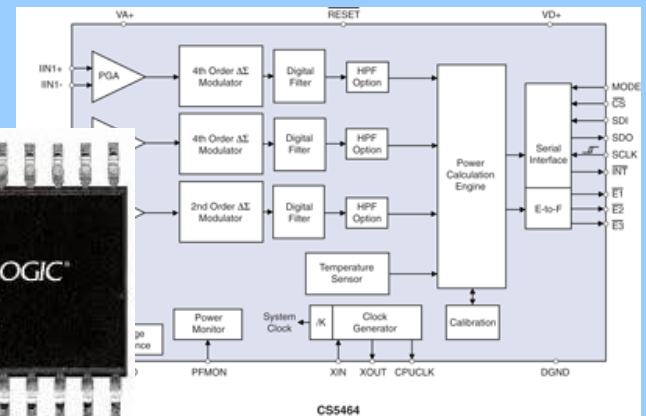


Power Distribution Unit

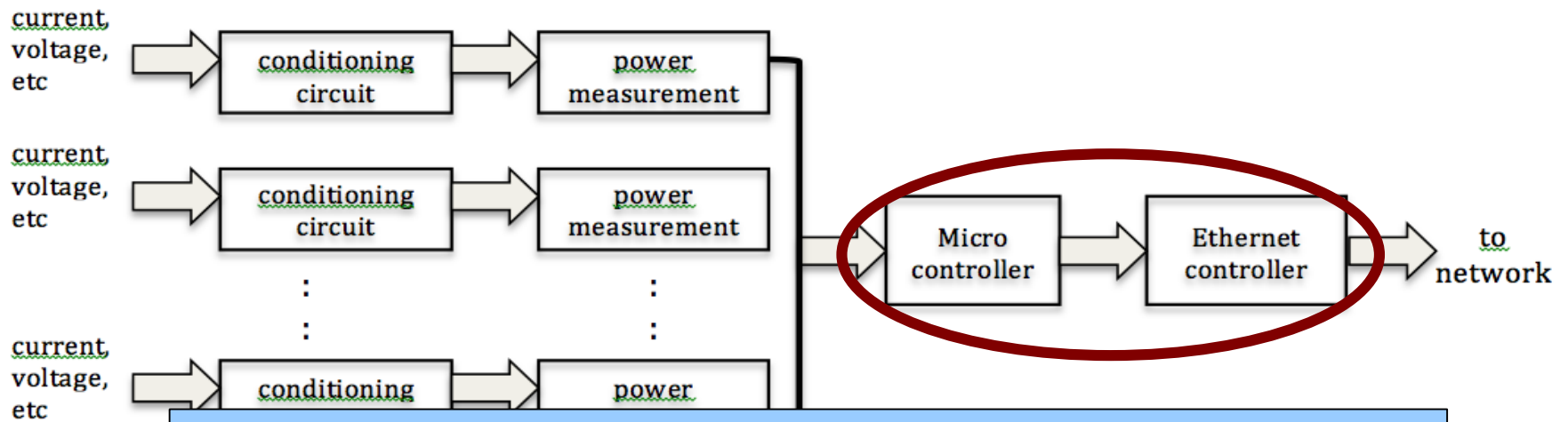


Power Measurement:

CS 5464: Computes real-time power from voltage and current signals.

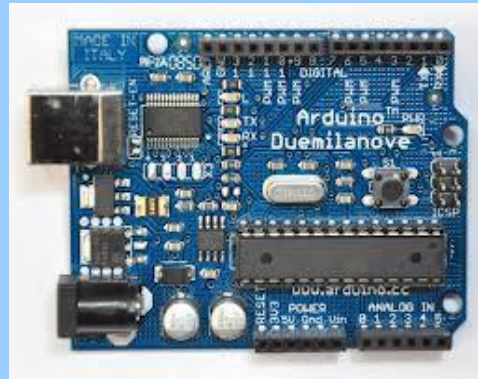


Power Distribution Unit



Arduino Board
Processing and control

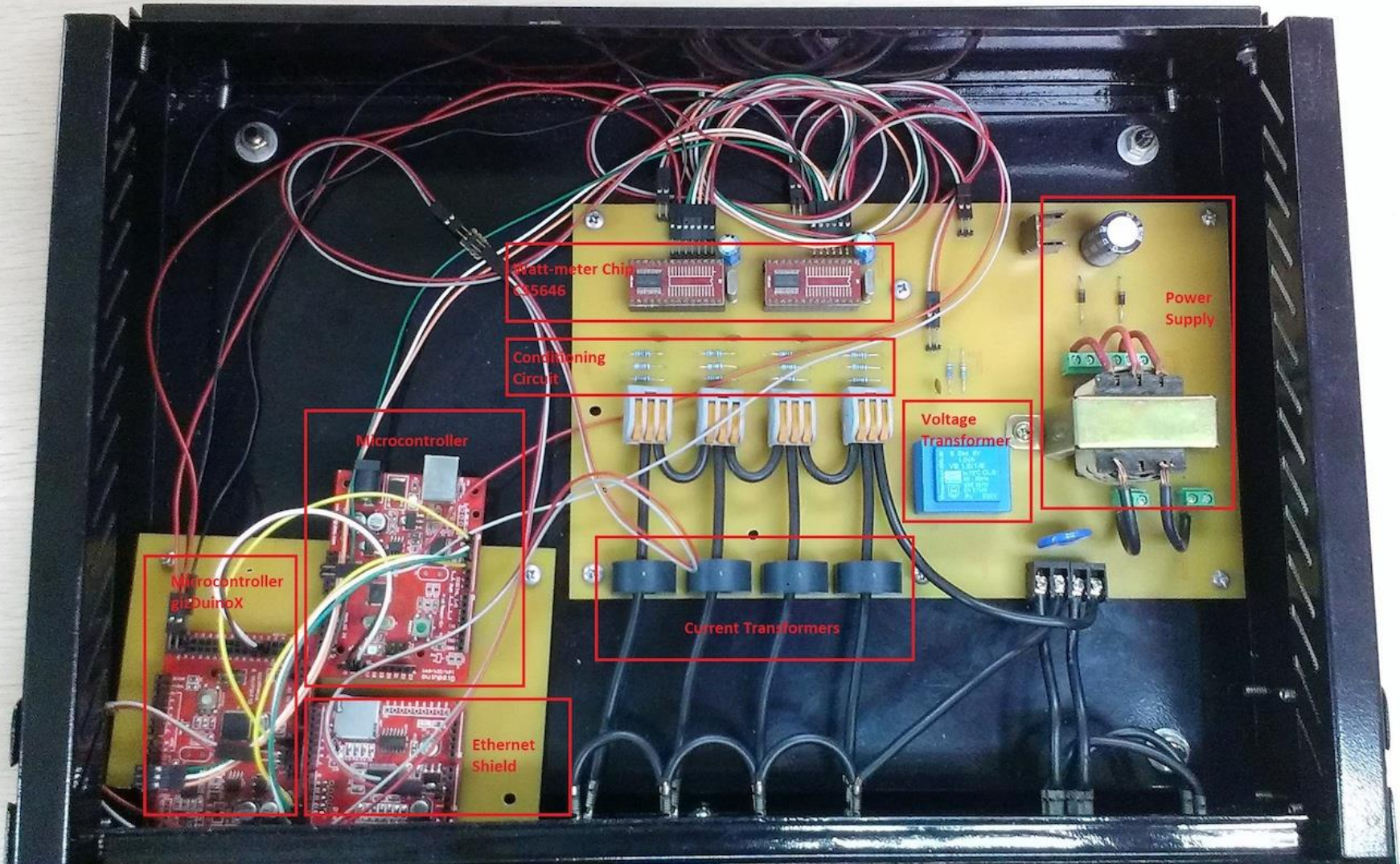
Ethernet Shield
Networking capability



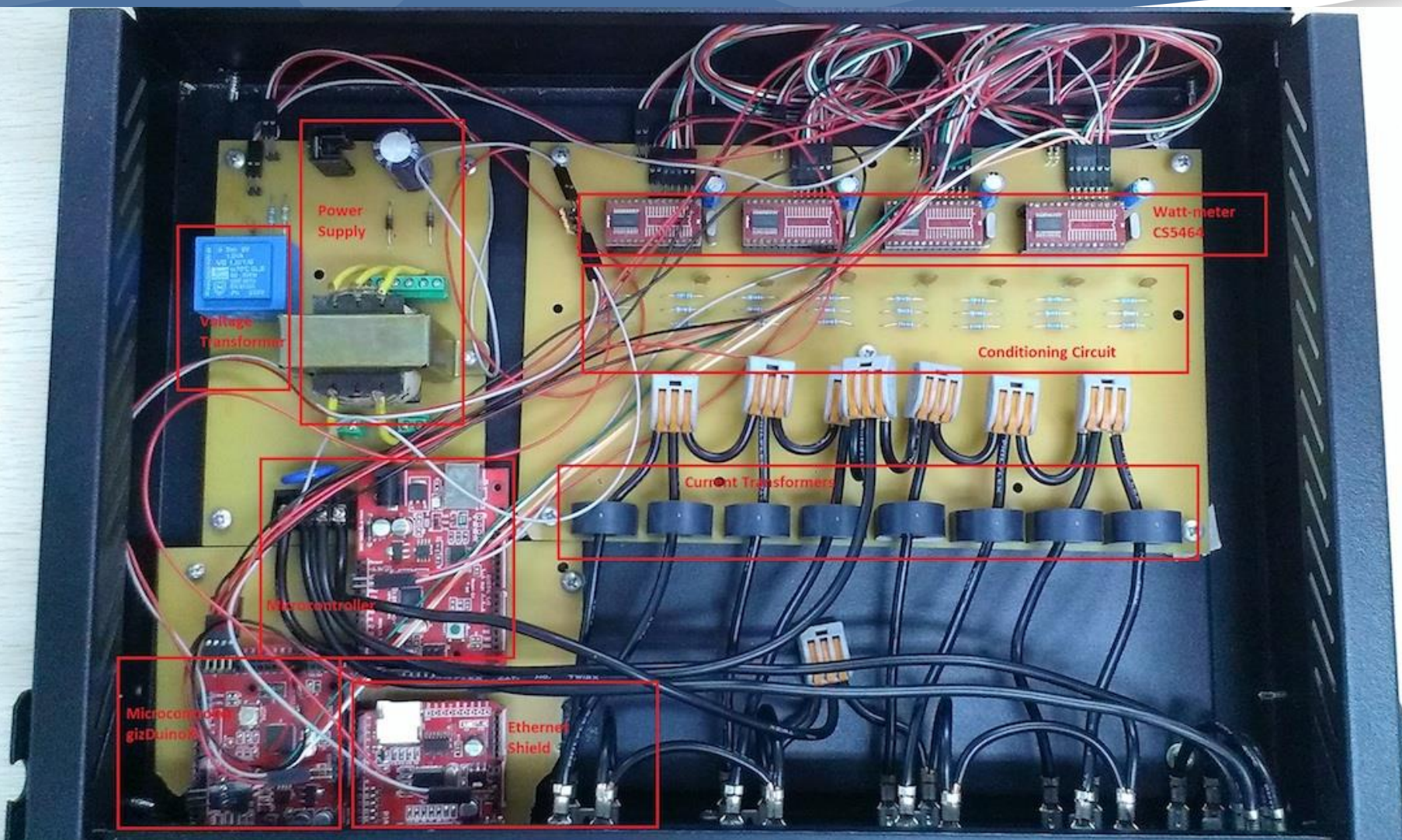
PDU Hardware



4-socket PDU Hardware



8-socket PDU Hardware



Bill of Materials

4-Socket PDU

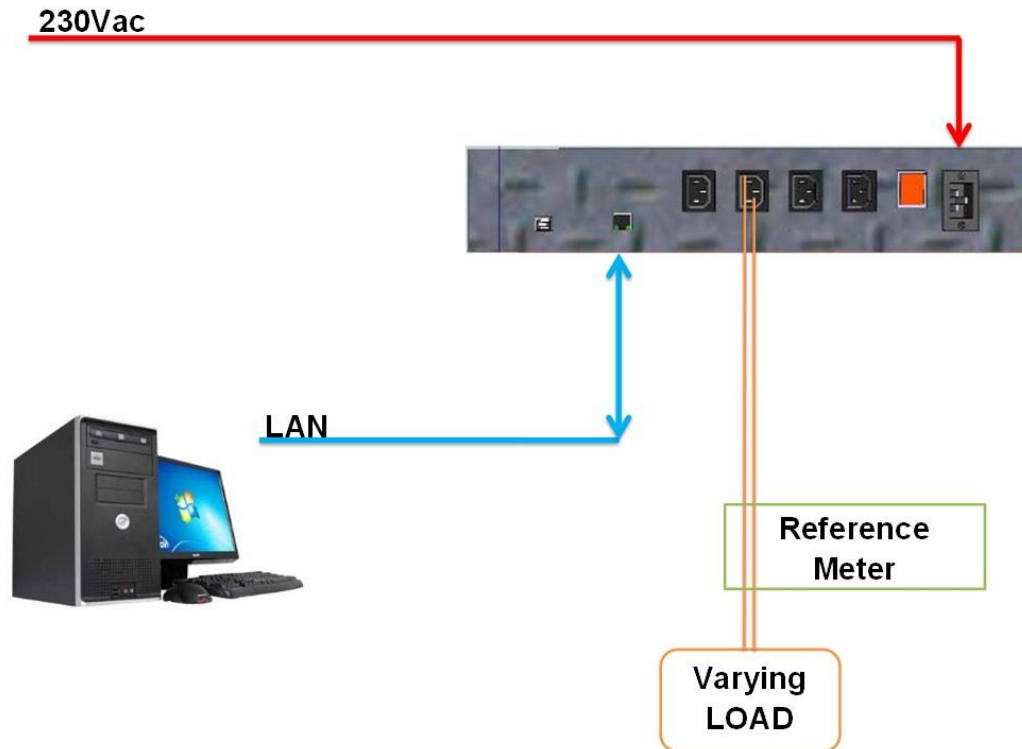
- Electronic Components + PCB: P 4,000.00
- Metal Enclosure: P 4,000.00
- Total: P 8,000.00

8-Socket PDU

- Electronic Components + PCB: P 5,000.00
- Metal Enclosure: P 4,000.00
- Total: P 9,000.00

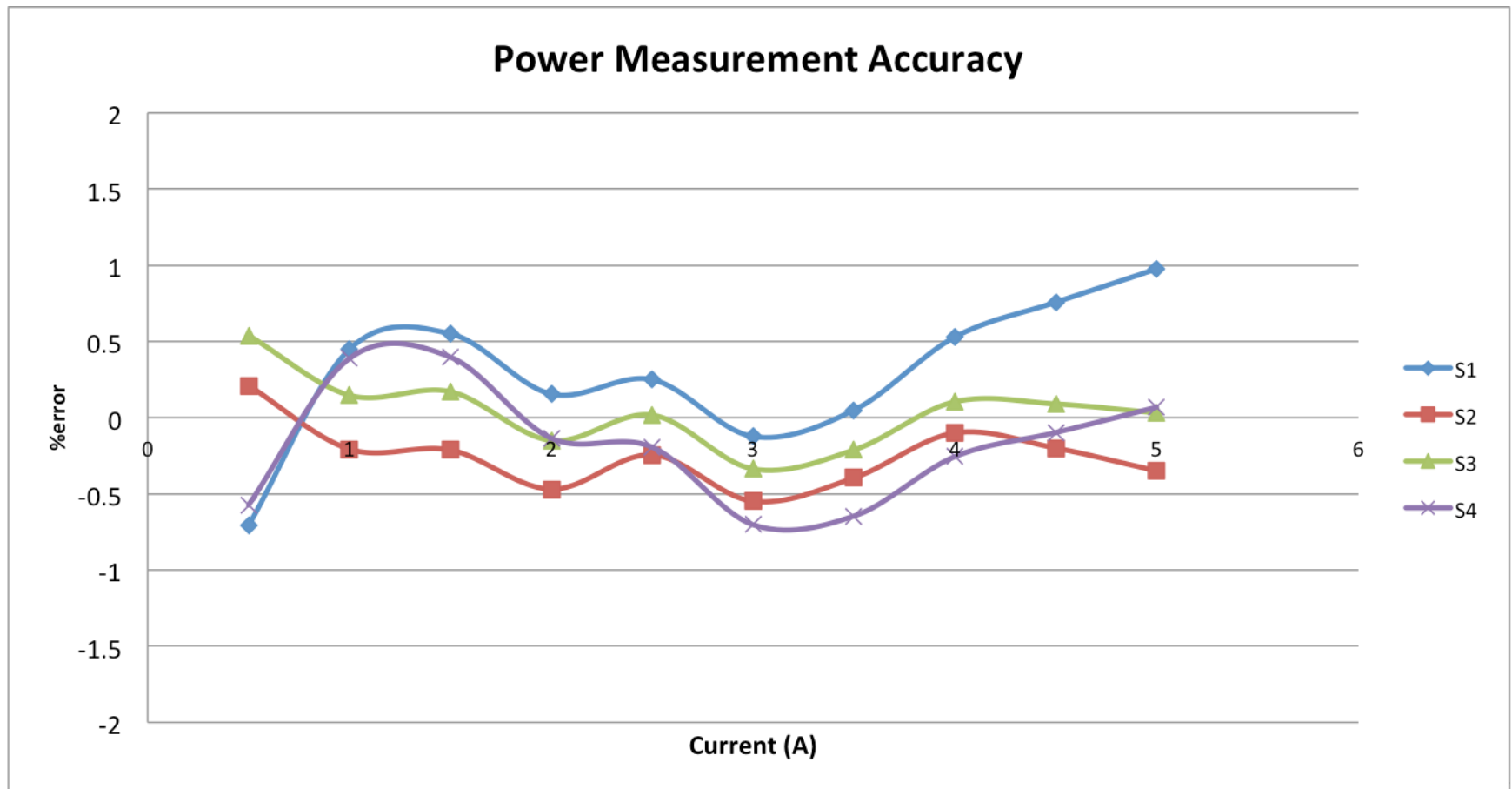
Improvement of Measurement Accuracy

- Nonlinear characteristics of current transformer
- Software-based correction of power measurements.



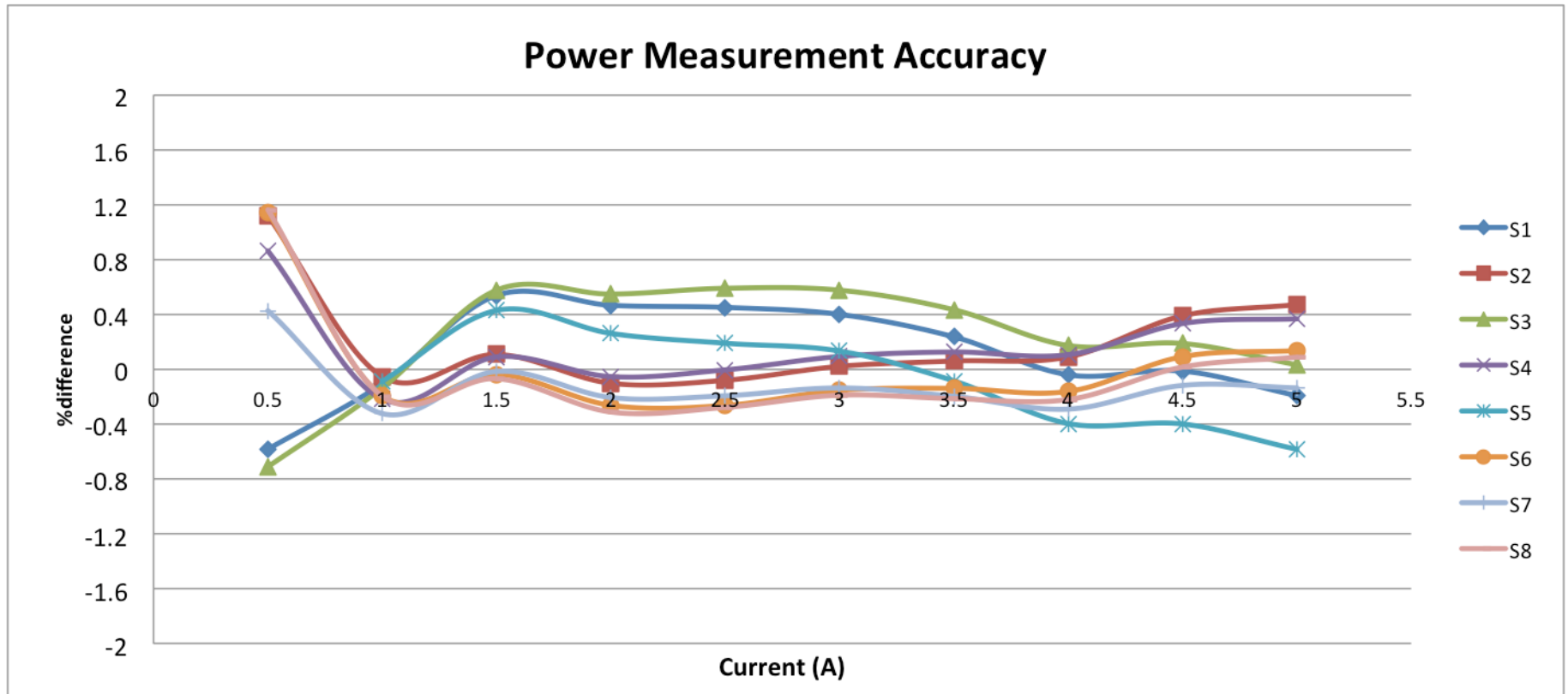
Measurement Accuracy

Accuracy of power measurements, 4-socket PDU



Measurement Accuracy

Accuracy of Power Measurements – 8 Socket PDU

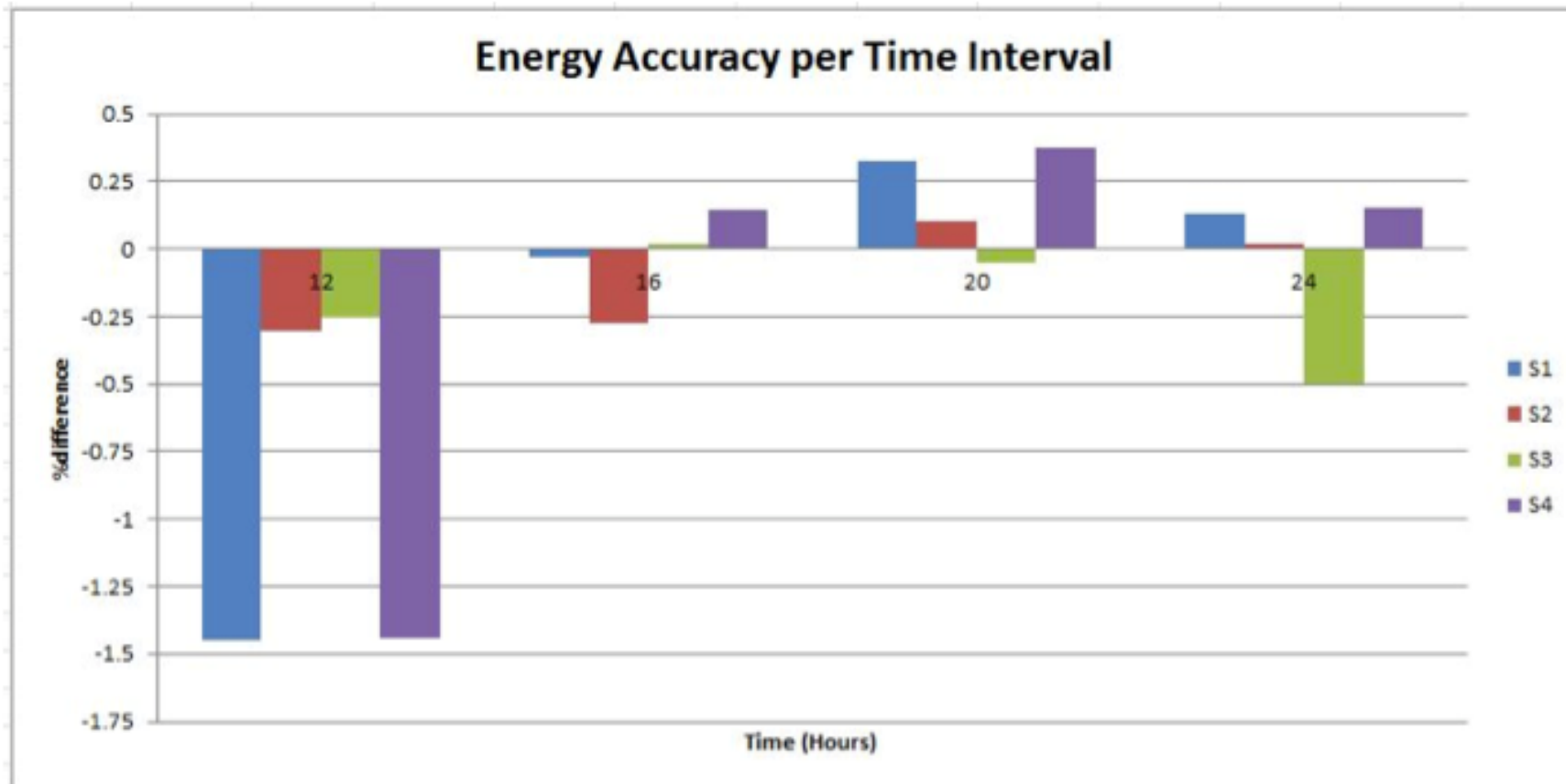


Accuracy of Energy Measurements

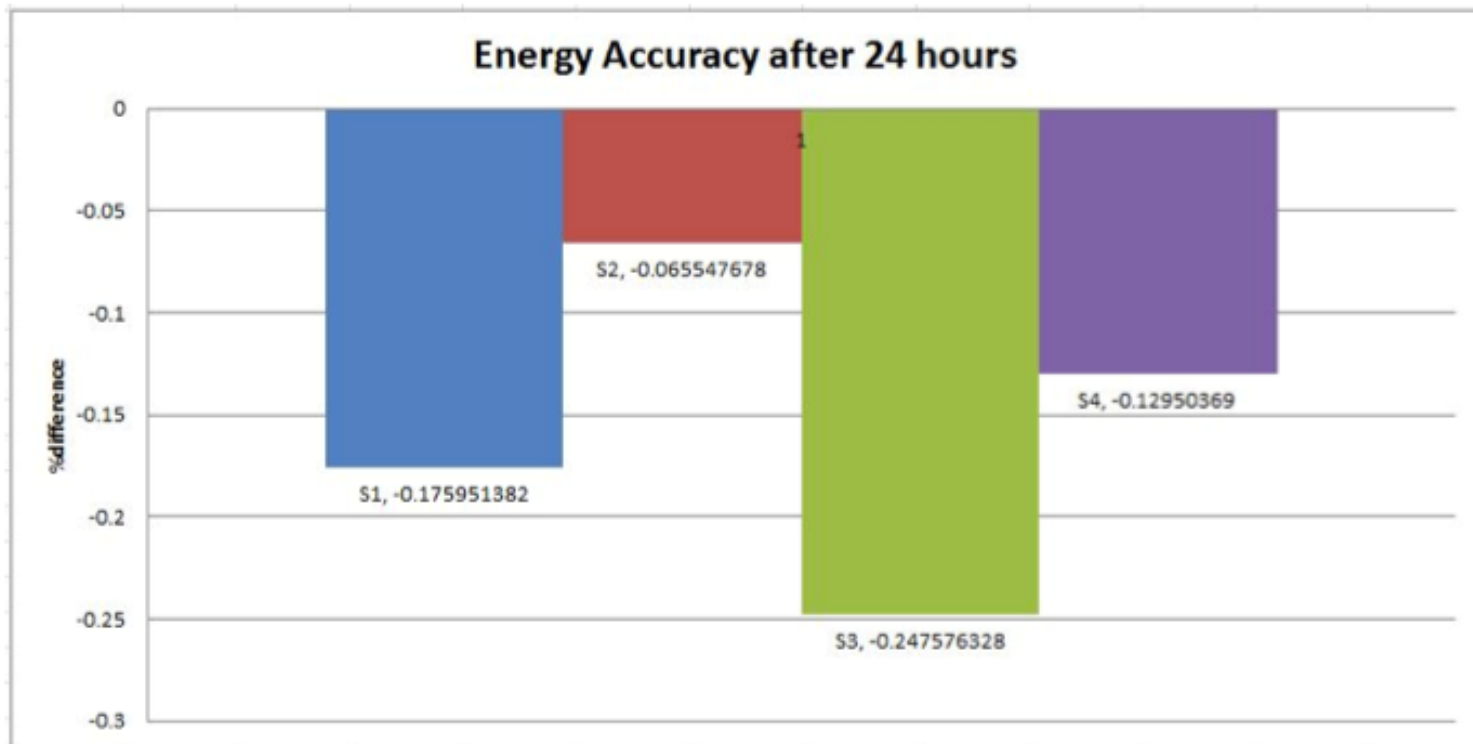
The following load was connected to all sockets over a 24 hour period:

- Hour 0 to hour 12: 0.5 A
- Hour 12 to hour 16: 1.0 A
- Hour 16 to hour 20: 2.0 A
- Hour 20 to hour 24: 3.0 A

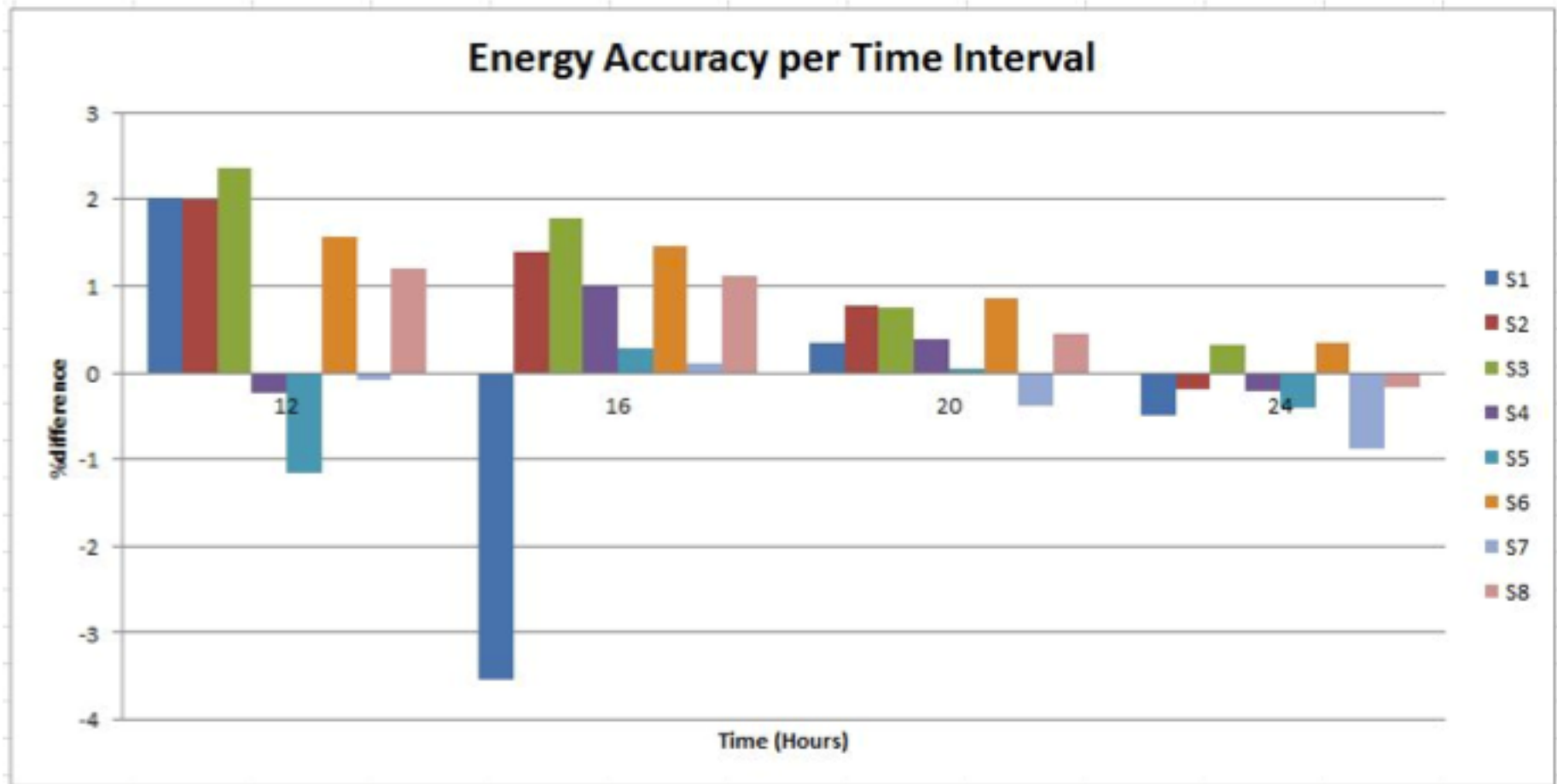
Accuracy of Energy Measurements 4 Socket PDU



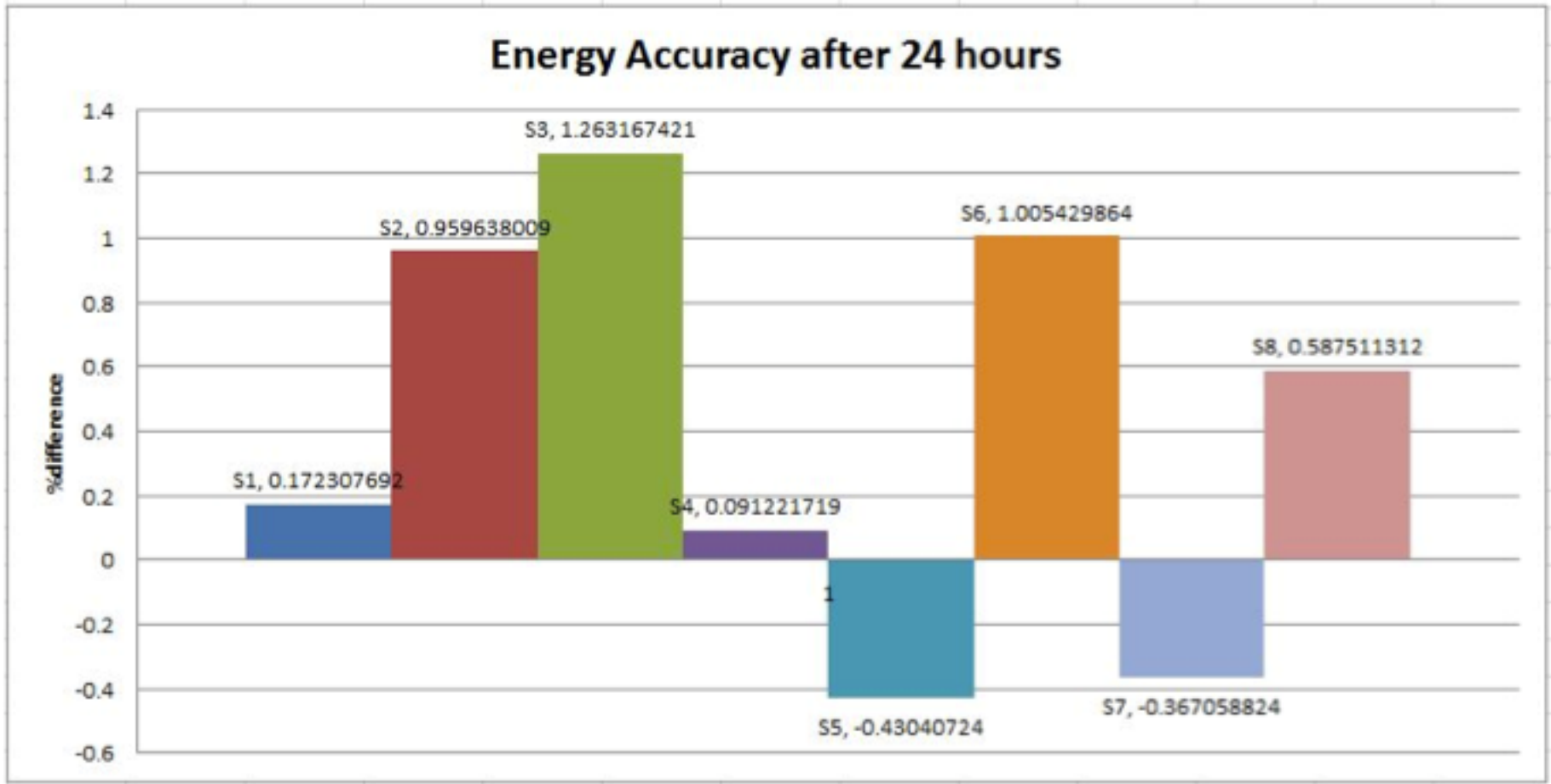
Accuracy of Energy Measurements 4 Socket PDU



Accuracy of Energy Measurements 8 Socket PDU



Accuracy of Energy Measurements 8 Socket PDU



Energy Monitoring Software

WAMP Framework

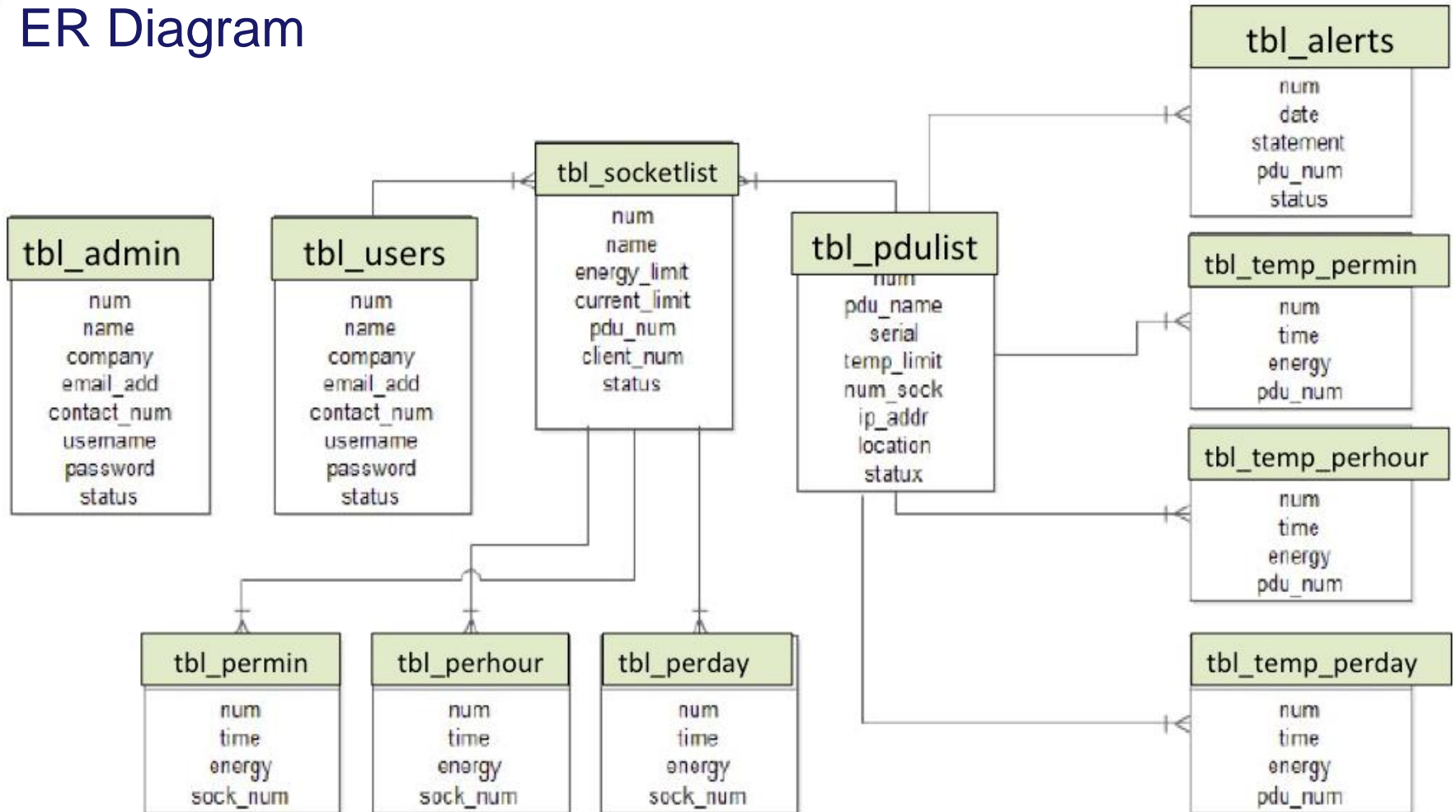
- Windows
- Apache Web Server
- MySQL Database
- PHP

Major Components

- Database: MySQL
- Back-end Process: Codeigniter PHP
- Front-end UI: Twitter Bootstrap, HTML, AJAX

Energy Monitoring Software

ER Diagram



Energy Monitoring Software

Browser-Based User Interface

- User types
 - Administrator: Data center operator / administrator
 - User: Equipment owner / lessee
- Functions
 - Manage user: add, delete, socket permissions
 - Manage PDU: PDU type and attributes, socket assignments, over-limit thresholds, temperature threshold
 - Energy graphs: hourly, daily, monthly
 - Temperature graphs: hourly, daily, monthly

Web-based Interface Usability Test

- Nine respondents (have taken up HMI course)
 - Methodology
 - Students given some time to explore software
 - Set of tasks to perform on their own
 - Interview + survey
 - Over-all, users either agreed or strongly agreed that the website is easy to use
 - easy of use with respect to content organization, lay-out, choice of font styles and icons
-

Web-based Interface Usability Test

| | Item | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|----|--------------------------------------------------------------------|----------------|---------|---------|----------|-------------------|
| 1 | The terms used are appropriate and easy to understand | 0.00% | 100.00% | 0.00% | 0.00% | 0.00% |
| 2 | The texts are easy to read | 33.33% | 44.44% | 11.11% | 11.11% | 0.00% |
| 3 | The font styles and sizes are appropriate | 22.22% | 33.33% | 44.44% | 0.00% | 0.00% |
| 4 | The labels/headings of elements are consistent | 33.33% | 55.56% | 11.11% | 0.00% | 0.00% |
| 5 | The placement of elements such as icons, tabs, buttons are optimal | 44.44% | 33.33% | 22.22% | 0.00% | 0.00% |
| 6 | The icons used are easy to understand | 55.56% | 22.22% | 22.22% | 0.00% | 0.00% |
| 7 | The colors used are not too flashy | 44.44% | 33.33% | 22.22% | 0.00% | 0.00% |
| 8 | The fill color of the labels/headings makes it easier to read | 33.33% | 44.44% | 22.22% | 0.00% | 0.00% |
| 9 | The color coding of the elements are appropriate and consistent | 33.33% | 33.33% | 33.33% | 0.00% | 0.00% |
| 10 | The dashboard is able to provide a quick view of the system | 22.22% | 33.33% | 22.22% | 22.22% | 0.00% |

Web-based Interface Usability Test

| | Item | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|----|-----------------------------------------------------------|----------------|--------|---------|----------|-------------------|
| 11 | The side menus are useful | 66.67% | 33.33% | 0.00% | 0.00% | 0.00% |
| 12 | The lists available provide the necessary information | 0.00% | 66.67% | 33.33% | 0.00% | 0.00% |
| 13 | The Plot feature is easy to use | 11.11% | 44.44% | 33.33% | 11.11% | 0.00% |
| 14 | The generated plots are easy to read | 11.11% | 44.44% | 33.33% | 11.11% | 0.00% |
| 15 | The tabs (Plot feature) are noticeable | 11.11% | 66.67% | 22.22% | 0.00% | 0.00% |
| 16 | The website allows the users to easily access information | 22.22% | 66.67% | 11.11% | 0.00% | 0.00% |
| 17 | The website is organized | 33.33% | 66.67% | 0.00% | 0.00% | 0.00% |
| 18 | It is easy to navigate within the website | 33.33% | 55.56% | 11.11% | 0.00% | 0.00% |
| 19 | The website is attractive | 22.22% | 44.44% | 33.33% | 0.00% | 0.00% |
| 20 | The website is easy to use | 33.33% | 55.56% | 11.11% | 0.00% | 0.00% |

Monitoring Software Screenshots

Admin Homepage

The screenshot displays the Admin Homepage of the EMS4DC Data Center Energy Monitoring System. The browser address bar shows the URL `127.0.0.1/ems4dc/index.php/pages_new/index`. The page title is "Data Center Energy Monitoring System".

System Information:

- System Date and time: 18 June, 2014 14:14
- 4 PDU(s)
- 1 User(s)
- 2 Admin User(s)
- 315.0683 kWh Total Consumed for this Month

Navigation Menu:

- Dashboard
- PDU Management
- User Management
- Energy Graphs
- Temperature Graphs

Calendar: June 2014

| Su | Mo | Tu | We | Th | Fr | Sa |
|----|----|----|----|----|----|----|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| 29 | 30 | | | | | |

Real-time Power & Temperature Data:

Controls:

- Select PDU
- Select Socket
- Show Real-time Plot

Watt-hr

deg C

No Data

Highcharts.com

Event Logs: Clear All

System tray: ENG INTL 2:14 PM 6/18/2014

Monitoring Software Screenshots

PDU Management: Adding PDU

The screenshot displays the EMS4DC Data Center Energy Monitoring System interface. The browser address bar shows the URL `127.0.0.1/ems4dc/index.php/pages_new/add_pdu`. The page title is "Data Center Energy Monitoring System".

System Date and time: 18 June, 2014 14:15

Navigation Menu: Dashboard, PDU Management >, User Management >, Energy Graphs >, Temperature Graphs

Calendar: June 2014 (18th is highlighted)

Add PDU Form: Make sure to fill up all the information.

PDU Information:

- *PDU Name:
- *Description & location:
- *IP Address:
- *Temperature Limit (deg C):
- *Serial:

Socket Configuration:













*Socket Type:

| Socket Number | Socket Description | Assign to Client | Alarms (Power Limit Current Limit) | |
|---------------|----------------------|-----------------------------------|---------------------------------------------|-----------------------------------------------|
| 1 | <input type="text"/> | <input type="text" value="None"/> | <input type="text" value="No Power Limit"/> | <input type="text" value="No Current Limit"/> |
| 2 | <input type="text"/> | <input type="text" value="None"/> | <input type="text" value="No Power Limit"/> | <input type="text" value="No Current Limit"/> |
| 3 | <input type="text"/> | <input type="text" value="None"/> | <input type="text" value="No Power Limit"/> | <input type="text" value="No Current Limit"/> |
| 4 | <input type="text"/> | <input type="text" value="None"/> | <input type="text" value="No Power Limit"/> | <input type="text" value="No Current Limit"/> |

Monitoring Software Screenshots

PDU Management: View Status

The screenshot displays the 'Data Center Energy Monitoring System' interface. The main content area is titled 'PDU List' and contains a table with the following data:

| # | PDU Name | IP Address | Location | Number of Sockets | Temp Limit (deg C) | Status | Control |
|----|------------|---------------|------------|-------------------|--------------------|--------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 49 | PDU_4A | 10.158.13.205 | PDU_4A | 4 | 50 | Online |    |
| 52 | PDU_4A_lab | 10.158.13.206 | PDU_4A_lab | 4 | 50 | Online |    |
| 54 | PDU_8A_lab | 10.158.13.207 | PDU_8A_lab | 8 | 50 | Online |    |
| 55 | PDU_8B_lab | 10.158.13.208 | | 8 | 50 | Online |    |

The interface also includes a sidebar with navigation options: Dashboard, PDU Management, User Management, Energy Graphs, and Temperature Graphs. A calendar for June 2014 is visible, with the 18th highlighted. The system date and time are shown as 18 June, 2014 14:15. The browser address bar shows the URL 127.0.0.1/ems4dc/index.php/pages_new/view_manage_pdu.

Monitoring Software Screenshots

User Management

The screenshot shows a web browser window with the URL `127.0.0.1/ems4dc/index.php/pages_new/add_user`. The page title is "Data Center Energy Monitoring System". The main content area is titled "Add User Form" and contains the following fields:

- Log-in Credentials:**
 - Username* (Input Username)
 - Password* (Input Password)
 - Retype Password* (Retype Password)
- User Information:**
 - Complete Name* (Enter Complete Name)
 - Contact Number* (Enter Contact Number)
 - Email Address* (Enter Email Address)
 - Company* (Enter Company Address)
 - User Type (Admin)

A "Submit" button is located at the bottom of the form. The left sidebar contains navigation links: Dashboard, PDU Management, User Management, Energy Graphs, and Temperature Graphs. A calendar for June 2014 is also visible, with the 18th highlighted. The system date and time are displayed as "18 June, 2014 14:16".

Energy Monitoring Software

Client Homepage

The screenshot displays the EMS4DC Client Homepage. The browser address bar shows the URL `127.0.0.1/ems4dc/index.php/pages_user/home`. The page title is "Data Center Energy Management System".

System Information:
System Date and time: 18 June, 2014 16:15

Key Metrics:

- 4 Active Sockets
- 2 Inactive Sockets
- 432.0014 Watt-hr Total Energy Consumed for this Month

Energy Consumption Section:

Plot Control:
Select Socket (dropdown menu)
Show Plot (button)

Data:
• Total Energy (kWh):

Charts:

- Total Energy Consumption For the month of June, 2014:** A line chart showing energy consumption in Watt-hr over the days of June. The y-axis ranges from 0 to 600. A single data point is visible on June 18th, reaching approximately 432 Watt-hr.
- For the year 2014:** A bar chart showing total energy consumption in Watt-hr for each month of 2014. The y-axis ranges from 0k to 50k. A bar is visible for April '14, reaching approximately 25k Watt-hr.

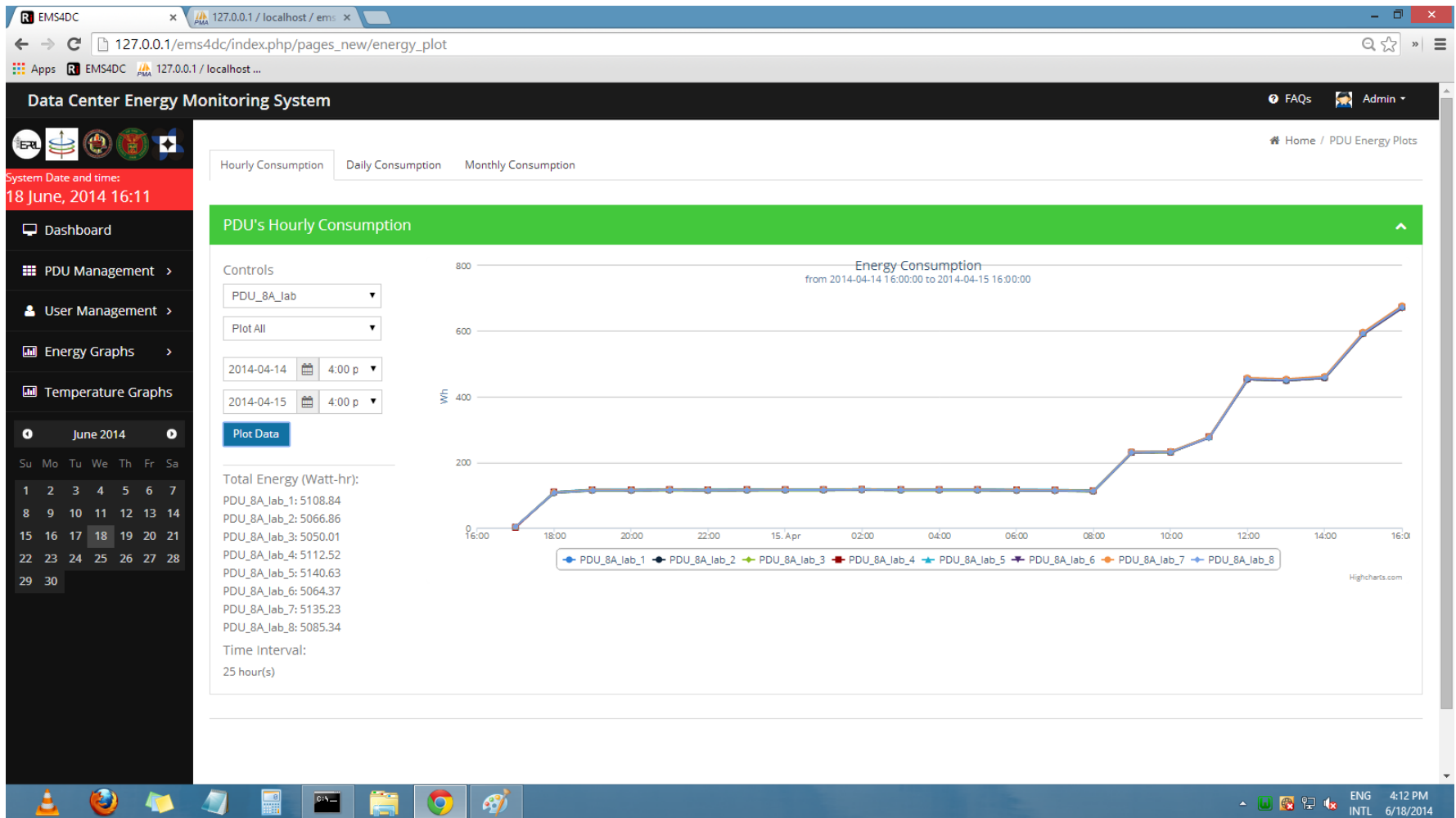
Navigation Menu (Left Sidebar):
Dashboard
My Sockets
Consumption History
June 2014 (Calendar view)

System Status (Bottom Right):
Welcome romanansal!

Taskbar (Bottom):
Windows taskbar showing various application icons and system tray information: ENG 4:15 PM INTL 6/18/2014.

Monitoring Software Screenshots

Energy Plot



Summary and Conclusion

- We were able to design and implement a power monitoring system for a datacenter
 - Two 4-socket PDU + two 8-socket PDU
 - Central monitoring software
- PDU Features
 - Energy measurement per socket
 - Energy measurement every 15 minutes
- Monitoring Software Features
 - PDU and User Management
 - Archiving and Visualization

Bringing the Energy Monitoring System to the Market

- Design for manufacturability
 - Integration of modules into a single board
 - Reduction of size of boards and enclosure
 - Review of components used to improve measurement accuracy
- Integration of additional features to the PDU
 - Remote power on and off, control of outlet access, turning off of idle equipment, power on sequencing
 - Improve PDU interface to enable rack level energy and power monitoring, and display of historical information

Thank you!

Power Distribution System for Data Centers

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Associate Professor, EEE Institute, UP Diliman



Problems Encountered (and Solutions)

- Limitation of microcontroller interface: cannot control the ethernet shield and metering chip simultaneously
 - Redesign of interface (too late)
 - Use another microcontroller
- Unstable operation after initial integration
 - Unreliable power supply within the microcontroller module was bypassed
- Sudden load changes causes frequent resets
 - Thermistor was inserted to minimize surge of current
 - Improve power supply stability by inserting bulk caps

Problems Encountered (and Solutions)

- Erroneous power measurements due to nonlinear CT
 - Software correction of power measurements
- Administrative problems
 - UP Procurement process
 - Delay in fabrication of metal enclosure