Electric Smart Load Meter

Senior Project 2015-2016
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Abstract

This project details the design of an electric meter that reads the signals of any device plugged into an outlet and displays cost readings that may potentially reduce power consumption. The sensor monitors whether a plugged in device continuously consumes power after completely charging up. For a charging device, the current remains constant until the device reaches 100% charge. Once the device becomes fully charged, the current discontinues for proper power usage. A unique aspect of the meter is that it displays cost per hour, day, and year. Displaying the cost per unit of time creates awareness for customers, potentially causing them to use less energy to power or charge their devices.

Chapter I: Introduction

California recently passed Title 24 which states California's efficiency code of regulations to conserve energy and reduce carbon emissions. All constructed and renovated buildings must abide the environmental standards [11]. The Electric Smart Load Meter (ESLM) creates an easy way to observe power usage and cost in kilowatts per hour. People use power for their computers, cell phones, smart tablets, televisions and the list goes on. The ESLM reads voltage, current, frequency, power factor, and expenses per unit of time. One way to change the behavior of people is to see how much power their device consumes while plugged in and the resulting usage cost per hour or day. Displaying the kilowatt per unit of time on the meter causes people to change the way they consume power and reduce their overall energy consumption.

Many companies create products to help automate a home in different ways. Most of these products now have a wireless application where power usage can be seen on consumer's smart phones or computers. Although consumers are able to see their power usage, they do not see how much their consumption costs. Table 1 shows the current smart outlet market leaders.

Table I: Current Smart Outlet Devices in the Market

Device Name	Price	Features
Meter Plug	$50	Allows the user to monitor power usage over extended periods. The user can monitor and control stand-by power.
Belkin WeMo Switch	$49.99	Allow users to send information about the device's energy usage directly to their smartphone or tablet.
Samsung SmartThings Outlet	$54.99	Smart Power Outlet can control and automate lamps, electronics, and small appliances directly using smartphones.
Kill-A-Watt	$24.99	Counts consumption by the kilowatt-hour

The ESLM Meter differs from the rest of the outlets because the meter detects whether or not a plugged-in device is fully charged at 100%. Once a device charges completely, the device operates not by the battery, but with the charger [5]. The electric smart meter cuts off the charge completely to reduce power consumption. Cutting off the signal to one device isn't enough to make a difference, but cutting off hundreds or thousands of charged devices can save money and reduce power usage.

Utilities such as PG&E, SMUD, and Roseville Electric have different rates and plans depending on how consumers use their electricity. In 2014, California's average price of electricity stood at 16.25 cents/kWh with the average monthly consumption at 562 kWh, totaling the average monthly bill to $91.26 [14]. According to the U.S. Energy Information Administration, U.S. electricity use is projected to grow slowly by an average of less than 1% per year from 2014 to 2040 [15]. As each year increases electricity usage, so does the pricing as well. Figure 1 displays the residential electricity distribution within the U.S.

How electricity is used by the U.S. residential sector, 2014

air conditioning 13%

space heating¹ 12%

lighting 11%

water heaters 9%

refrigerators and freezers 9%

televisions and related equipment 7%

all other appliances² 38%

Notes:
¹Includes consumption for heat and operating furnace fans and boiler pumps.
²Includes miscellaneous appliances, clothes washers and dryers, computers and related equipment, stoves, dishwashers, heating elements, and motors not included in the uses listed above.
Source: U.S. Energy Information Administration, *Annual Energy Outlook 2015*, Reference case, Table 5 (April 2015)
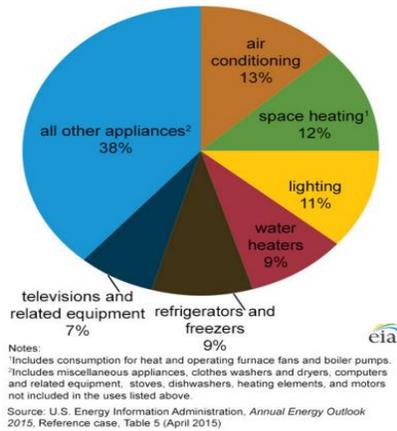
Figure 1: Residential Electricity Uses in 2014

The largest single use of electricity in the U.S. residential sector on an annual basis is for air conditioning, followed by space heating, lighting, water heating, refrigeration, and televisions and related electronic equipment. About 40% of annual electricity use contain all other appliances such as washers and dryers, computers and related equipment, dishwashers, and electrical equipment. The ESLM would be best used for the television and related equipment category. With the recent push for green energy and environmental friendliness, more and more people are concerned about their personal daily power usage. I developed a microcontroller-based device to measure AC power. The user will be able to insert the device between the wall socket and the device under test (DUT) to measure the amount of AC power being used.

Chapter II: Customer Needs, Requirements, and Specifications

Customer Needs Assessment

Middle class customers need a device that monitors current waveforms in order to reduce their electricity bill cost. The smart electric load meter features voltage and current readings along with the cost per some unit of time. Customer backgrounds comes mostly from personal experience: customers want to save money and conserve energy. Devices such as the Meter Plug can cost up 100 dollars and may not have all the features vital to customer needs. Features include displaying cost per unit of time and cutting off power to fully charged devices. Having a small device help customers use it anywhere around the U.S. With an OLED screen, they can monitor voltage, current, and kilowatts per hour. To make the Electric Smart Load meter easy to use, only one button is used to switch between the features.

Requirements and Specifications

The device must fit into any electrical outlet, output a voltage of 120 VAC with 60 Hz frequency to power the devices, and display readings of voltage, current, power factor, frequency, and expenses in hours, days, and years. Safety is key in making the product usable in the market as the device is powered in the U.S with 120 VAC. The device contains low-voltage chips from the microprocessor and is powered by a voltage of 5 volts DC. The microprocessor, Arduino, has an ADC clock speed at 125 kHz, providing a sampling rate of 9600 samples per second [6]. An OLED screen uses electricity for the parts of the screen that need color while the remaining parts that remain black use no power, making OLEDs more energy-efficient compared the LCD screens.

Most of these requirements and specifications closely reflect the Kill-A-Watt device [3], except for cutting current off for fully charged devices. To determine whether or not the device has charged, the ESLM detects the current of the device. Once a device has been charged, the current decreases to a smaller amp [1]. The device starts using power from the charger rather than the battery. At that moment, the meter cuts off the current from the charged device. Table II below explains concise requirements and specifications for the electric load meter. Table III refers to important events and reports that completes the senior project.

TABLE II: ELECTRIC SMART LOAD METER REQUIREMENTS & SPECIFICATION

Marketing Requirements	Engineering Specifications	Justification
1, 5	Device must weigh less than 10 ounces	The device should plug into any electrical outlet within the U.S.
2, 4	Meter must cut off signal to fully-charged devices	Cutting off the current to fully charged devices reduces power consumption.
2	Cost per device less than $40	Other similar devices such as the Kill-A-Watt sell up to $100 depending on its feature.
4, 7	Minimal power draw from microprocessor $Power = 5V * 20\ mA = 100mW$	The customers do not want a constant high power draw from components. Having an AC to DC converter always result in power loss [17].
4, 6, 7	Operating voltage: 115 VAC Max voltage: 125 VAC Max current: 15 A Max Power: 1875 VA	Everything electrical device must pass the National Electric Code NFPA 70 in order for a device to properly be used [16].
3, 5, 6	Display voltage, current, frequency, and consumption by the kilowatt-hour from any plugged-in device on a OLED screen	Having multiple features gives customers more background information about the plugged-in device.
4, 6	Meter powered by 120 VAC outlet	The meter provides 120 AC voltage to plugged-in devices within the U.S.
7	All readings have to be within 0.2% accurate	Line voltages are controlled at +/-5% [5]. Once the device gets plugged into the meter, data processing in the analog-to-digital converter inside the microprocessor. Through mathematical software coding, the device outputs precise readings.

Marketing Requirements
1. Small
2. Affordable
3. Monitorable
4. Efficient
5. User-friendly
6. Multiple power options
7. Accuracy

TABLE III: ELECTRIC SMART LOAD METER DELIVERABLES

Delivery Date	Deliverable Description
March 23, 2016	Design Review
April 22, 2016	EE 461 Demo
June 5, 2016	EE 461 Report
Oct. 28, 2016	EE 462 Demo
Nov. 11, 2016	ABET Sr. Project Analysis
Dec. 8. 2016	Sr. Project Expo Poster
Dec. 20, 2016	EE 462 Report

Chapter III: Functional Decomposition

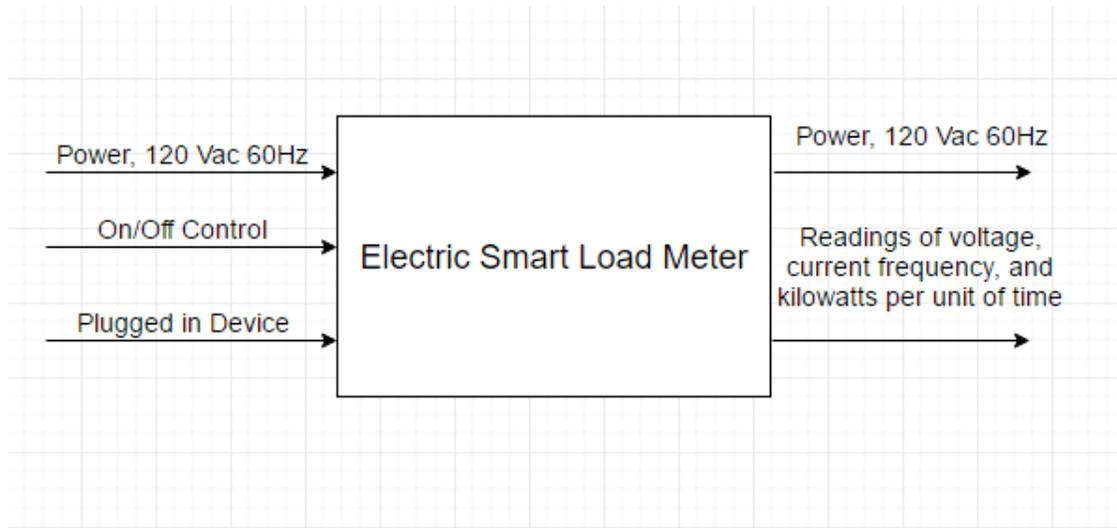Figure 2 below shows the level 0 block diagram of the Electric Smart Load Meter.

Figure 2: Level 0 Block Diagram

TABLE IV: LEVEL 0 FUNCTIONALITY TABLE

Module	Electric Smart Load Meter
Input	- Power: 120 VAC 60 Hz (+/- 5% for standard fluctuations) - Any plugged-in device for monitoring - On/Off control
Output	- Displays voltage, current, frequency, and kilowatts per hour 120V AC 60Hz (+/- 5% for standard fluctuations)
Functionality	Displays accurate readings of voltage, current, frequency, and expenses in kilowatts per hour for any plugged in device. An on/off switch allows the user to power the load for the microcontroller to display readings for energy efficiency.

The first input starts with the standard 120V AC 60Hz power from the U.S. Once a device gets plugged into the meter, the user can toggle a switch to test the load. The meter also outputs 120V AC 60Hz to power up the device being plugged in and a 9V DC battery supply to power up the microcontroller and the linear optoisolators. Adding an on/off switch allows the meter to be energy efficient. Figure 3 below explains the level 1 block diagram.
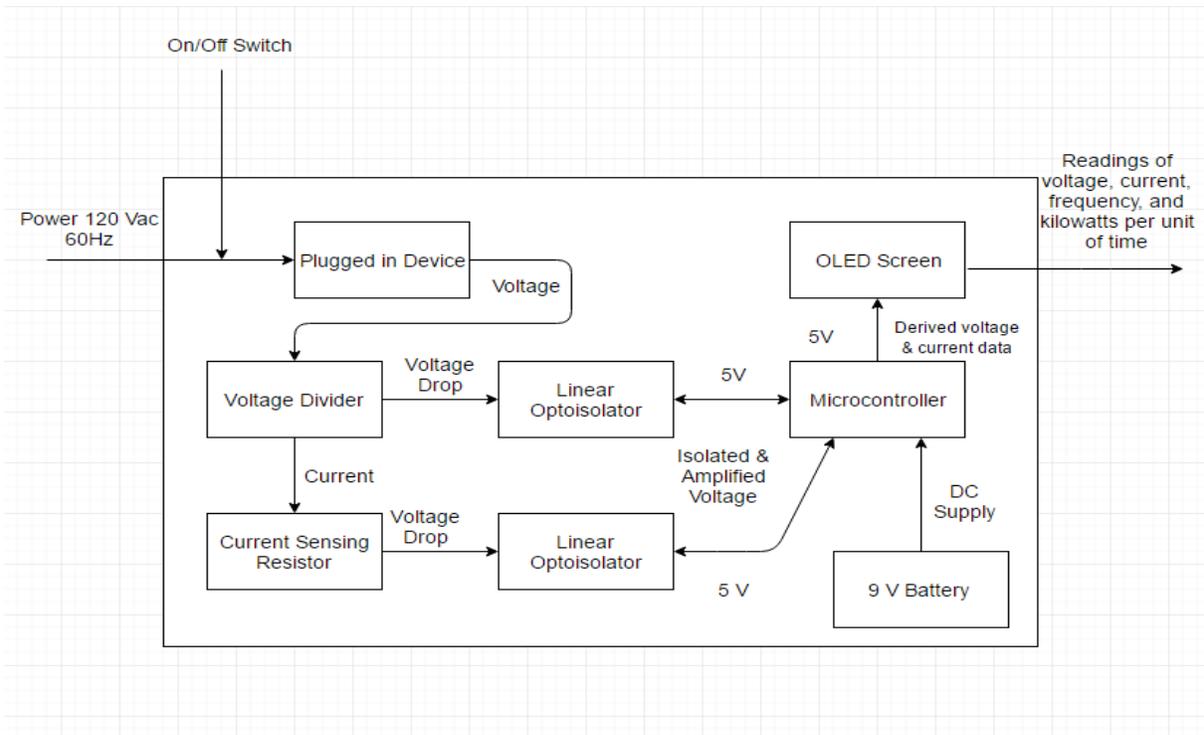
Figure 3: Level 1 Block Diagram

TABLE V: LEVEL 1 FUNCTIONALITY TABLE

Module	Voltage Divider	Microcontroller	OLED Screen	Plugged in device
Input	• Voltage	• DC Voltage • Isolated & Amplified Voltage	• 5V DC power • Derived Calculations	• Power, 120V AC
Output	• Voltage	• 5 volt DC supply • Derived voltage and current data	• Readings of voltage, current power, frequency…	• Voltage & current
Functionality	The voltage divider turns a large voltage into a smaller voltage value.	The microcontroller gets powered up by DC voltage and supply other components with 5 volts. It also indirectly derives many operating parameters by direct calculation, which outputs the data into the OLED screen.	DC voltage powers up the OLED screen. Once the microcontroller derives the parameters, the screen displays accurate readings of voltage, current, and cost in kilowatts per hour.	Serves as the main component to obtain data from voltage and current. Once plugged into meter, data goes into the microcontroller for processing.

Module	Current Sensing Resistor	Linear Optoisolators	9V Battery Supply
Input	• Current	• Voltage drop	• None
Output	• Small voltage drop	• Isolated & Amplified Voltage	• 9 Volts
Functionality	The resistor has a very small resistance, creating a small voltage drop for the optoisolators.	The chip is used for general analog signal isolation. In this case, the optoisolators take in small AC signals to be processed inside the microcontroller.	DC voltage powers up the OLED screen. Once the microcontroller derives the parameters, the screen displays accurate readings of voltage, current, and cost in kilowatts per hour.

Most modern ac line monitors use one or more analog-to-digital converters to convert analog power line signals into a digital formal then convert data using a local high-speed processor [2]. One ADC would measure the voltage and another to measure current of the device. The microprocessor can indirectly derive parameters by direct calculation from the measured voltage and current. Parameters such as frequency, and cost in kilowatts per hour can be calculated and displayed into the OLED screen.

Chapter IV: Project Planning
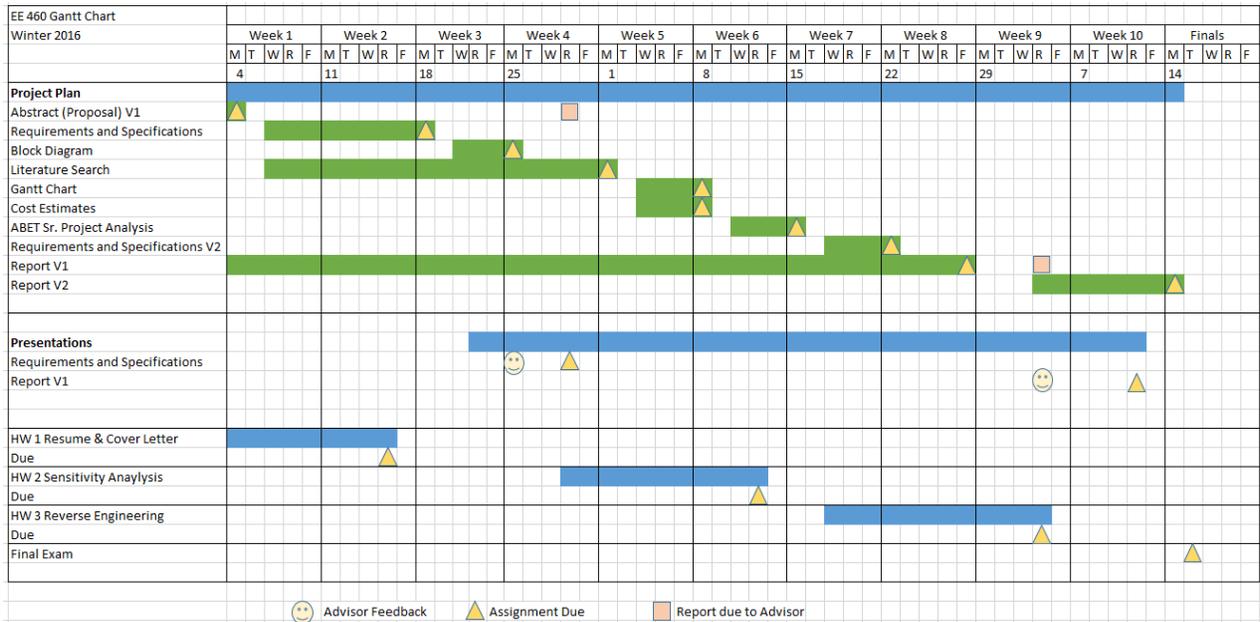
Figure 4: Gantt chart Winter 2016
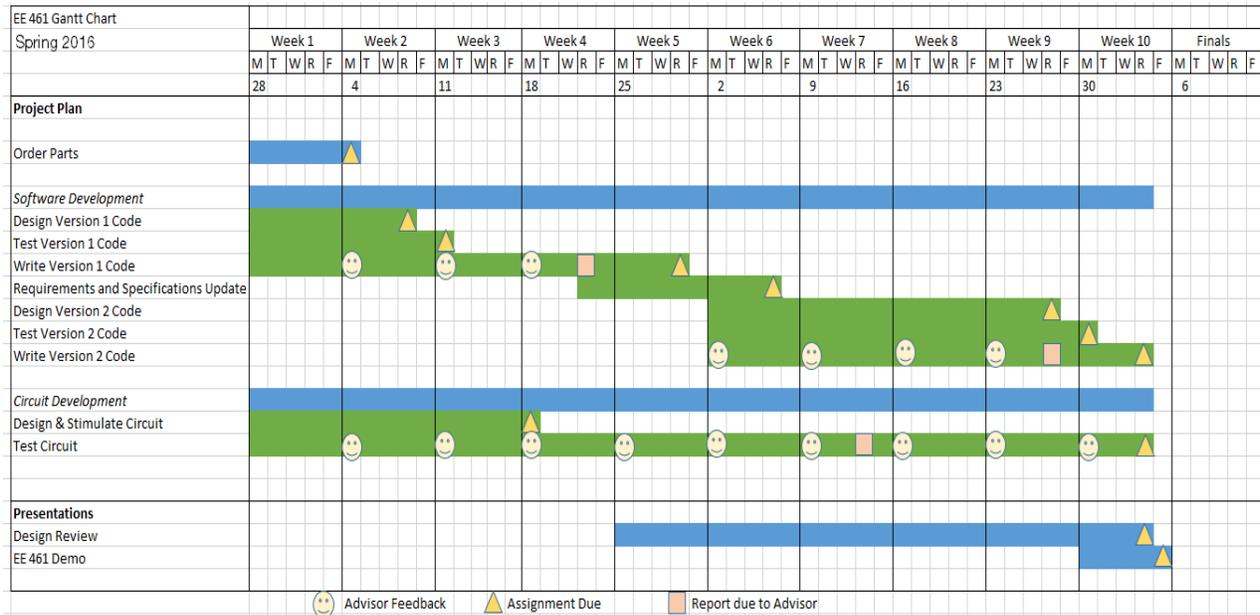
Figure 5: Gantt chart Spring 2016
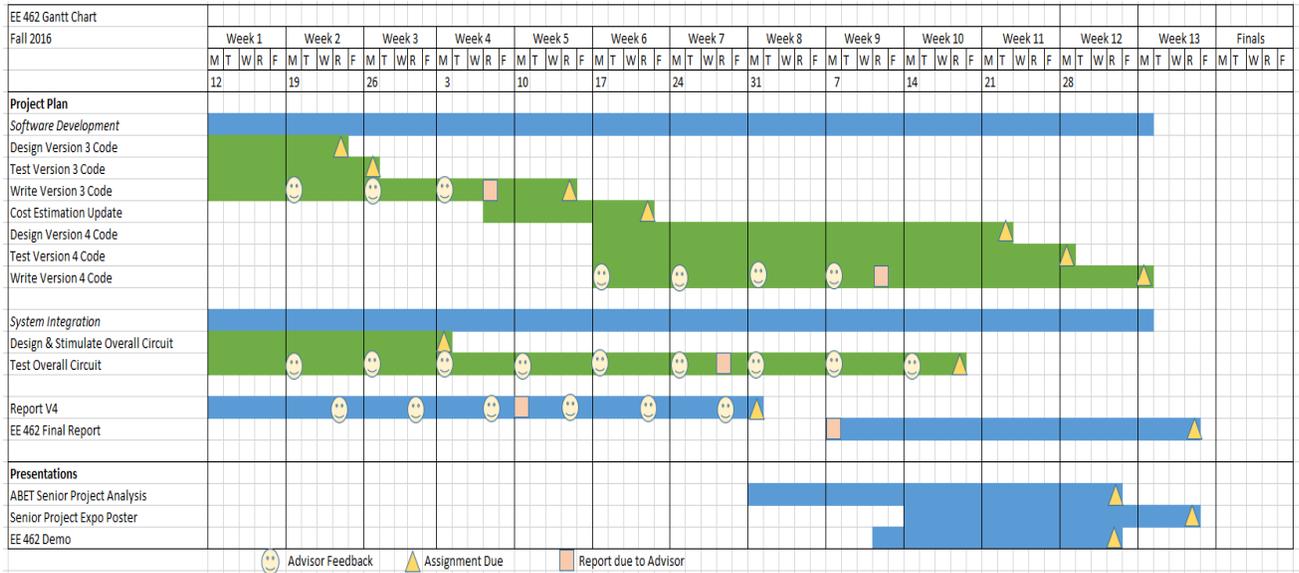
Figure 6: Gantt chart Fall 2016

Figure 4, 5, and 6 reflects the estimated timeline in designing the Electric Smart Load Meter. There are four main categories in putting it all together: project planning, software development, circuit development, and system integration. During winter of 2016, the project gets planned out with requirements and specifications along with the cost of parts. Software and circuit development begins in the following quarter. The timeframe for both developments include design, build, and test iterations for multiple test cases. Once the software and circuit development gets completed, system integration follows within the same quarter. Within the last quarter, another set of design, build, and test occurs for better revision.

Table VI depicts a cost and labor estimation in creating the meter. To determine how much time gets put into labor, equation (1) explains the following:

$$\text{Time} = [\text{time (a)} + 4\text{time (b)} + \text{time (c)}] / 6 \tag{1}$$

Where time (a) represents the most optimistic time estimate, time (b) represents the most likely time estimate, and time (c) represents the most pessimistic time estimate. The base salary for starting as an electrical engineer is roughly $30 an hour [12].

TABLE VI: ELECTRIC SMART LOAD METER COST ESTIMATION

Labor	*Time[hrs]*	*Time(a) [hrs]*	*Time(b)[hrs]*	*Time(b) [hrs]*	*Cost [US Dollars]*
Programming code	181	160	180	210	$5430
Ordering parts	2	0.5	1	2	$60
Testing device	29	20	30	35	$870
Writing reports	10	5	10	15	$300
Project demoing	10	6	10	14	$300
Total	*232*	*191.5*	*231*	*276*	*$6960*
Parts					
Microcontroller	N/A	N/A	N/A	N/A	$23.99
AC to DC converter	N/A	N/A	N/A	N/A	Salvaged
Ohmite 13FR200E current sense resistor	N/A	N/A	N/A	N/A	$1.72
OLED Screen	N/A	N/A	N/A	N/A	$11.79
NEMA 5-15 Toggle Switch	N/A	N/A	N/A	N/A	$7.65
Breadboard	N/A	N/A	N/A	N/A	$4
Sharp S216S02 Relay Switch	N/A	N/A	N/A	N/A	Salvaged
Avago Technologies HCPL-7520 linear optoisolators (2)	N/A	N/A	N/A	N/A	$9.72
9 AA Batteries	N/A	N/A	N/A	N/A	$9.99
Total	N/A	N/A	N/A	N/A	$68.86

Chapter V: Final Design and Test Data
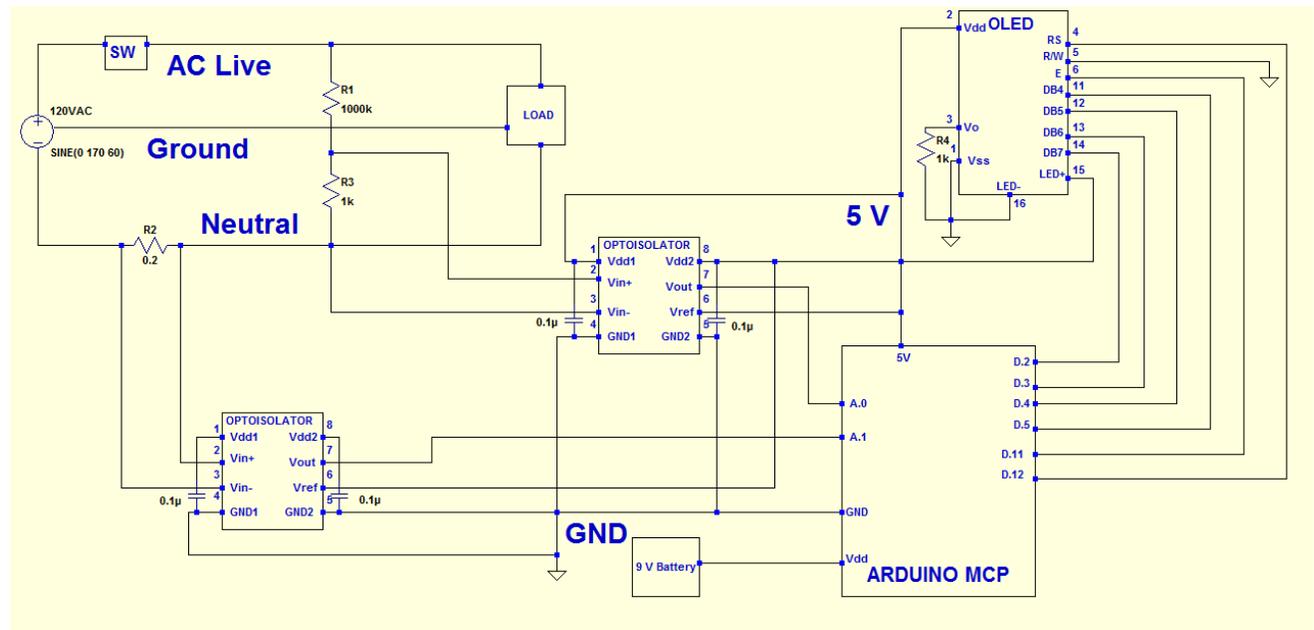
Figure 7: Schematic of Electric Smart Load Meter

The full schematic is shown in figure 7. The ESLM sits between the main line and the load, or device under test. All signals are isolated before reaching the microcontroller.

Hardware Design

Voltage Measurement

To measure voltage, two resistors, 1 MΩ and 1 kΩ, were used to create a large voltage divider. Using 1000:1 voltage divider, 170 V peak-to-peak (120V$_{rms}$) was brought down to 170 mV peak-to-peak, which is within the limits of the linear optoisolators. The 1 MΩ was used to limit the current between the AC live and neutral line. Assuming a 170 V drop, only 0.17 mA flows through the 1 MΩ resistor, dissipating 0.03 W, well within the power ratings of the resistor. To calculate the voltage divider, the following equation can be used:

$$V_{line} = 1001 V_{divider}$$

Eq. 1

Current Measurement

To measure current, a very small current sensing resistor (0.2 Ω) was placed in the neutral line to create a tiny voltage drop. Since the voltage drop and the resistor value is known, we can mathematically determine the current through the neutral line. Because the sensing resistor is rated for 3 W, we expect little power to be dissipated through it. The following equation can be used:

11

$$I_{line} = \frac{V_{current-sense}}{R_{current-sense}} = \frac{V_{current-sense}}{0.2\Omega}$$

<div align="center">Eq. 2</div>

Linear Optoisolators

The Avago Technologies HCPL-7520 linear optoisolators created an easy way to measure voltage and current through the microcontroller. This device has a linear transfer characteristics curve for input range -256 mV to 256 mV. The input is differential and output is scaled to V_{ref}. It also allows us to bias the signal to V_{ref} / 2, amplify it, and isolate it which results in a simpler and cheaper solution to manufacture. The output of the optoisolators were isolated analog signals that were read through the ADCs of the microcontroller.

Power Switching

The sockets used in most American homes adhere to the NEMA 5-15 standard, set by the National Electrical Manufacturers Association. It is rated for 15 A / 125 V at 60 Hz.

Figure 8: NEMA 5-15 Socket with Toggle Switch

Figure 7 shows a switch that can turn the bottom outlet on or off. The left wider flat blade is the neutral line and the right blade is the AC live line. The voltage on the live contact is measured with respect to the neutral contact, which serves as the zero voltage reference point. Within the U.S., AC live oscillates between ±170 V peak to peak (120V_{rms}) at a frequency of 60Hz. The bottom hole is earth ground which serves as a safety mechanism for devices with metal casings.

Power Conversion

When designing the AC to DC converter for the ESLM, three factors come into play: power consumption, cost, and physical volume of the component. The original idea was buying the RAC04 five volt converter to power up the microcontroller and the two HCPL-750 linear optoisolators. I decided to use the Arduino UNO for the conversion for three reasons: it supplied DC voltages of 3.3 & 5, has built-in libraries that

make compiling code easier, and reduced the total cost of the project. The RAC04 consumes 4 watts of power whereas the Arduino DC supply consumes roughly 0.25 watts.

Software Design

The outputs of the optoisolators were connected to the analog inputs of the Arduino Uno. The Uno has 6 analog inputs, labeled A0 through A5 [6], each of which provide 10 bits of resolution (1024 different values). By default they measure from ground to 5 volts. Voltage measurements were connected to A.0 and current measurements were connected to A.1. Timer 1 was created as an interrupt and set to run every 250 ticks. The ISR's job is the refresh data every time new data occurs.

Since the Uno has a 10 bit resolution, the serial values range from 0 to 1023. The input measurements through the optoisolators are values that are positive and negative, but the Uno can only read positive values. Therefore, the zero reference value as a sine wave is half of the bit values, which is 512. To bring these serial values to numbers we can understand, mathematical functions were compiled in the code.

Voltage & Current Calculations
To calculate the voltage and current measurements, the serial values had to be adjusted to values we can understand. The followings equations were finalized and shown below [18]:

$$V_{line} = 1001 \cdot \frac{0.512}{V_{ref}} \left(V_{out, voltage} - \frac{V_{ref}}{2} \right)$$

Eq. 3

$$I_{line} = 5 \cdot \frac{0.512}{V_{ref}} \left(V_{out, current} - \frac{V_{ref}}{2} \right)$$

Eq. 4

Frequency & kWh Calculations
To calculate frequency, the time of individual 0 voltage crossings are stored. In other words, whenever the serial value crosses 512, it gets store in a variable and the differences are calculated. The frequency samples were averaged over 1 second to reduce error. Kilowatts per hour measurement was calculated by multiplying voltage and current RMS, dividing by 1000 for converting watts to kilowatts, and dividing by 3600 to acquire hours.

Results

The project was successful but during the execution, I stumbled upon few issues that proved challenging to resolve in the allotted time. When trying to measure the current for any load, the voltage drop across the sensing resistor was so small that the Uno doesn't know whether or not a plugged in device was live. The OLED screen would fluctuate it's the current values as well as zero. I used cardboard to build the frame of the ESLM that should have been plastic for safety reasons. Before I test the device, I made sure that all connections were checked and nothing was shorted. To calibrate and test the ELSM, I used a commercial power measuring device Kill-A-Watt to measure power drawn with a 50 W and 100 W light bulb. The results were organized in Table VII and Table VIII.

Table VII: Comparison of a 50 W Bulb

	Electric Smart Load Meter	Kill-A-Watt Meter	Error
Total Power Drawn [W]	46.5	48.0	3.1%
RMS Voltage [V]	122.4	123.1	0.56%
RMS Current [A]	0.38	0.39	7.7%

Table VIII: Comparison of a 100 W Bulb

	Electric Smart Load Meter	Kill-A-Watt Meter	Error
Total Power Drawn [W]	75.6	94.5	20%
RMS Voltage [V]	132.2	119.6	10.5%
RMS Current [A]	0.57	0.79	27.8%

The 50 watt bulb turned out to have better results than the 100 watt bulb. When compiling the code, the noise level of the signals were very high that I had to adjust the math equations. Since I was mostly testing with the 50 watt bulb, I calibrated the measurements based off the lower power bulb. If I were to adjust the measurements towards the high powered bulb, then the 50 watt bulb would become less accurate.

Conclusion

The Electric Smart Load Meter turned out accurate only for one certain load, the 50 W bulb. I originally planned to have the ESLM detect whether a device has been fully charged so that current may be cut off, but that technology is too complicated to build. When adjusting the current measurement, the serial value was relatively close to the zero reference point, 512, causing the OLED screen to display 0 amps frequently. To improve on this project, I would have added an external button for additional features such as power and power factor. The total cost of this prototype did not meet one of the marketing requirement of $40. Overall, I am happy for the results and accuracy of the 50 watt bulb. The ESLM would only be accurate if the rating of any load plugged in is roughly around 50 watts.

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APPENDIX
ANALYSIS OF SENIOR PROJECT DESIGN

Electric Smart Load Meter
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1) Summary of Functional Requirements

The Electric Smart Load Meter measures the voltage and current of any device plugged into the monitor within US parameters of 120V AC 60Hz. It's an easy plug and check and the meter displays the power consumption along with how much it cost an hour if left plugged in. Fully charged devices consume current while being plugged in, slowly degrading the battery over time [5]. The smart meter detects the fully charged device and cuts off the current, reducing power consumption.

2) Primary Constraints

The meter must run using a 120Vac 60Hz input voltage and output 120Vac 60Hz. Creating an AC to DC conversion may potentially be costly and take up a good amount of space. Instead, the Arduino must be powered externally by a 9 volt DC battery supply to allow access for the 5 volts. Using this voltage would power up the linear optoisolators as well as the OLED screen. Since we are dealing with lethal current, the wiring must be checked before plugging in any device.

3) Economic

Manufacturing the Electric Smart Load Meter would create jobs for design engineers and technicians and provide business for industrial companies. People may use less electricity, causing companies like PG&E to make less money. Consumers look at the cost of devices plugged in and possibly reduce the number of devices that need to be plugged to reduce their electricity bill. Profit is highly likely if consumers purchase and use the monitor.

Production of the meter becomes cheaper if mass produced. The manufacturing companies end up making money by producing the components. Hardware stores like Home Depot would sell the product to consumers and gain profit through a mark-up price. The meter contains silicon, gold, copper, aluminum, and PCB boards that requires responsible recycling [6]. The major cost for the project occurs during the software and circuit development. Once the project becomes successful, it's a win-win situation for both the company selling the product and the consumers using it. The consumers reduce their electricity bill in monitoring their power consumption while the producers profit from the consumers purchasing the product [3].

Profit occurs after the second half of the initial round. From there on, an estimated profit of $10 per unit will occur. Figure 1 and table VI describes the inputs and cost of the project. During the design, build, and test stages, money will come out of my pocket to complete the product. Once completed, customers from Home Depot pays for the product.

4) If manufactured on a commercial basis

    a) Estimated number of devices sold per year
        i) Initial rounds of production: approximately 100 units
        ii) Final rounds of production: approximately 1000 units
    b) Estimated manufacturing cost for each device: $30 per unit when bought in bulk
    c) Estimated purchase price for each device: $40 per unit
    d) Estimated profit per year: $10000 for 1,000 units
    e) Estimated cost for user to operate device, per unit time: 1-2 minutes per use

5) Environmental

Using the Electric Smart Load Meter, consumers reduce their electricity bills by decreasing energy consumption. It also decreases the demand for energy which decreases the manufacture of energy, which decreased pollution possibly. At the same time, producing components such as silicon wafers produces toxic chemicals [16], causing hazard to the manufacturing company. The industry may pride itself on its laboratories and its suited workers, but it should be noted that the suits are not designed to protect their wearers from hazardous materials but rather to protect the actual semiconductor products from coming into skin contact.

The meter directly uses electricity. Indirectly, it uses silicon, copper, gold, and aluminum within the device [13]. If consumers use the product successfully, more energy can be used from saving power. On the other hand, producing silicon wafers causes harm from toxic chemicals. A typical facility producing semiconductors on six-inch wafers reportedly uses not only 240,000 kilowatt hours of electricity but also over 2 million gallons of water every day [16].

6) Manufacturability

The main problem would be trying to use the least material in creating all the parts of the ESLM. To produce a "green" product that may potentially save energy, the product itself has to be "green" as well. To keep cost to a minimum, the ESLM will only have one manufacturing company that also tries to save on materials.

7) Sustainability

Manufacturing the ELSM, like any other device, takes up energy and materials and create pollution. The goal is to build the components with possibly biodegradable materials that's cheaper and abundant. If the device is built upon materials that are "green," then consumers will know that the ESLM serves to provide an environmental, friendly product. By reducing consumer's power consumption, this limits the amount of power needed to produce, which significantly increases product sales.

Upgrades such as creating a Wi-Fi module to monitor devices using computers or smart phones would improve the product. Creating a Wi-Fi module requires more components built inside the device, adding more electronic capacity to Earth's pollution and harming the workers producing the components.

8) **Ethical**

Safety for the ESLM include electric isolation for low-voltage chips such as the microprocessor and the optoisolators. If the device is improperly wired, this could potentially injure the consumers, violating IEEE's code of Ethics section one. Before testing the device, I made sure all connections were secured and warned people around to stay clear. All live tests conducted are done with the whole device fully packaged within a box. Devices like the ESLM already exist commercially but partially improved on having a power switch. If the device started smoking, the user can manually turn off the meter.

If the ESLM were to become available to the public, it may potentially reduce the profit of energy companies such as PG&E. At the same time, consumers are using less energy to save money from their electricity bill and provide more energy for others.

9) **Health and Safety**

Standard electrical outlets for commercial and residential have 120Vac 60Hz, which can cause serious harm or death if users misuse the product. Before making the product available, the connections must be examined and checked by an engineer. Worker safety and chemical contamination at chip-making plants has received an increasing amount of attention over the course of the past decade [16]. Because each chip takes dozens of trained personnel several weeks to complete, an enormous amount of time and effort is expended to produce a single wafer.

10) **Social and Political**

California Title 24 states that new or refurbished buildings must turn off standard electrical outlets at times when not in use. The Electrical Smart Load Meter's purpose is to display cost of plugged in devices, informing users to reduce power consumption and ultimately reduce their electrical bill. In reducing power consumption, energy production can also be reduced, lowering the amount of non-renewable resources expended.

The project impacts companies that constantly use energy 24/7. By allowing consumers to see the cost of constant power, they may use less energy, benefiting them with lower cost. Companies like PG&E may lose profit in supplying energy. The only companies that can manufacture components of the ESLM would only be those who follow child labor free and environmental friendly laws.

11) Development

In creating the ESLM, I improved on using C with the Arduino Uno which will be useful in the future in working with tech companies. Creating Gantt charts and citing through IEEE standards helped in making the report professional. Acquiring credible sources was the hardest task because the article may say it's credible, but some have false and misleading cites. I have demoed the project to certain professors and acquired useful criticism. For safety concerns, it was a routine that before plugging in a device, the connections had to be checked in case a wire got disconnected. To improve on this, a PCB should have been implemented instead of a breadboard.

```
/* Name: Johnny Tran
* Final Code for Electric Smart Load Meter
*/

#include <LiquidCrystal.h>
#include <TimerOne.h>

// Assigns the proper pin connections between Arduino and the display
LiquidCrystal lcd(12,11,5,4,3,2);
int sensor, loop_prev = 0, loop_timer = 0, loop_new = 0, period = 0, count = 0,
refreshDisplay = 0, refreshCur = 0, freq = 0, i = 0;
double voltage = 1.0, current = 1.0, low_voltage, high_voltage, low_current = 512,
high_current = 512;

void setup() {
 // Set up the LCD's number of columns and rows
 lcd.begin(20, 4);

 // Print a message to the LCD
 Serial.begin(9600);

 // Initialize Interrup timer
 Timer1.initialize( 1 );
 Timer1.attachInterrupt( timerIsr );
}

void loop()
{
 // Check Frequency
 loop_prev = loop_new;
 loop_new = analogRead(A0);

 if (loop_prev < 512 && loop_new >= 512)
 {
   period = loop_timer;
   loop_timer= 0;
 }

 loop_timer++;
}

void timerIsr()
{
 //Voltage Calculation
 sensor = analogRead(A0);
 double temp = (sensor * 380.0)/1023 - 190;
 low_voltage = (temp < low_voltage)? temp : low_voltage;
 high_voltage = (temp > high_voltage)? temp : high_voltage;
 double voltage_value = temp;

 if(voltage_value > -5 && voltage_value < 5)
 {
   if(++count > 40)
   {
     high_voltage = 0.0;
```

```
      count = 0;
   }
}

//Current Calculations
double subtractValue = 0;
sensor = analogRead(A1);
low_current = (sensor < low_current)? sensor : low_current;
high_current = (sensor > high_current)? sensor : high_current;
subtractValue = ((high_current + low_current) / 2.0);
double curVal = ((high_current - subtractValue) / 1023) * 120;

if(sensor < 525 && sensor > 495)
   curVal = 0.0;

curVal /= ((sqrt(2) * 120.0));

if(++refreshCur > 100000)
{
    refreshCur = 0;
    curVal = 0;
}

if(refreshDisplay > 5000)
{
  lcd.clear();
  refreshDisplay = 0;

  // Print Voltage
  lcd.setCursor(0, 0);
  lcd.print("Voltage: ");

  if(high_voltage < 25)
    lcd.print(0.0);
  else
    lcd.print(high_voltage);
  lcd.print(" V");

  // Print Current
  lcd.setCursor(0, 1);
  lcd.print("Current: ");

  if(high_current < 25)
  {
    curVal = 0;
    high_current = 0;
    lcd.print(0.0);
  }
  else
    lcd.print(curVal, 6);
  lcd.print(" A");

  //Print Frequency
  lcd.setCursor(0, 2);
  lcd.print("Frequency: ");

  if(high_voltage < 25)
    lcd.print(0);
```

```
    else
      lcd.print(freq);
    lcd.print(" Hz");

    //Print kW/h
    lcd.setCursor(0, 3);
    lcd.print("kW/h: ");
    lcd.print(high_voltage * curVal / 1000 / 3600, 8);
  }
}
```