Switch Doctor

ECE4012 Senior Design Project

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Executive Summary

The "Switch Doctor" project was a sponsor project by Hubbell Power Systems. Hubbell designs high voltage substation equipment which includes the substation switches that carries high voltage to manufacturing industries, businesses and to the households. Usually, after storm restoration and during high demands the switches get heated up due to high current flowing through them. At extreme high temperature (above 150 °C), the switch would break down and become non-operational. The team Switch Doctor had designed a temperature sensing device to monitor temperature fluctuation in high voltage substation switches. This device is capable of periodically monitoring and recording the temperature of the switch. The temperature data will be sent through Wi-Fi network to a computer (the receiver) in the utility office that is connected to the same Wi-Fi network as the device. The temperature sensor will prevent the destruction of the switch by notifying the utility office before the switch exceed the extreme temperature and thus prevent the cost of manufacturing the new switches. The second benefit of having a sensor on the switch is for maximizing the efficiency of the substation by regulating the current across the switches depending on the temperatures reading from the sensor. The expected outcome of the device to monitor the temperature of the switches and wirelessly notify the utility office by sending the temperature data, which will prevent the any possible damage to the switch and eliminate the repair cost. The major components used in the design includes a temperature sensor, a thermocouple amplifier, a microcontroller, Wi-Fi board with an antenna, an enclosure box, and a power source with a energy harvesting ICs.

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Self-Powered Wireless Temperature Monitoring Device

1. Introduction

Switch Doctor project is developing a wireless self-powered temperature sensing device under the sponsorship of the Hubbell Power System, with an approximately cost of about four hundred dollars to came up with the final product.

1.1 Objective

The team Switch Doctor is designing a wireless temperature sensing device that periodically detect the temperatures at the switchgear and report the recorded data to the nearby utility office, thereby preventing any maintenance cost due to damages to the switch at high fluctuation on temperature.

1.2 Motivation

The main motivation for the development of the product is a system reliability. With the developments in data and communication technologies, reliability improvements can be achieved through predictive maintenance. By periodically checking the temperature at specific joints on a switch, one can predict the current state of the switch and the grid. If a switch is undergoing overload, the utility company can open the switch before it reaches failure and requires replacement. This product will allow the utility company to provide consistent uninterrupted service to its customers. This predictive system will also save the utility company a large sum of money by cutting down the number of switches that must be replaced and maximize the efficiency of each switch.

1.3 **Background**

The Switch Doctor system is a proactive form of maintenance. The system prevents switch failure through predictive maintenance. With the utility company's ability to redirect power and change loads, the utility company can act when the switch experiences current fluctuations and short time overloads. The utility company can also take advantage of this system by increasing overall loads where the switch factor is high enough to permit additional excess load. Phase IV has a product that can produce the same results; however, it only has temperature sensing capabilities of -40 ℃ to 125 ℃. While this may seem like a small problem, the design is also only able to survive electrical conductors operating up to 15KV [7]. The key components in the design includes a Type K Thermocouple sensor, a MAX 3855 thermocouple amplifier, a MSP430G2 microcontroller, CC3100 wifi board with an antenna, an Aluminum enclosure box, and a power source (PV Cell) with a energy harvesting S6AE101A0DGNAB000 ICs.

2. Project Description and Goals

The goal of the Switch Doctor team was to design a temperature sensing system that can monitor the temperature of the switches at high voltage power substations. The purpose of the device is to prevent the potential damage to the switchgear due to high-temperature fluctuations during the restoration and during high demand after restoration high demand. Some of the key features of our design are listed below.

- Real-time temperature data monitoring using the thermocouple sensor.
- Delivery of recorded temperature via CC3100 module with a duration of 10 minutes.

- The sensor system will be composed of a Type K Thermocouple sensor.
- Amplifier MAX31855 Breakout Board, an MSP430G2 Microcontroller.
- CC3100 Wi-Fi module with a corona ring around its antenna.
- A powering system includes PV cell, supercapacitor, and energy harvesting ICs.

3. Technical Specifications & Verification

The technical specifications of the various components that are integrated in the design is tabulated below.

3.1 Type K Thermocouple Sensor

Table 1. Specifications of the Type K Thermocouple

Design Requirements	Specifications
Thermocouple grade wire	-454° to 2,300°F (-270 to 1,260°C)
Extension grade wire	-32° to 392°F (0 to 200°C)
Measurement accuracy	Standard: ± 2.2C% or ±.75%
Special Limits of Error	± 1.1 C or 0.4%

3.2 Thermocouple Amplifier MAX31855 Breakout Board

Table 2. Specifications of the MAX31855 breakout Board

Design Requirements	Specifications
adaptability	It can work well with Type K Thermocouple
Accuracy	± 2° C to ± 6° C
Temperature range	-454° to -1350°
Supply power Range	0.3 V – 5 V

3.3 **MSP-EXP430G2 Microcontroller**

Table 3. Specifications of the MSP-EXP430G2 microcontroller	
Microcontroller Design Requirements	Specifications
Interrupt Service Routine Timer	Once every 10 minutes
RAM Memory	512 bytes
Flash Memory	16 kB
Input Voltage	1.8 V- 3.6 V

3.4 **CC3100 Wi-Fi Board**

Table 4. Specifications and design parameters of Wifi module	
Design parameters	**Specifications**
Protocol	TCP/IP stack
Supply Voltage	2.1 V to 3.6 V
Ambient Temperature Range	-40°C to +85 °C
Low-Power Deep Sleep (LPDS)	115 µA
Communication	Powerful Crypto Engine for Fast, Secure Wi-Fi and Internet Connections with 256-Bit)
Dimensions	Length = 367 mm, Width = 387 mm, Height = 38 mm
Operating frequency	2.5 GHz

3.5 Energy Storage and Harvesting

Table 5. PCAP0050 P230 S01 Nesscap Supercapacitor	
Rated Voltage	2.3 VDC
Surge Voltage	2.5 VDC
Rated Capacitance	50 F
Initial DC-ESR	36 mΩ
Maximum Leakage Current	76 µA
Projected DC Life at Room Temperature	10 years

Table 6. TSP63805 High Current, High Efficiency Single Inductor Buck-Boost Converter	
Vin	1.3-5.5 V
Vout	1.8-5.5 V
Peak Reverse Current at Vin=3.6 V and Vout=3.3 V	-0.9 A
Thermal Shutdown	150 ℃

Table 7: FYD-004 Solar Panel	
Cell Type	Monocrystalline
Cell Efficiency	16%
Max Output Power	1.5Wp
Voltage at Max Power	2.2 V
Current at Max Power	0.68 A
Panel Dimension	100x100x2.5mm

4. Design Approach and Details

4.1 Design Approach

The team Doctor Switch begin with a team effort to find a solution to an existing problem that Hubbell have been encountering with their high voltage switches. Since our project is not a continuation of an existing projects, the team had begun from scratch to come up with a temperature sensing device as a solution to the problem. After several hours of brainstorming and joint team research, the team come up with a design approach that used about six or more pieces of building blocks to begin the design. The key building blocks consists of a Type K Thermocouple sensor, a MAX 3855 thermocouple amplifier, a MSP430G2 microcontroller, CC3100 Wi-Fi board with an antenna, an Aluminum enclosure box, and a power source (PV Cell) with energy harvesting (S6AE101A0DGNAB000) ICs. The design approach can be understood in more detail by observing the design topology in **figure 1.**

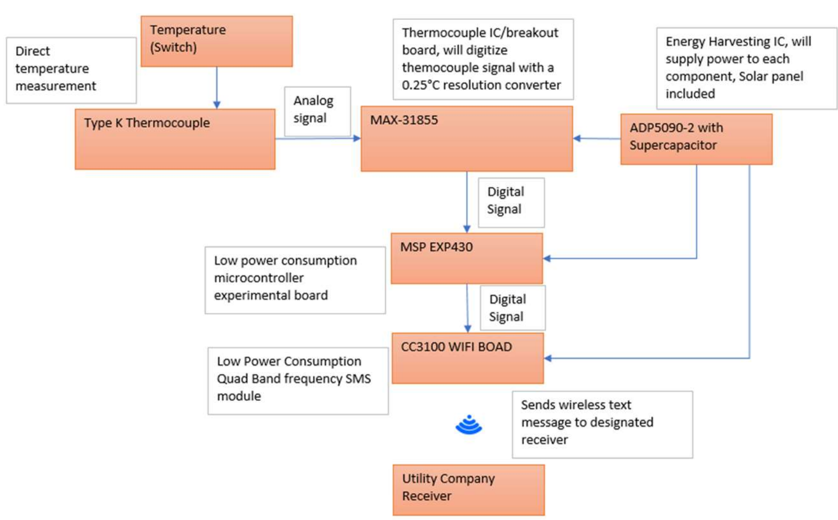

Figure 1. The overall topology of the sensing device

As shown in the design topology above, the type K Thermocouple Sensor is in direct contact with the switchgear arm and can detect the heat signal of the switch. A sensor works on the principle of Thermo Effect, which states that when the junction of the thermocouple is exposed to a Temperature gradient, a voltage proportional to the temperature is observed at the other end between the two metals [3] as shown above in **figure 2.** These voltages observed is usually on the order of microvolts (an analog signal) which is amplified using the thermocouple amplifier board (MAX-31855).

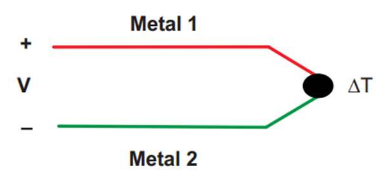

Figure 2. Type K thermocouple works in Thermo Effect Principle (ΔT→Heat source)

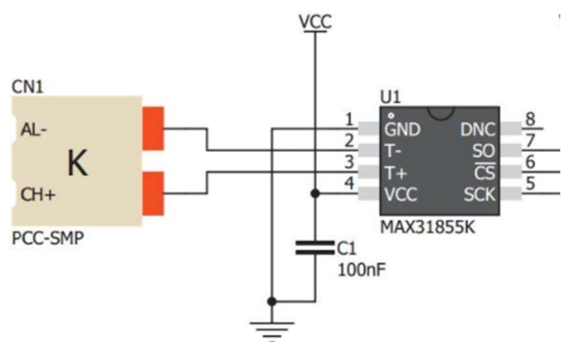

Figure 3. Connection of thermocouple type to MAX31855 board.

As seen on the **figure 3** above, the two outputs of the type K thermocouple will be inserted to the pin two and pin three of the MAX31855 Breakout Board. The negative temperature is connected to pin two and the positive temperature is connected to pin three. The difference of the input temperature will interface with the MSP-EXP430G2 microcontroller [2]. It compensated Thermocouple-to-Digital Converters perform cold-junction compensation and digitize the signal from the type K thermocouple described above. The output of the MAX31855 will be connected to the MSP-EXP430G2 microcontroller through pins five, six and seven. Pin five (SCK) describes the Serial-Clock Input the clock of the MSP-EXP430G2 microcontroller, Pin six (CS) describes the Active-low Chip select. Setting MAX31855 to the CS mode will enable it to interface with the MSP-EXP430G2 microcontroller. Pin seven (SO) is the Serial-Data Output of MAX31855 [4].

The team used the MSP-EXP430G2 Microcontroller made by Texas Instruments. This microcontroller is a 16-bit microcontroller that is designed for consumption of ultra-low power levels. The microcontroller read input values from amplifier board the convert the values to digital temperature readings that can be displayed in an LCD display or transmitted to the utility office using the Wi-Fi network [6].

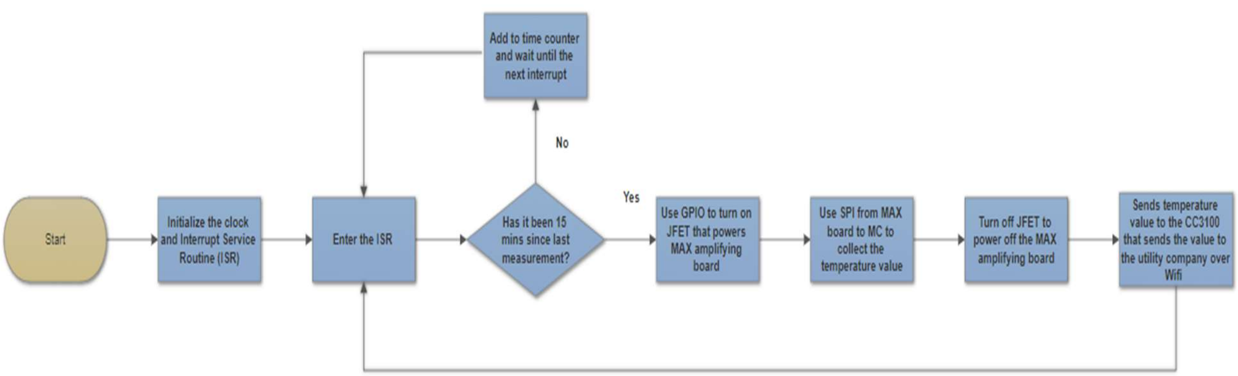

Figure 4. Logic flowchart for microcontroller

As shown in the **figure 4**, microcontroller enter the interrupt service routine (ISR) every fifteen minutes by setting the clock frequency from the oscillation frequency and the ISR frequency is set by the clock frequency. The microcontroller will extract the digital signal from the MAX31855 at a rate of the ISR frequency. The measured value from the MAX31855 will be converted to a current value inside of the timer ISR. Finally, the ISR will transfer the current data to the Wi-Fi module connected to the board. This part of the design project is essential to the success of the project because the microcontroller reads in values taken from the thermocouple and gives the Wi-Fi module a digital temperature signal that can be transmitted. The internal connection of the overall design is shown in the circuit diagram in **figure 5** below.

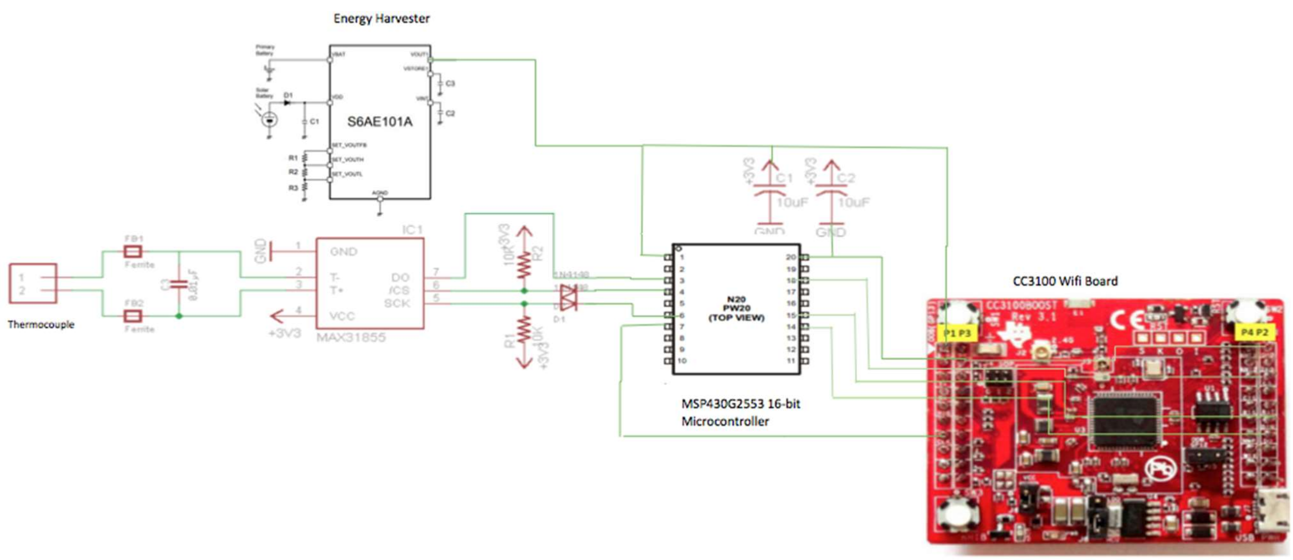

Figure 5. The overall circuit diagram of the design

The design team had used the CC3100 Wi-Fi Breadboard, which use 802.11 protocols for Wi-Fi and Internet, which greatly minimizes host MCU software requirements. This subsystem enables low-power consumption modes, such as the hibernate with RTC mode requiring about 4 µA of current. The CC3100 device can connect to any 8, 16, or 32-bit MCU over the SPI or UART Interface, thus it was suitable for the microcontroller that we have used. The device driver minimizes the host memory footprint requirements requiring less than 7KB of code memory and 700 B of RAM memory for a TCP client application.

As shown in the **figure 5** above, the CC3100 Wi-Fi breadboard can the take the digital temperature output and send those data to the computer in the utility office connected on the same Wi-Fi network. However, the team encountered server-clients connection error while implementing Wi-Fi functionality and hence used the LCD Screen display to show the temperature reading during the demo.

As a power source the team had used a PV cell to observe the energy from the sun which stored the energy in the super capacitor equipped with an energy harvesting ICs. The microcontroller works as a distributed power system that powers all the other functionalities of the system; however, the MSP-EXP430G2 microcontroller must first receive power. Through a three-step process, energy can be environmentally harvested and transferred into the MSP-EXP430G2 microcontroller. First, the energy must be harvested from the sun using Photovoltaic cells. Small solar cells are very low power, delivering milliwatts of energy; therefore, as much of it must be stored [5]. The FYD-004 can deliver a max output voltage of 2.2V and max current of 0.68A; however, these values are under ideal conditions. The PCAP0050-P230-S01 super capacitor can store any energy that is harvested by the solar panels and discharges periodically when the MSP-EXP430G2 microcontroller needs to be powered. Lastly, a buck-boost converter must be used to deliver a constant voltage into the super capacitor from the solar panel due the irregularity of the energy harvested. **Figure 6** shows the circuit necessary to connect all three components [9].

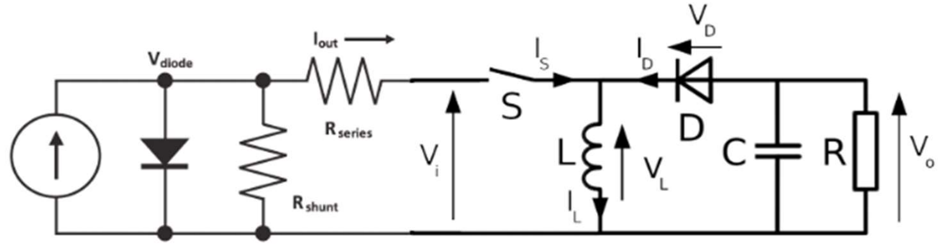

Figure 6. Connectivity of PV, Converter, and Supercapacitor

4.1.5 Mounting and Protection Device

The team used an aluminum watertight enclosure box of size 4 ¾" x 4 ¾" x 4" to adopt to the harsh environment and to provide safety to the internal components. The enclosure box would also prevent the internal components from the external influence due to electric and magnetic field. The thermal conductivity of aluminum and its alloys is 88 to 251 W/m K, or 164 Btu (h ft F), which increases with increase in temperature. Therefore, the internal components are placed into a three-layer temperature resistant case design by the team as shown in **figure 7** below.

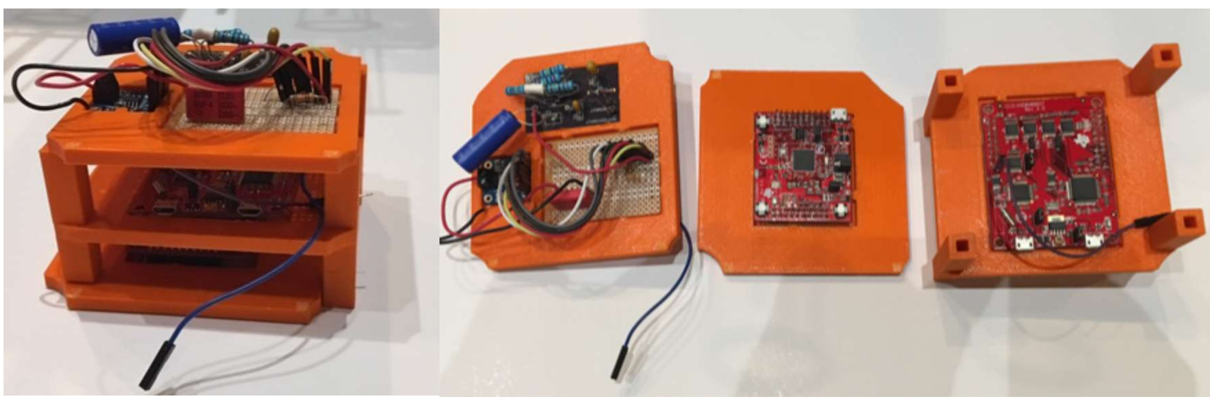

Figure 7. Three-layer case design to assemble the internal components

These high temperatures resistant case was design to prevents the direct contact of the components on the internal surface of enclosure box. The case was expected to ensure additional safe by preventing unnecessary heat flowing into the components. The team had used a Square U-Bolt made of Stainless Steel with internal dimension of (4" X 6 5/8") to clamp device onto the switchgear arm. The Square U-bolt was routed along the enclosure with its inside width of 4" that corresponding with the size of the depth of the enclosure i.e. 4". The mounting was done such way that thermocouple sensor will be in contact with the hot surface, the antenna will be on the opposite side, and the PV cell will be on the top surface. An illustration of the mounting on the switch arm is shown on **Figure 8** below.

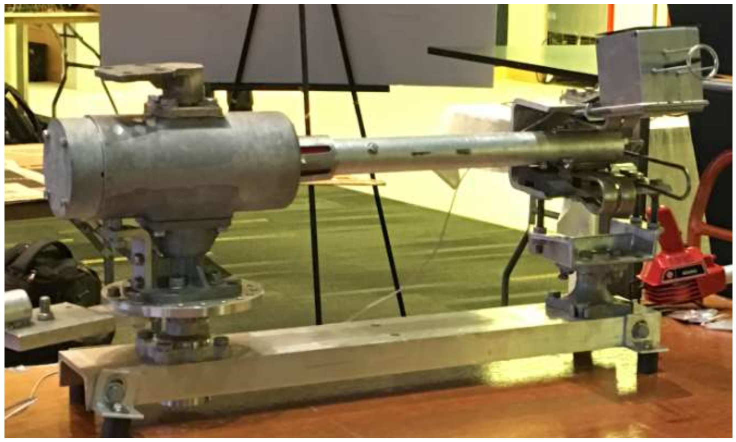

Figure 8. Enclosure box mounted on the switchgear

Our design uses the Wi-Fi network for communicating the temperature data to the utility office. Thus, the team drill a hole on the enclosure box to stick the antenna for communication using the Wi-Fi. In order to reduce the attenuation of the signal on the antenna due to high electric field the team had used the corona ring to reduce the electric field effect on the antenna. The corona ring is composed of 3 zinc threaded rods (5" length) were connected to a ¼" x 1-½" zinc ring. The role of the corona ring is to distribute the electric field gradient and lower its maximum values below the corona threshold as shown in **figure 9**.

Figure 9. Corona ring used to distribute the electric field.

4.2 Codes and Standards Reference

MSP-EXP430G2 MCU features:

- USB debugging and programming interface featuring a driverless installation and application UART serial communication with up to 9600 Baud.
- Supports MSP430G2xx2, MSP430G2xx3, and MSP430F20xx devices in PDIP14 or PDIP20 packages.
- Two general-purpose digital I/O pins connected to green and red LEDs for visual feedback.
- Two push buttons for user feedback and device reset.
- Easily accessible device pins for debugging purposes or as socket for adding customized extension boards.
- High-quality 20-pin DIP socket for an easy plug-in or removal of the target device

Hardware that control and limit the development of MSP-EXP430G2

- LaunchPad emulator socket board (MSP-EXP430G2)
- Mini USB-B cable, 0.5 m
- Two MSP430 flash-based MCUs
- MSP430G2553: Low-power 16-bit MSP430 microcontroller with an 8-channel 10-bit ADC, on-chip comparator, touch-sense enabled I/Os, universal serial communication interface, 16kB flash memory, and 512 bytes of RAM (preloaded with a sample program)
- Two 10-pin PCB connectors female
- 32.768-kHz clock crystal from Micro Crystal

CC3100 Wi-Fi features:

- CC3100 SimpleLink Wi-Fi Consists of Wi-Fi Network Processor and Power-Management Subsystems
- Wi-Fi CERTIFIED™ Chip
- Wi-Fi Network Processor Subsystem
- Featuring Wi-Fi Internet-On-a-Chip™
- Integrated DC-DC Supports a Wide Range of Supply Voltage:
  - VBAT Wide-Voltage Mode: 2.1 to 3.6 V
  - Pre-regulated 1.85-V Mode
- Advanced Low-Power Modes
- Package and Operating Temperature 0.5-mm Pitch, 64-Pin, 9-mm × 9-mm QFN
- Ambient Temperature Range: –40°C to 85°C

TCP/IP Stack

There are several factors that limits design processes. The microcontroller memory download speed, and upload speed will limit amount of information is being transmitted in each time. The device can only function in the certain temperature range that will affect the design decision, which will be used during the very severe temperature range.

4.3 Constraints, Alternatives, and Tradeoffs

As we finalize our design topology, we came across some alternatives and possible tradeoffs for each component choice. For instance, there are four different choices available for the selection of sensing devices such as a thermocouple, thermistors, resistance temperature detectors (RTD), integrated circuit (IC) sensors. However, due to the temperature constraints and requirements to work under high electric and magnetic field, we decided to use type K

Thermocouple sensor for our design. Compared to other sensors, the type K is nickel-based and exhibit good corrosion resistance in adverse weather conditions. It is the most common sensor calibration type which provides a wider temperature range reaching up to 1260°C and was the best fits for our design.

The Adafruit MAX31855 Thermocouple Amplifier breakout board using one of the

Serial Peripheral Interface Buses (SPI) available on the Electric Imp. Then we will connect a K-type thermocouple and send the data to SMS module. Compare to The AD8495 K-type thermocouple amplifier from Analog Devices is so easy to use. Power the board with 3-18VDC and measure the output voltage on the OUT pin. You can easily convert the voltage to temperature with the following equation: Temperature = (Vout - 1.25) / 0.005 V. So, for example, if the voltage is 1.5VDC, the temperature is (1.5 - 1.25) / 0.005 = 50°C Thermocouples are very sensitive, requiring a good amplifier with a cold-compensation reference. It can have a couple digital thermocouple amplifiers in the shop already from Maxim. Now we're happy to introduce an excellent analog-output amplifier. This is a very simple sensor to use, and if your microcontroller has analog input capability, you'll be ready to go fast.

The 16-bit MSP-EXP430G2 Microcontroller used was the basic microcontroller compared to the 32-bit microcontroller. The 32-bit controller comes with a faster clock, more pins, more peripherals, and more memory. All these tradeoffs are beneficial to have in a controller but are not used for our design. The controller will only take data once every ten minutes which means the clock speed on the controller will be more than enough to take the needed measurements. The additional pins and peripherals are not necessary for this project since team will have minimal connections to the board and don't need any additional features included. The addition of more memory will not be necessary either because there is not much memory space will be needed, and the temperature can be truncated to an integer without any large ramifications. The main two points of interest when choosing the best microcontroller were cost and power consumption. The team's microcontroller MSP-EXP430G2 is specifically designed for ultra-low power consumption that easily beats the 32-bit microcontroller power consumption because of the extra features and peripherals included. The 8-bit controller option offers comparable power consumption options to the 16-bit controller but not a large discrepancy. The problem with the 8-bit controller would be manually assembling the chip onto a board and creating the microcontroller configuration to obtain the ultra-low power feature. The cost of the 16-bit microcontroller used had met all the basic requirements the team needs, while being cheap and requires no assembly of the microcontroller.

The CC3100 Wi-Fi Board device integrates all protocols for Wi-Fi and internet, which greatly minimizes host MCU software requirements. With built-in security protocols, the CC3100 solution provides a robust and simple security experience. Additionally, the CC3100 device is a complete platform solution including various tools and software, sample applications, user and programming guides. Thus, the team had chosen to use CC3100 as a Wi-Fi board for the design. However, the team fail to establish commination network using this device and use the alternative LCD display to show the temperature data during the demo.

A lithium Ion battery pack could have been used to store any energy harvested by the solar panels and could have delivered the power needed to power the microcontroller and other components; however, lithium ions use chemicals to store energy. Storing energy with chemicals causes reliability issues, because the constant change in temperature and the high temperature would negatively affect the overall performance of the battery. The use of chemicals also shortens the lifespan, because a capacitor does not use any chemicals, but it used plates to store energy, they have a longer lifespan. Batteries also have a larger environmental impact when being disposed of. Thermal energy harvesting was a possibility for powering the system due to the abundance of heat being radiated by the substation. Thermal energy harvesting however are relatively expensive and have a low energy conversion efficiency. In places where winters are very cold and last a long time, this system would not help power the system.

5. Schedule, Tasks, and Milestones

The Doctor Switch team will be designing and implementing this prototype over next three months. The Gantt chart in **Appendix A** shows the tasks that must be completed. The chart contains number of days that requires to complete each tasks (duration), start date, end date, and associated timeline. The critical path shows difficult parts of the project because all team members do not have experience in those areas.

6. Final Project Demonstration

Our sponsor "Hubbell" had delivered an actual piece of switch that was used by the team in the final demonstration. However, we did not have an actual high voltage power source to deliver the current through the switchgear during the demonstration. Thus, as an alternative the team used a heat gun to heat up the sensor while demonstrating the temperature fluctuation in the switchgear. As described in the technical part, the sensor detected the heat signal and output the analog signal which is a variation in voltage. The analog signal was amplified using the thermocouple amplifier board (MAX-31855). The amplifier breakout board passed a digital signal into the Microcontroller. The team had encountered server-clients connection error while implementing the Wi-Fi functionality and wasn't able to demonstrate the data transmission using the Wi-Fi network. Thus, as an alternative an LCD Screen display was used to show the temperature reading during the demonstration. The recorded temperature fluctuation from 150°F to 254°F during the demonstration shown in the **Figure 10** below.

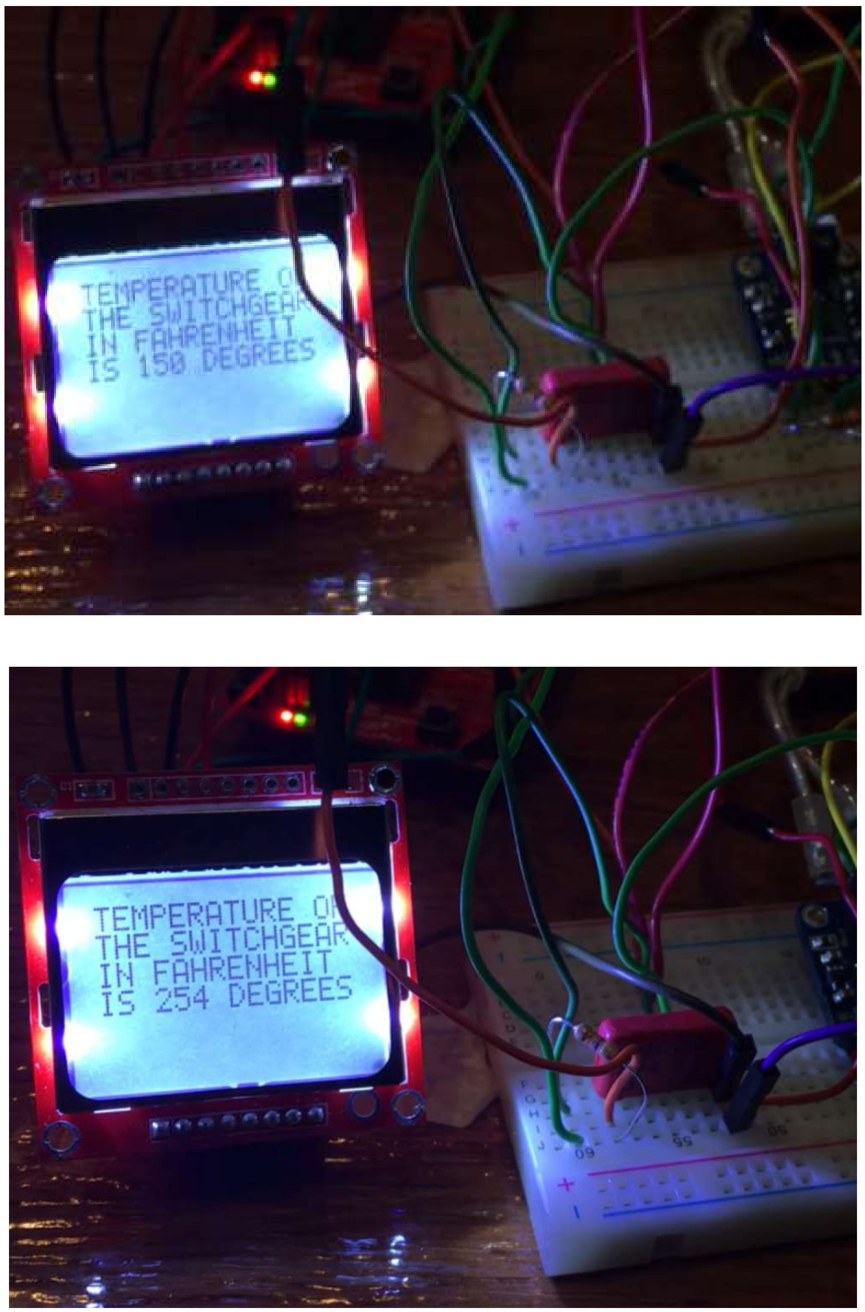

Figure 10 . LCD displaying temperature fluctuation during the demonstration

There are few things that the team did not achieved as proposed. This digital temperature data that was displayed above in the LCD display was supposed to be transmitted to utility office's computer using Wi-Fi network. The team encountered server-clients connection error while implementing Wi-Fi functionality. Thus, the team wasn't been able to demonstrate the data transferred feature using the Wi-Fi network. Therefore, as an alternative the team used the LCD Screen display the temperature reading during the demonstration. The setup for the final demonstration is shown in the **figure 11** below.

Figure 11. The device setup in the final demonstration

The team was able to successfully demonstrate most of the tasks as proposed in the design solution other than the Wi-Fi functionality. Among some other task, the device clamping task had been quite challenging for the team during the design process. However, it somehow worked out very well as you could see in the demonstration setup. The team had drilled the hole on the enclosure box to make sure that the thermocouple sensor was in direct contact with the switchgear arm when mounting the device. This was done reduced the heat loss and hence to achieve the temperature data with high accuracy. The Wi-Fi antenna aligned on the opposite face of the enclosure box as the sensor and the PV cell lay on top of the enclosure as shown in the **figure 12** below.

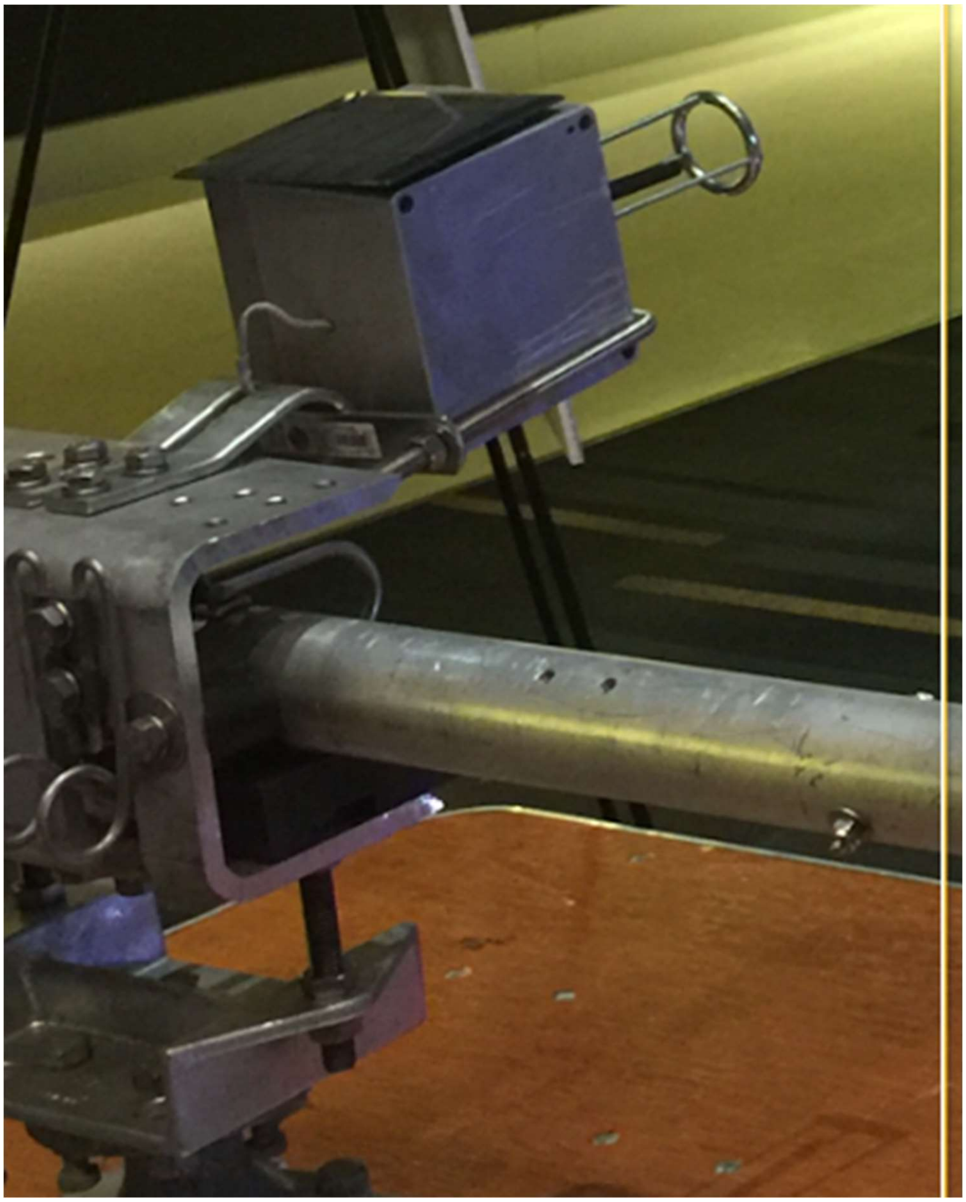

Figure 10. Contact of the thermocouple with the surface of switch.

7. Marketing and Cost Analysis

7.1 Marketing Analysis

As we look at the marketing aspect of the device, we can conclude that the device could have multiple application. Even though, this device was initially design for preventing the damage of the substation switch, it can be used in monitoring the temperature of machineries in manufacturing industries and many more. For instance, we have witnessed cars caught on fires on the highway. We could attach our device to the engine of vehicles to monitor the temperature and alert the driver before it caught fire.

7.2 Cost Analysis

The detail analysis based on the labor charge is analyzed in detail here under. The cost associated on the purchase of the components that are used in the design is tabulated below.

Supplier	Part#	Manufacturer #	Description	Qty	Price
Digi-Key	E52-CA1GTY 2M	Z3795-ND	K - Type Temperature Sensor 0 ~ 300°C Grounded Exposed Lead Wires, Crimping Terminals	1	$ 81.90
Digi-Key	1528-1000-ND	269	MAX31855 Thermal Management Power Management Evaluation Board	1	$29.90
Mouser	595-MSP-EXP430G2	MSP-EXP430G2	Development Boards & Kits - MSP430 MSP430 Value Line LaunchPad Dev Kit	1	$10.37

Mouser	80-FG0V155ZF	FG0V155ZF	Supercapacitors 3.5V 1.5F -20/+80% LS=5.08mm	1	$3.72
Analog Devices	ADP5090-2-EV	EVAL-ADP5090-2	Evaluation Board	1	$49.00
Mouser	581-SCCS30E106SRB	SCCS30E106SRB	Supercapacitors / Ultracapacitors 3V 10F ESR50mOhms 10x30mm Radial Leads	1	$3.49
Mouser	538-47950-2011	47950-2011	Antennas WIFI 2.4/5G ANTENNA 16*200MM ASSY	1	$4.03
Digi-Key	1927-1052-ND	3605	5.0V 200MA Polycrystalline Solar	1	$26.71
National Hardware	None	#2191	National Hardware N222-406 2192 Square U Bolts in Zinc, #677-3/8"x4"x7"	1	$6.71
Amazon	none	none	GE 100% Silicone is 100% waterproof and 100% weatherproof.	1	$4.79

The doctor switch consists of five brilliant engineers who had real commitment to the accomplishment of the project with a some-level of satisfaction. The breakdown of the Doctor Power engineers is included in Table 9.

Table 9. Development hours per engineer

Item	**Hours**
Class	30
Weekly Meetings	13
Reports	18

research	7
Presentation	1
Fabrication	10
Assembly	9
Testing	7
Total	**95**

Assuming an annual salary of $60,000 for each Doctor Switch engineer, Table x shows how the total are obtained. Ninety-five hours for five engineers' totals to $13,701 according to table 10.

$60000/52 weeks = $1153.84	$1153.84/40 hours =$28.84 which is the hourly rate for each engineer	$28.84 * 5 engineers =$144.23
95 hours of labor is	144.23*95 = **$13701.9**	

Table 10. Total Development Cost	
Development Component	**Cost**
Cables/Wires	$20
Power Supply	$10
Shielding	$40
Parts	$141.81
Labor	$13071.9
Fringe Benefits, % of Labor	$100
Total	$13293

The weekly profit of Doctor Power is presented on table 6. If ten units cost $120 to Doctor Power every day ($840 weekly) and a 10% discount if the customer buys in bulk ($798 weekly). Adding a sale expense of $90, will lead Doctor Power sell the un bb bit at least $500 to make up the margin and double the benefit. A 50% profit will be the result of the daily transaction.

Table 11. Doctor Power Weekly Profit	
Expense & Income	**Dollar Amount**
Parts Cost	$120
Assembly labor	$30
Testing Labor	$40
Subtotal	$190
Sales Expenses	$90
Profit	$290
Selling price	$500

8. Conclusion

The team was able to successfully demonstrate most of the tasks as proposed in the design solution. The only task that the team did not achieved as proposed was the data transmission using the Wi-Fi network. As explained in the demonstration part, the team encountered server-clients connection error while implementing Wi-Fi functionality. As a result, the team wasn't been able to demonstrate the data transferred feature using the Wi-Fi network. However, if we must take this project into next level, we need about two weeks of deadline to fix the Wi-Fi connection issue. Other than that, the team had successfully demonstrated the other functionality as proposed in the design solution. Hence, the design can be considered as a successful project.

9. Leadership Roles

Each of the five team members on the Doctor Power team are responsible for one or two leadership roles for the design project. Fabrizzio was responsible for scheduling. His roles include scheduling the weekly meeting with Hubbell and also played a key role in the poster design. Ryan was design project coordinator and was responsible for documenting the project. He played a key role in documenting and preparing the final report. Habtamu had played the key role as webmaster. His leadership role was mainly focused in the website design and mechanical design of the project. Mamadou was the team's lead researcher. He was also responsible for setting deadlines for each team members progress to keep the team on a prompt timeline. He focus on getting the task completion toward the end of the project deadline. Derek's leadership role was mainly focus on the coding part of the project. He had taken a leading role in coding and assigning duties to team members role to the team members.

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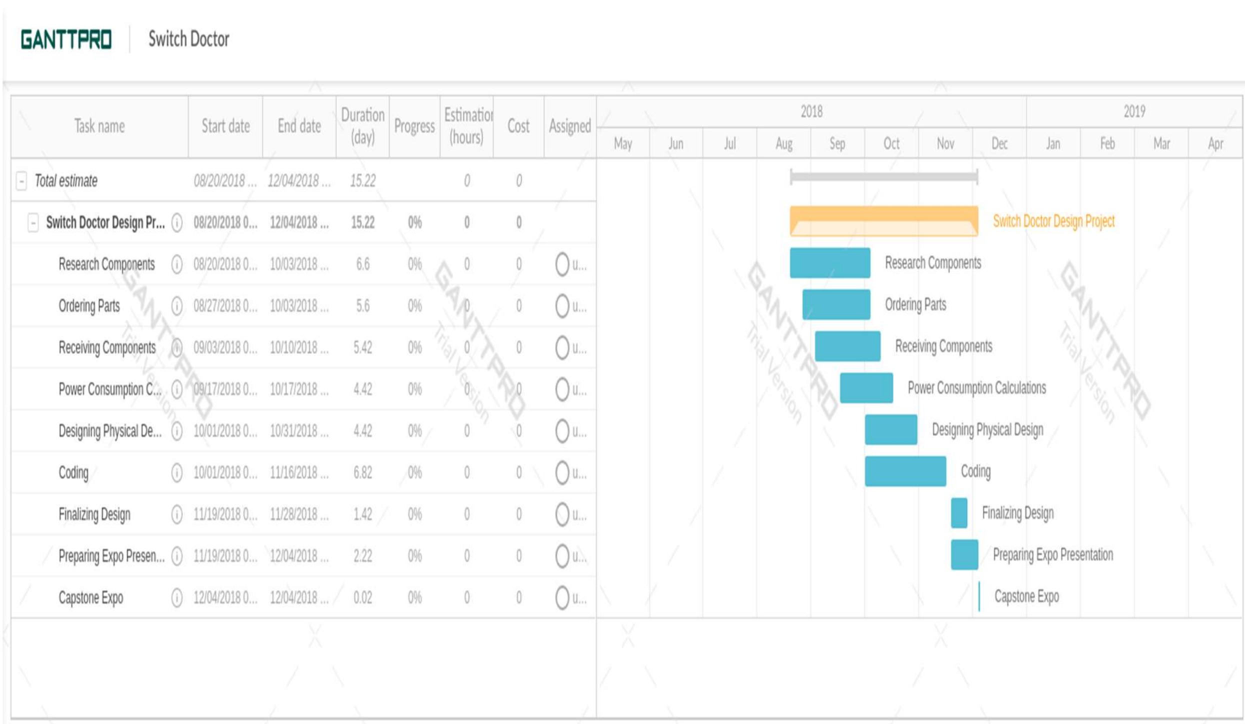
Appendix A


GANTTPRO
Switch Doctor
Task name
Start date
End date
Duration (day)
Progress
Estimation (hours)
Cost
Assigned
2018
2019
May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr
Total estimate 08/20/2018 ... 12/04/2018 ... 15.22 0 0
Switch Doctor Design Pr... 08/20/2018 0... 12/04/2018 ... 15.22 0% 0 0
Research Components 08/20/2018 0... 10/03/2018 ... 6.6 0% 0 0
Ordering Parts 08/27/2018 0... 10/03/2018 ... 5.6 0% 0 0
Receiving Components 09/03/2018 0... 10/10/2018 ... 5.42 0% 0 0
Power Consumption C... 09/17/2018 0... 10/17/2018 ... 4.42 0% 0 0
Designing Physical De... 10/01/2018 0... 10/31/2018 ... 4.42 0% 0 0
Coding 10/01/2018 0... 11/16/2018 ... 6.82 0% 0 0
Finalizing Design 11/19/2018 0... 11/28/2018 ... 1.42 0% 0 0
Preparing Expo Presen... 11/19/2018 0... 12/04/2018 ... 2.22 0% 0 0
Capstone Expo 12/04/2018 0... 12/04/2018 ... 0.02 0% 0 0
Switch Doctor Design Project
Research Components
Ordering Parts
Receiving Components
Power Consumption Calculations
Designing Physical Design
Coding
Finalizing Design
Preparing Expo Presentation
Capstone Expo
GANTTPRO Trial Version