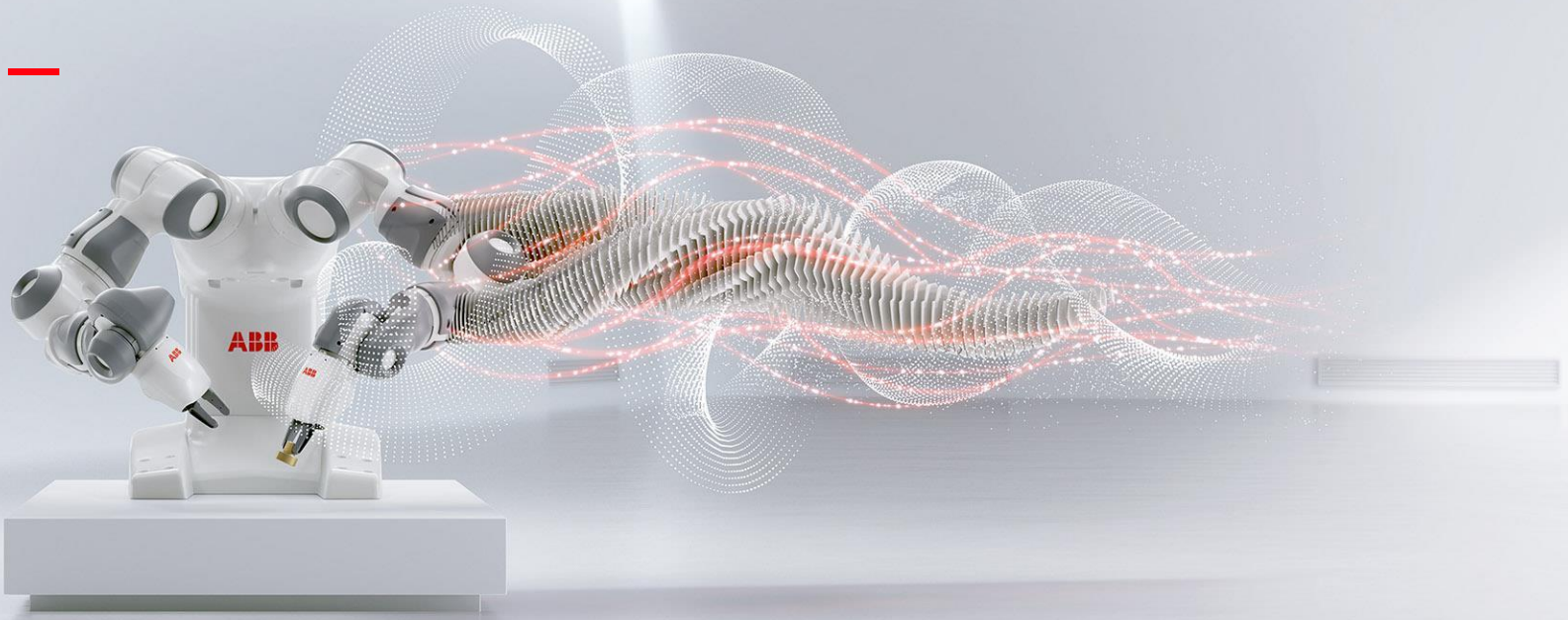


Switchgear System Control Interface

Control System for Circuit Breaker Compartment Motorized Track

EE/CpE Senior Design Group 14: Christopher Miller, Huy Tran, Michael Dean

Overview

- Objectives
- Specifications
- Design overview
- Basic Controller
- Control Board
- Advanced Controller
- Software Design

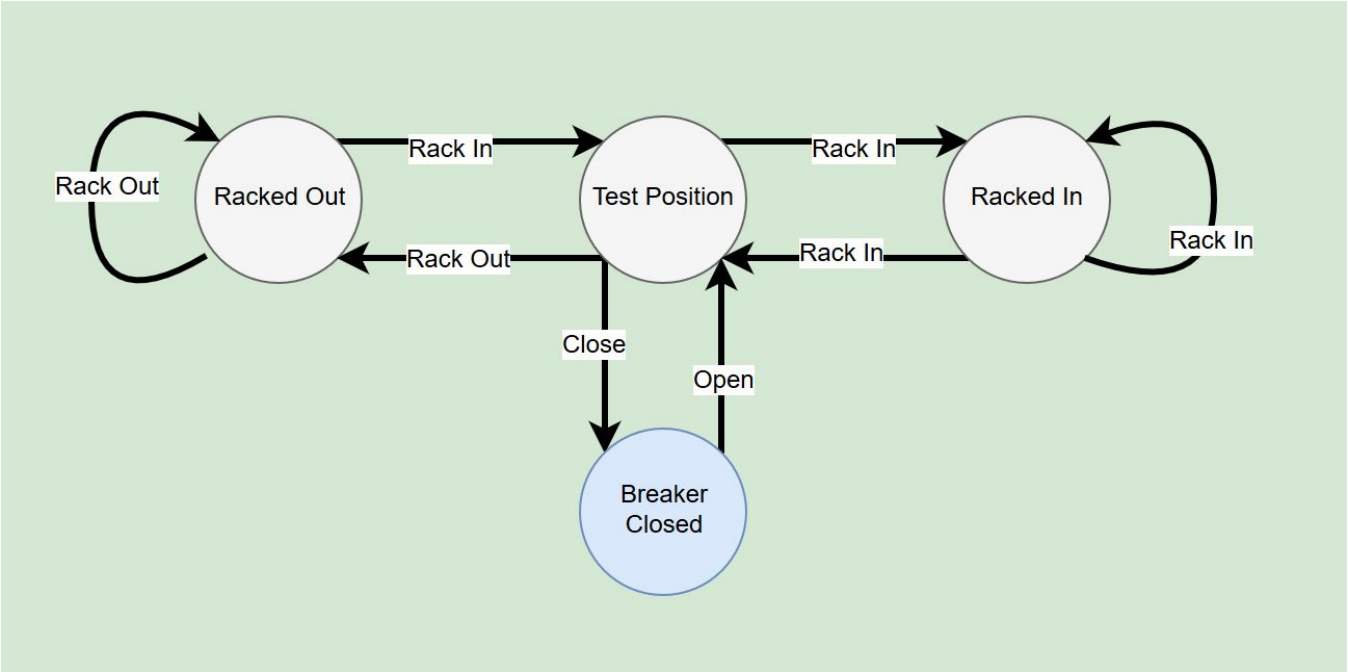
Objectives

- Produce two remote control interfaces:
  - Basic controller:
    - Hand held controller with button to adjust the position of racking system
    - Indicates information to the user with LEDs
  - Advanced controller:
    - Software based controller that allows the manipulation of single and/or multiple switchgear systems
    - Can give the user a more detailed view of the switchgear

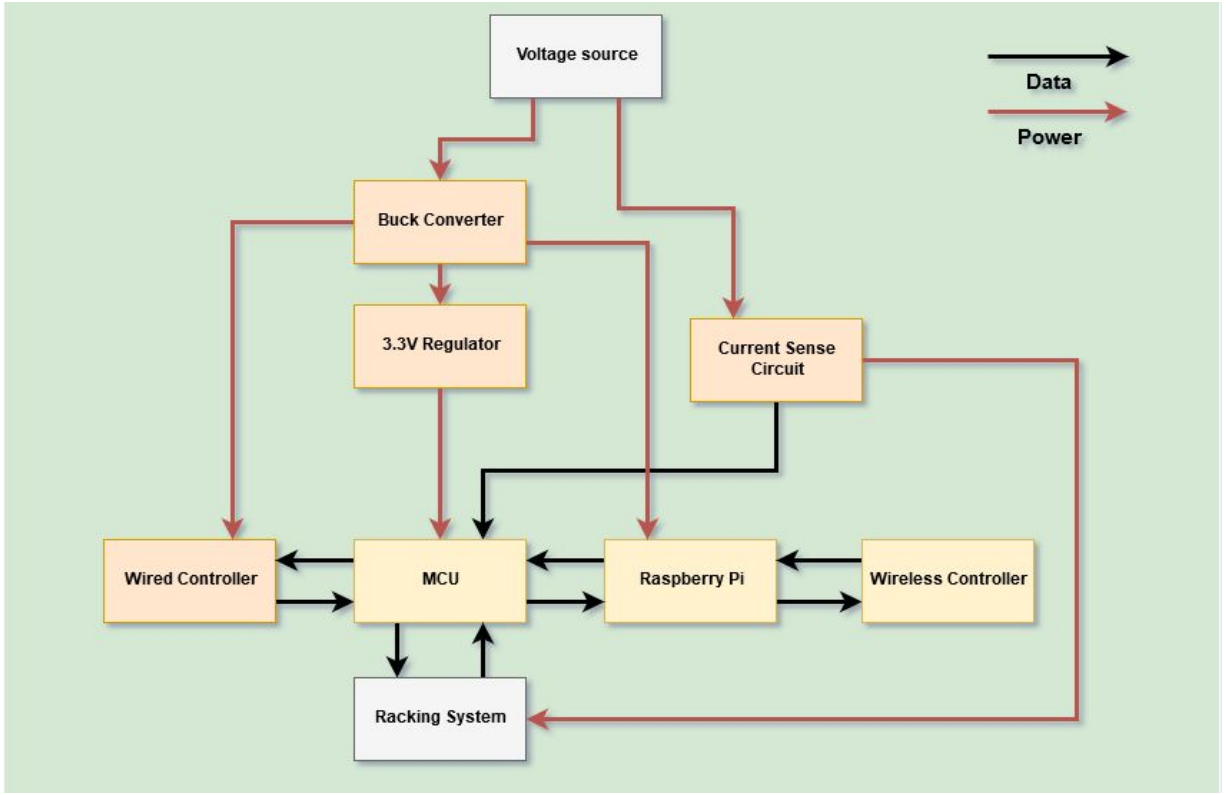
Specifications

Component	Parameter	Specification
Wired controller	Wire length	25-50 ft
Wired controller	Output	6 LEDs
Wired controller	Input	5 buttons
Wired controller	Overcurrent option	Can choose to either reverse or stop when overcurrent is active
Wire	Type	RJ45 connector
Software application	Usability	Scalable to large number of racking systems
Software application	Usability	Logs all commands sent to the racking system
Software application	Usability	Windows based

Circuit Breaker Racking System - States



Block Diagram



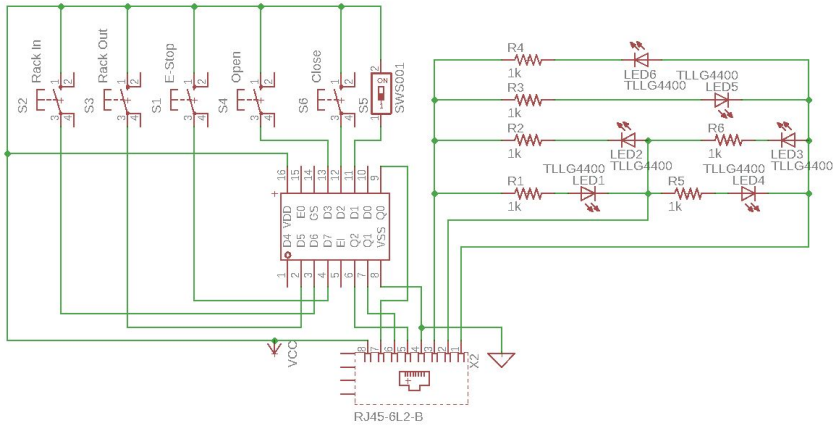
Basic Controller - Overview

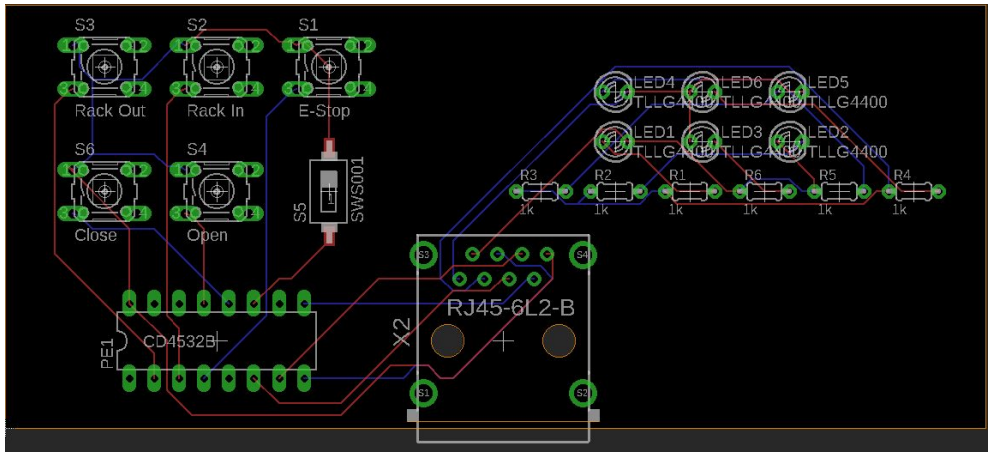
- Input: 5 buttons and 1 switch
- Buttons: Rack in, Rack out, Emergency stop, Open breaker, Close breaker
- Switch: overcurrent option (reverse/stop)
- Output: 6 LED’s
- Racked in position, test position, racked out position, breaker closed, in motion, and Emergency stop
- RJ45 8 pin cable to connect hand held controller with control board

Advanced Controller - Overview

- A GUI that shows a high level view of all the switchgears and racking systems that have the control board installed
- The advantage of this controller over the basic wired controller is that it’s wireless and scales easily with the amount of switchgears in the facility
- Has a connection to an API on a Raspberry Pi that will accompany the main control board
- The manager of a certain substation could use this to, at a glance, see what state every circuit breaker he/she is responsible for

Basic Controller - Schematic and Board



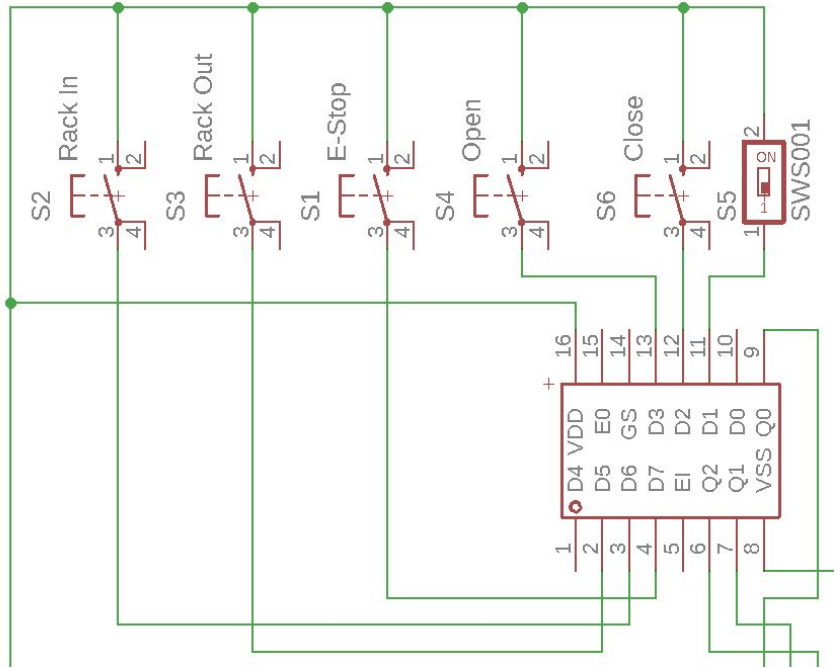


Basic Controller - Inputs

Button	Function
Rack In	Sends signal to MCU to start motor forward
Rack Out	Sends signal to MCU to start motor backward
E-Stop	Sends signal to MCU to immediately cut power
Close Breaker	Sends signal to MCU to close breaker
Open Breaker	Sends signal to MCU to open breaker
Overcurrent option (flipped off)	Sends signal to MCU that when overcurrent is encountered cut power to motor
Overcurrent option (flipped on)	Sends signal to MCU that when overcurrent is encountered reverse to previous position

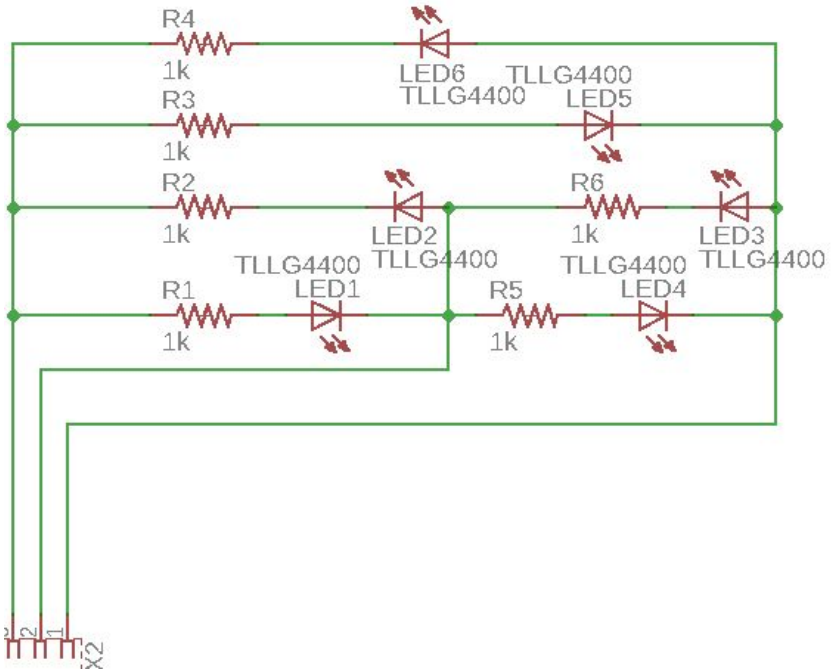
Basic Controller - Inputs

- 8:3 priority encoder (UA741) used in order to reduce the amount of wires needed to send all the possible inputs
- Priority : Emergency Stop, Rack in, Rack out, Close breaker, Open breaker, Overcurrent option
- Unique output pin combination for each input selection



Basic Controller - Outputs

- 6 LEDs
- Charlieplexed in order to reduce pin usage
- Only one LED can be lit at a time
- Several LEDs can appear to be lit at the same time by turning the necessary pins on and off at a high rate
- This is needed in order to communicate all the different status/error codes to the user
- This reduces the need for 6 pins down to 3



Basic Controller - Output States

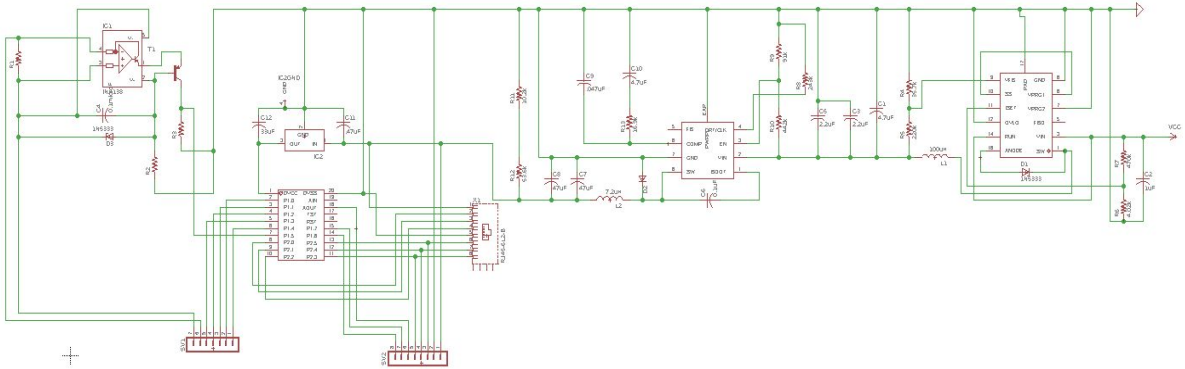
- The output LEDs are charlieplexed in order to allow just 3 pins for output signals
- The lights on the board turn on, off, and flash during certain situations

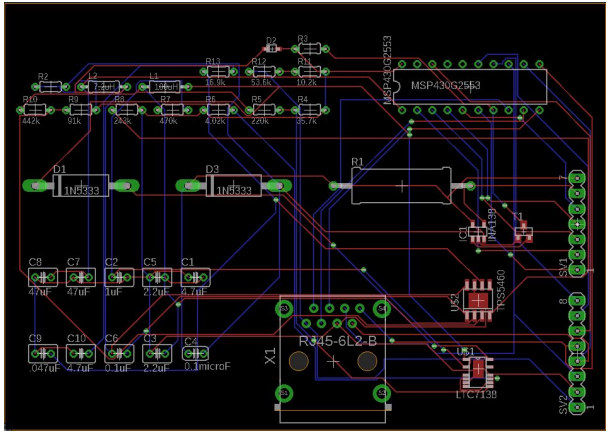
BREAKER STATUS		RELAY OUTPUTS				
CLOSED	OPEN	DISCONNECT	TEST	CONNECT	RACKING	Error conditions
OFF	OFF	OFF	OFF	OFF	OFF	Breaker either not inserted or racking umbilical not connected
X	X	ON	OFF	OFF	OFF	Breaker locked into DISCONNECT position
X	X	OFF	ON	OFF	ON	Breaker locked into TEST position
X	X	OFF	OFF	ON	OFF	Breaker locked into CONNECT position
OFF	ON	ON	ON	OFF	ON	Breaker racking between DISCONNECT and TEST
OFF	ON	OFF	ON	ON	ON	Breaker racking between CONNECT and TEST
OFF	ON	FLASHING	FLASHING	OFF	FLASHING	Racking error between TEST & DISCONNECT
OFF	ON	OFF	FLASHING	FLASHING	FLASHING	Racking error, between TEST & CONNECT
X	X	FLASHING	FLASHING	FLASHING	FLASHING	Mechanical blocking of racking operation
FLASHING	OFF	X	X	X	FLASHING	Racking operation attempted breaker in closed position

Control Board Design - Overview

- Only voltage source inside the switchgear is 125V DC
- Need to bring that down to a useable 5V using buck converter
- Current sensing circuit is needed on the board in order to know when too much current is being delivered to the DC motor
    - Too much current for too long means the racking system is being physically blocked and damage can happen
- MSP430G2553 microcontroller is used to control input and outputs
- Raspberry Pi integration with control board

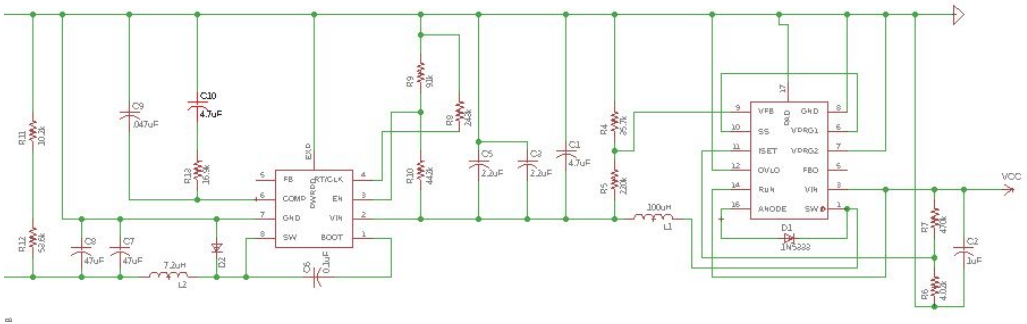
Control Board - Schematic and Layout





Control Board Design - Buck Converters

- Preferable to a battery for powering components on the board
- The LTC7168 has a 140V max input voltage which is needed for the high voltage supply but only outputs a max of 400mA
- The TPS54560 has a max input voltage of 60V and outputs a variable voltage and 5A
- Need 2.5A to power Raspberry Pi alone
- Solution: Chain them together to achieve desired voltage and current



Part Selection - Buck converter

- Based on options, needed two in order to chain together
- Both TPS chips were available as samples
- LTC7138 was cheaper and had a higher current output
- TPS54560 had a higher current output

	LTC7138	LTC3639	TPS54560	TPS54260
Input V (max)	140V	140V	60V	60V
Input V (min)	5V	5V	4.5V	4.5V
Output V (max)	140V	140V	58V	58V
Output V (min)	0.8V	0.8V	0.8V	0.8V
Output Current	400mA	100mA	5A	3.5A
programmable output voltage	yes	yes	no	no
price	8.28	$9.30	$0.00	$0.00

Current Sensing Circuit

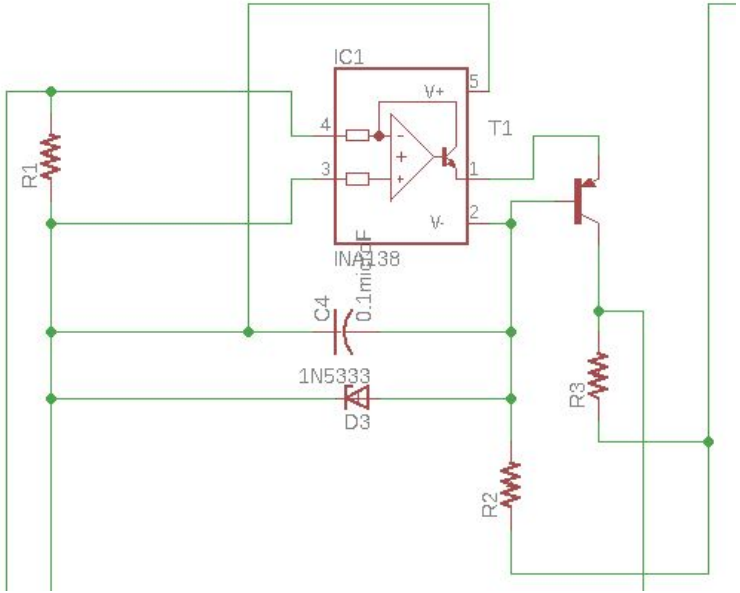
- By placing a shunt resistor in series with the load and measure the voltage drop across them.
- The voltage drop will then be amplified to serve as an output signal proportional to current

Low Side Sensing	High Side Sensing
Shunt resistor between the load and ground	Shunt resistor between the load and power supply
Harder to implement, introduces unwanted resistance to the ground path	Must be able to resist high voltage but easier to implement

Control Board Design - Current Sensing Circuit

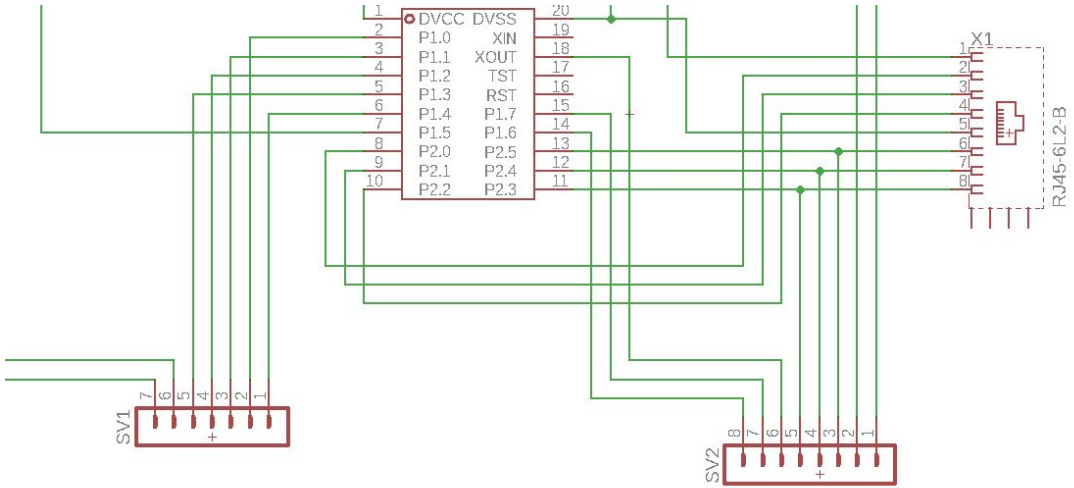
- Uses an INA138 IC
- High side sensing
- Turns the current through the shunt resistor into A measurable voltage on the output
- When a current greater than 1.3A goes through the shunt resistor then there is a voltage of 3.5V at the output, enough to signal logical high for the MCU
- $V_{out} = (I_{load} \times R_{shunt} \times R_3)/(5k\ Ohms)$

  $=> R_3 = 270k\ Ohms$



Control Board - Microcontroller

- Takes input from the RJ45 port and the pins for the Raspberry Pi
- Outputs to the RJ45 port, the Raspberry Pi header and the racking system pins
- Takes in a combinational input and output
- Will prioritize inputs from the hand held controller over the Raspberry Pi



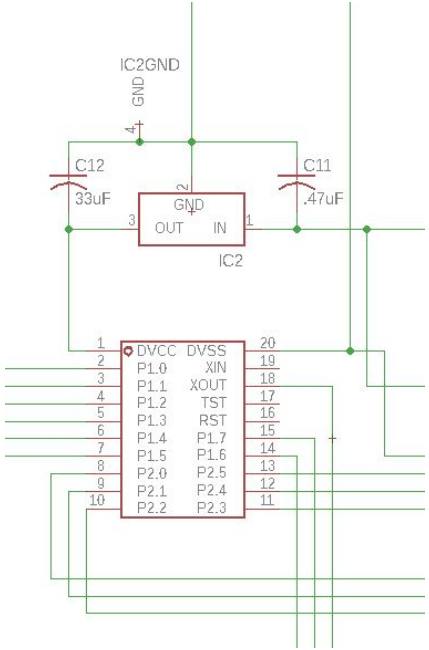
Part Selection - MCU

- ATmega32 has more flash and much more RAM
- MSP430 draws less power
- ATmega32 has many more pins
- Biggest factor is already owning a MSP430 Launchpad
    - Faster start developing and familiarity are two big pluses

	MSP430G3553	ATmega32
flash	16 KB	32 KB
RAM	512 B	2048 B
I/O	16 pins	32 pins
operating voltage	1.8-3.6	2.7-5.5
active current	.23 mA	1.1 mA
idle current	.5uA	.35 mA
power down current	.1 uA	< 1uA

Control Board - Voltage regulator for MCU

- Brings the 5v input down to 3.3v to power the MCU
- Chose to use the LM3940
  - Small package
  - Can hold 3.3v output with an input voltage as low as 4.5v
  - Was able to get free test samples to use

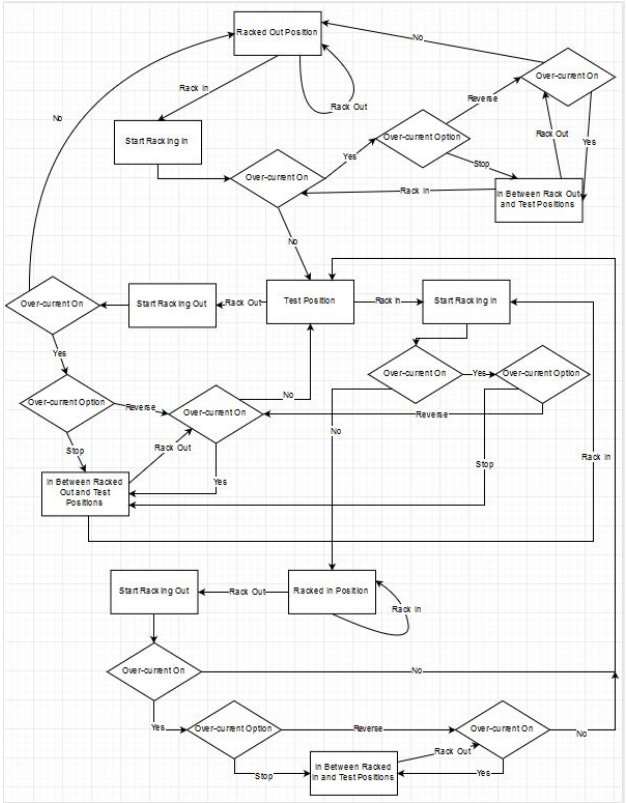


Control Board - Microcontroller

- Needed to control the inputs and outputs of the handheld controller and Raspberry Pi
- Interfaces with the racking system
- Send 60ms long rack in and rack out signals after receiving input from either the handheld controller or the Raspberry Pi

Microcontroller Design - Flowchart

- Needs to check if too much current is going to the motor every time the breaker is changing positions
- If the over current circuit goes high then the MCU will determine which option is selected, either reverse or stop
- If option is to reverse then the overcurrent still needs to be checked in case there is a blockage behind the circuit breaker too
- The emergency stop button immediately cuts power to the racking system
- The breaker close button only works in the test position and the rack can only move when the breaker is open



Prototyping

Control Board - Raspberry Pi3 Model B

- Needed for connectivity to a server
- Will be running Windows IoT as an operating system
- For the Advanced Controller to function properly there is a Pi with each control board so that it is individually addressable
- Is able to interface with the MCU in the same way as the hand held controller
- Powered from the 5V output of the chained buck converters
- Will also be used to simulate our controllers for our final presentation

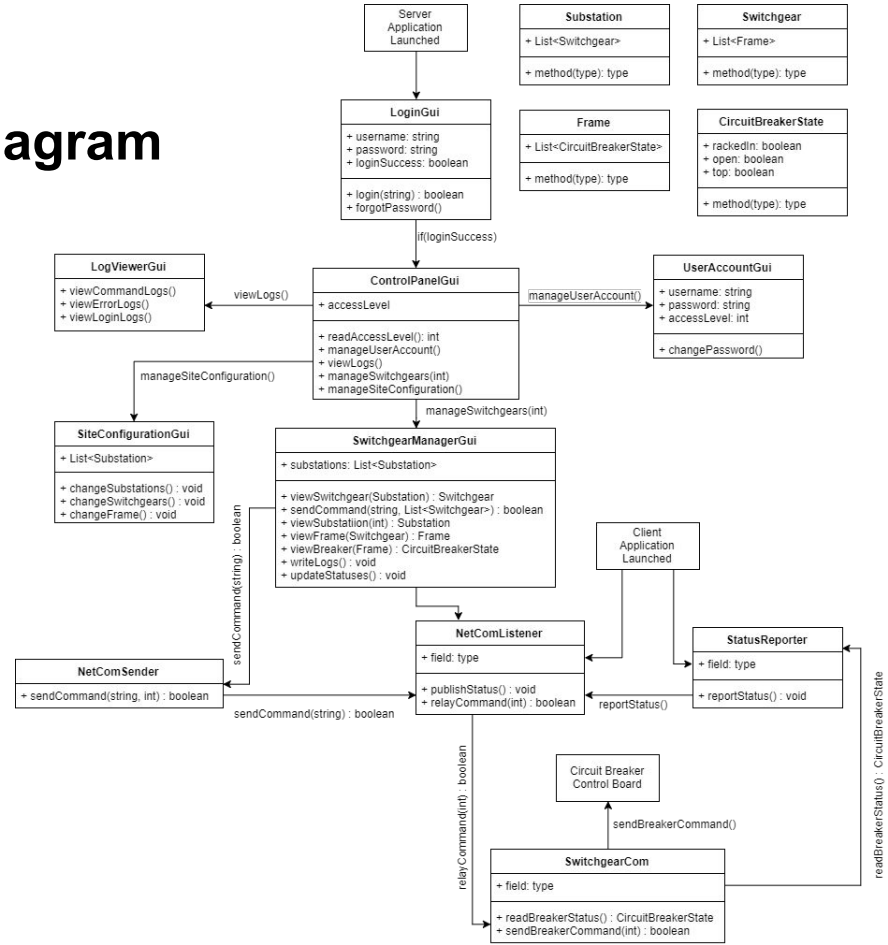
Advanced Controller - Software Application Design

- Simple, easy to use graphical user interface
- Secure application with encrypted network communication, user credentials, and access levels
- Can be deployed on any Windows based computer that is able to run a .NET application
- Capable of controlling and reporting the status of multiple Switchgear systems at once
- Deployment of the system is quick, easy, and requires little down time
- Two applications to be made:
  - Server Application
    - Used to send commands, view logs, looks at Switchgear systems and their status, and manage user accounts and site configuration
  - Client Application
    - Relays commands received from the Server Application and issues them to the Switchgear system, sends out the status of the circuit breaker component it is currently connected to

Software Application Class Diagram

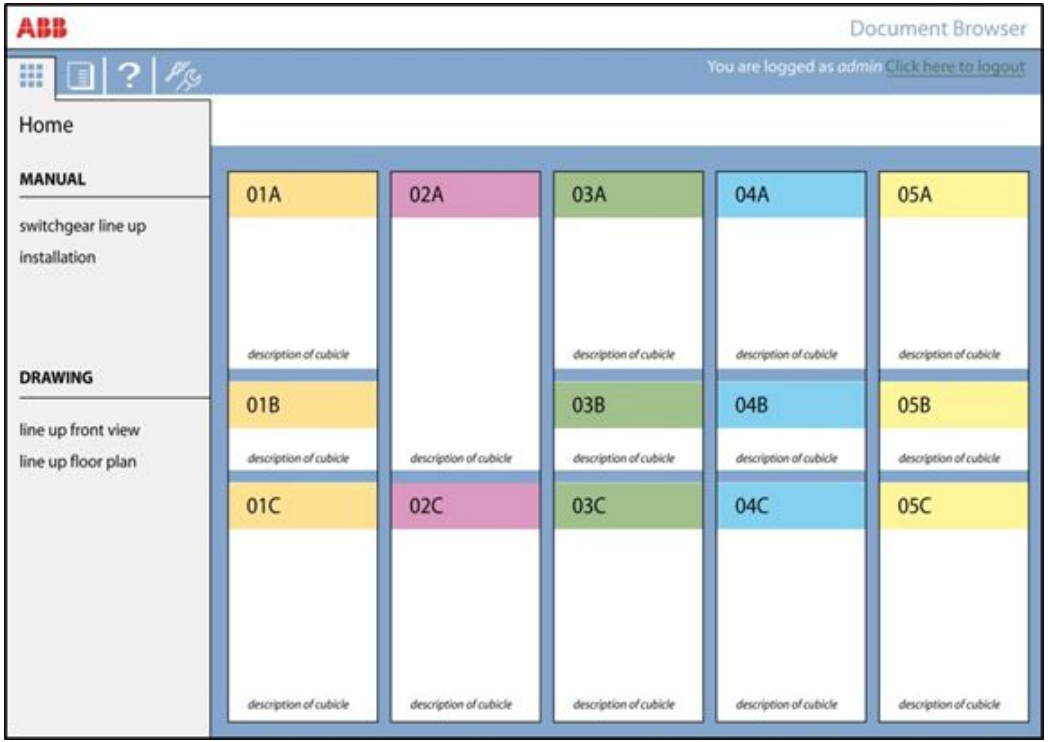
Features 5 major components:

1. Control Panel
2. Logging
3. Network Communication
4. Switchgear Communication
5. Site Architecture

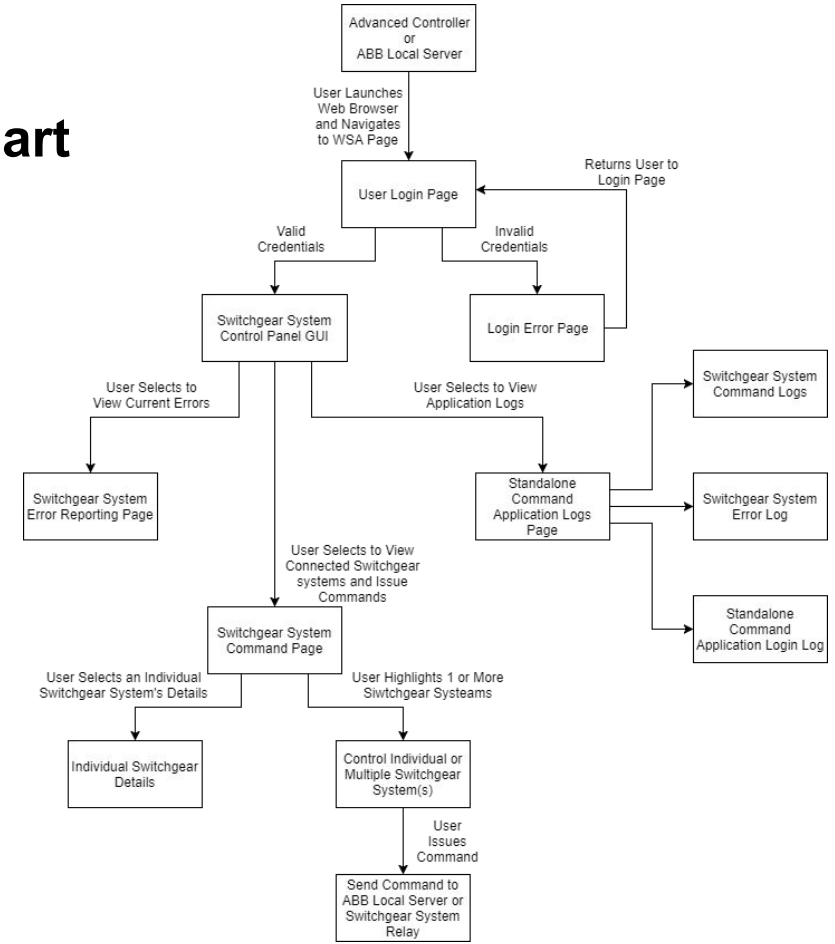


Software Application - GUI Concept

- Design allows Switchgear systems to be addressed down to a frame level
- Matches the visual layout of the Switchgear system so controlling and viewing the system is familiar
- Completely configurable according to the specific substation layout and configuration



Software Application User Flowchart



Software Application - Control Panel

- Based off the user's login credentials and access levels the user has access to certain features
  - Access Level 0: can view logs and the status of Switchgear systems at the site
  - Access Level 1: access to the same features as Level 0 but also has the ability to issue commands to control Switchgear systems
  - Access Level 2: access to the same features as Level 0 and Level 1 but also can access the site configurator to change the configuration of the site
  - Access Level 3: access to the same features as Level 0, Level 1, and Level 2 but also can adjust and manage user accounts and their access levels
- Main hub of the application
- All users have access to manage their own accounts and credentials.

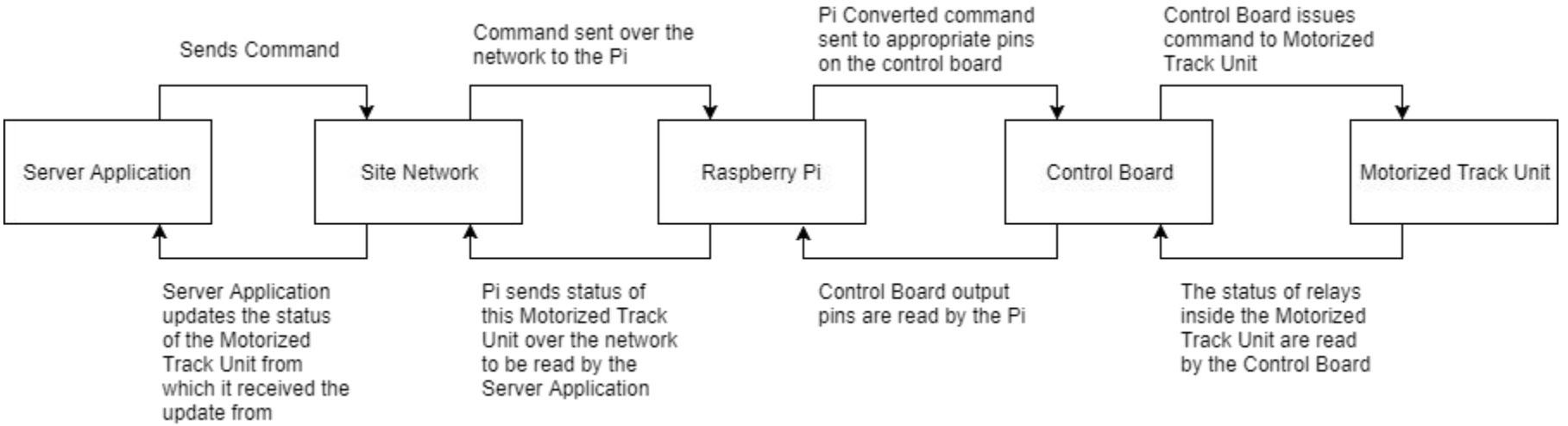
Software Application - Logging

- What is logged:
  - Commands issued to Switchgear systems
  - Errors generated by the control board
  - User inputs and user selections
  - Site configuration changes
  - Invalid operations
- Logs are accessible by anyone with valid login credentials
- All logs are written to CSV files for the respective log type along with time, date, and user information
- Logs are stored on the computer running the Server Application

Software Application - Network Communication

- The Server Application send commands to the Client Application for the Client Application to relay over to the control board
- As long as the Client Application is running it is reporting the status of that particular Switchgear system's circuit breaker component through multicast so all running instances of the Server Application can receive the information
- All network communication will be sent over a TCP socket and all network packets/commands will be encrypted prior to transmission
- Due to the entire site being a large local area network based network communication is nearly instantaneous between the Server and Client Applications

Software Application Network Communication Flowchart



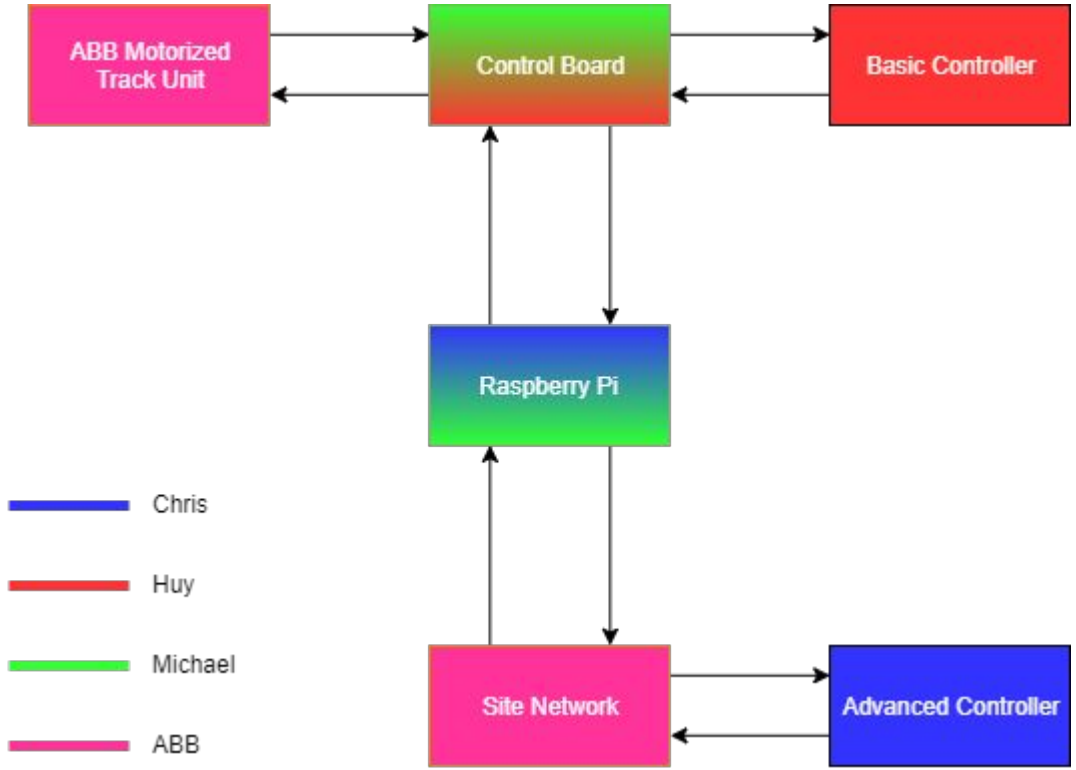
Software Application - Switchgear Communication

- Handled by the Client Application
- The system running the Client Application will be connected to the control board, this allows it to constantly read the status of the circuit breaker component
- The Client Application will issue commands to the control board through a wired connection using the input pins and will read the current status of the control board through the output pins
- The Client Application is able to issue all commands available to the Basic Controller to the particular circuit breaker component it is currently connected to

Software Application - Substation Architecture

- Because the configuration of the Switchgear systems is so modular and the control board is only connected to the circuit breaker component it is not possible to detect the configuration of a particular system automatically
- To alleviate this users with the appropriate access level are able to create an identical map of the entire site down to the compartment level of the Switchgear systems
- The breakdown of the substation architecture is as follows:
  - Site, substation, switchgear system, frame, compartment
- By allowing the entire site architecture to be entered into the Server Application the configuration of a particular Switchgear system is able to be viewed without the need to approach the system
- Should a part of the site architecture configuration change, any user with the appropriate access level can modify it

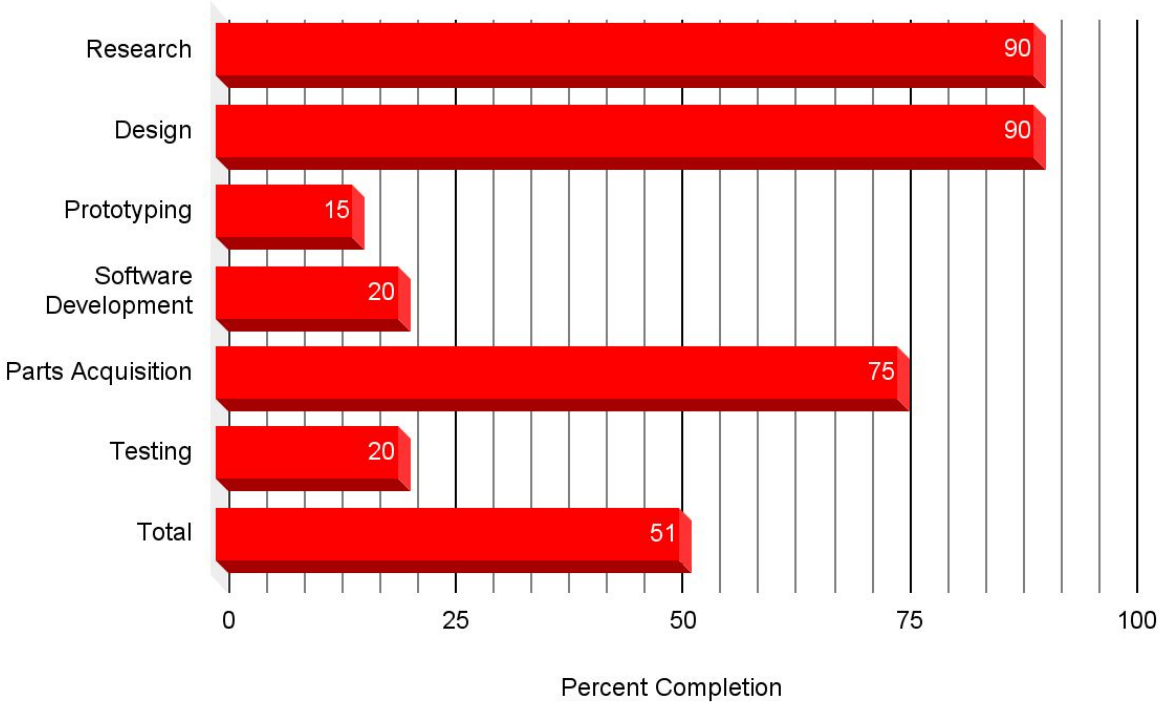
Administrative - Tasking



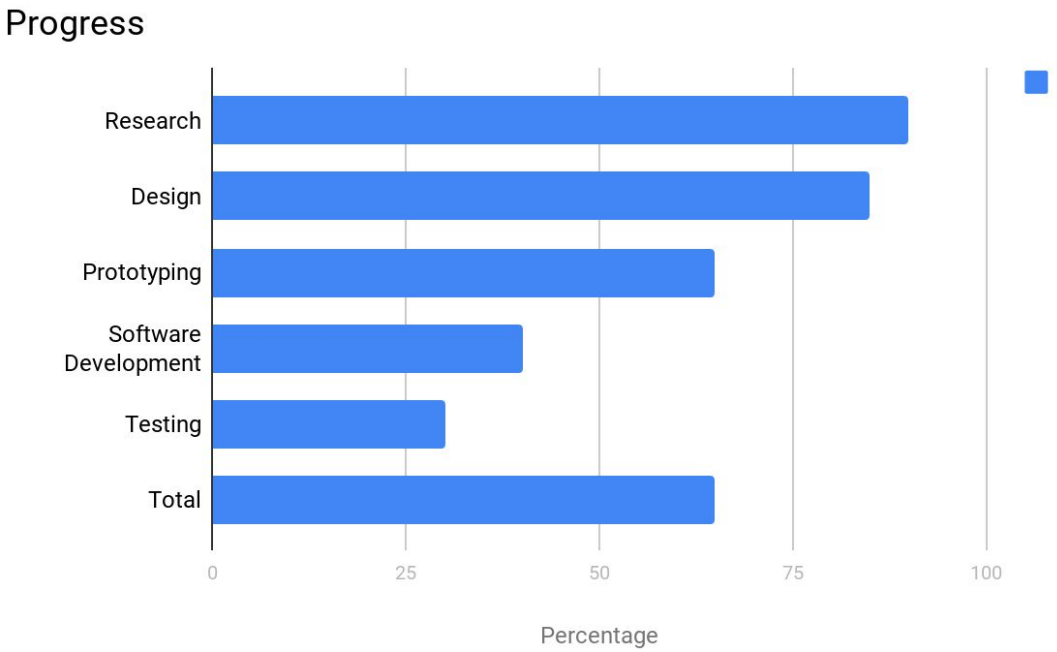
Administrative - Budget

Part Number	Description	Development Price	Production Price	Quantity	Development Cost	Production Cost
LTC7138	140V Max Buck Converter	$8.28	$6.25	1	$8.28	$6.25
LTC3639	140V Max Buck Converter	$9.30	$7.00	1	$9.30	$7.00
MSP430G2553	Low Power MCU	$2.69	$1.30	2	$5.38	$2.60
MSP430 launchpad	Used for Testing ISP	$10.00	$0.00	1	$10.00	$0.00
INA138	High Side Current Sensing Chip	$0.00	$0.75	1	$0.00	$0.75
PWR220T-20	Shunt Resistor	$4.00	$0.90	1	$4.00	$0.90
SOT-23 breakout board	Break Out Board for Testing Small Parts	$5.00	$0.00	1	$5.00	$0.00
PCB cost	PCB to Put Parts On	$25.00	$25.00	2	$50.00	$50.00
LVR05R0500FE73	50 mOhm Shunt Resistor	$2.40	$1.50	1	$2.40	$1.50
LED's	Basic Controller Status Indicators	$1.50	$0.50	6	$9.00	$3.00
6mm Tactile Buttons	Basic Controller Input Method	$3.00	$1.00	4	$12.00	$4.00
DIP Switch	Used to Set Specific Behaviors	$2.00	$1.40	1	$2.00	$1.40
TPS54560	60V Max Buck Converter	$0.00	$4.20	1	$0.00	$4.20
TPS54561	60V Max Buck Converter	$0.00	$3.70	1	$0.00	$3.70
	Total	$73.17	$53.50	24	$117.36	$85.30

Administrative - Current Progress



Administrative - Current Progress



Concerns

1)Power efficiency of the series buck converter

2)Using a 125 V_{dc} voltage power supply to test our design

3)Integrating our control board design with the actual switchgear

Questions?