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Measuring Voltage and Wire Continuity

FINAL REPORT

Contents

1 Introduction

1.1 Project statement

Our project is to develop a device that can detect the presence of a voltage up to 600V AC and DC and determine wire continuity in a 3-phase system. Our device will display to the user whether there is a voltage between 3V and 600V present in each of the wires in the three phase system. This is beneficial because it removes the necessity for users to manually check the voltage values of a system with a multimeter, which would require multiple measurements. Our device will also state if any of the wires are broken (if the power is turned off). Users will be able to determine when components need to be repaired without having to access the three phase system themselves, increasing convenience and safety. Our device should be a unique design that does not infringe on designs that other companies have developed. This will allow our clients to use our product as they please without having to deal with the complications that come with working with other company's products.

1.2 purpose

Currently technicians measure three phase voltage using some sort of multimeter. This is a perfectly functional way to do it, but it isn't very convenient because it requires the technician to hold the probes manually and take multiple readings. Additionally, there isn't any clear way to detect broken wires in a three phase system without running some kind of power through the system or using a device like ours.

1.3 Goals

1. Develop a concept solution during the fall semester.
2. Design and test a prototype device during the spring semester.

2 Deliverables

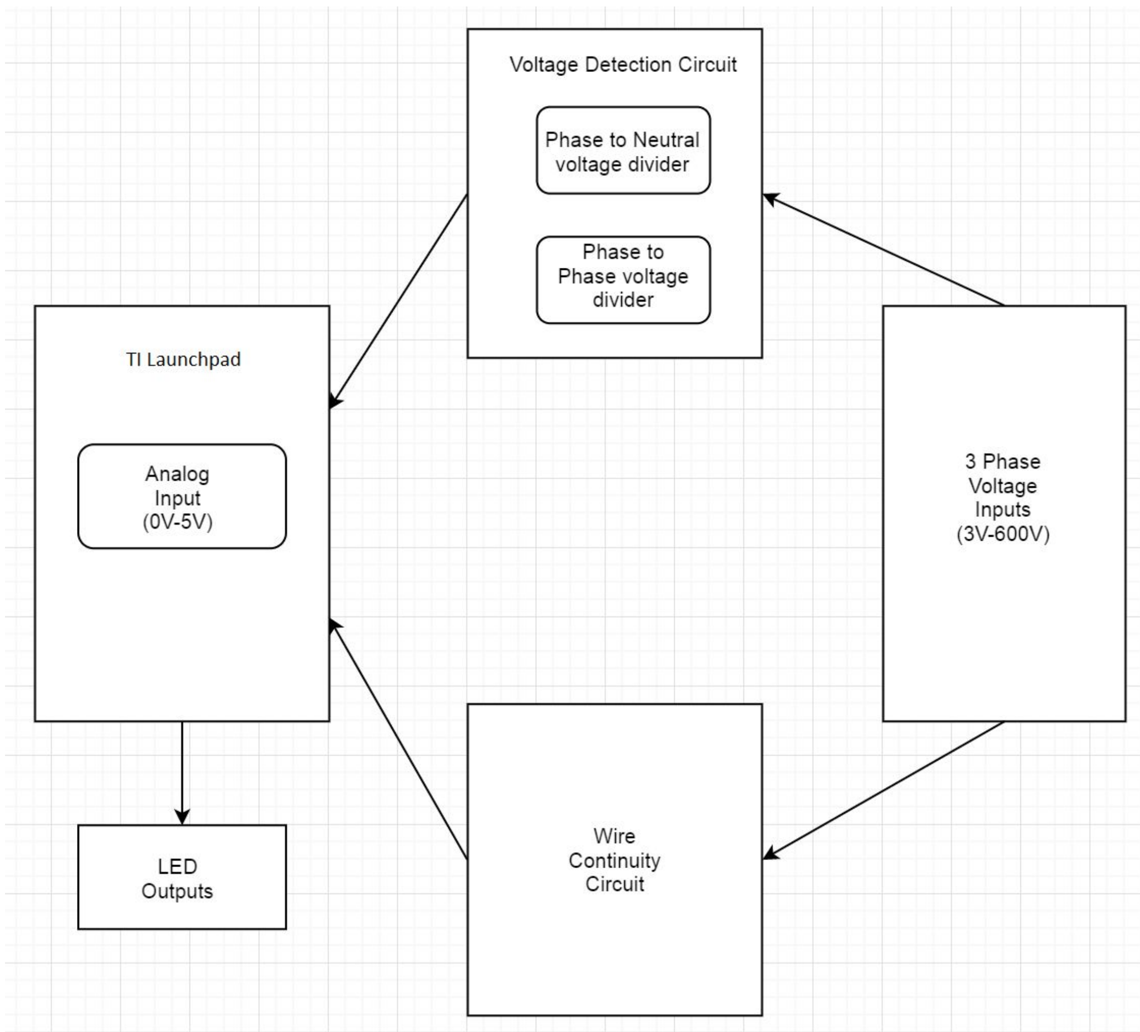
1. Develop a device that can measure the voltage in a 3-phase system.
2. The device would be permanently mounted in an electrical cabinet.
3. The device would be able to determine that the wires connected to the test are not broken.
4. The device would report the presence or absence of voltage.
5. The device would be able to provide indication locally as well as communicate via Ethernet/IP.
6. Device Layout and documentation shall be delivered to Grace Engineered Products

3 Design

3.1 Previous work/literature

We were provided a patent for a similar produce developed by another another company. That company used some proprietary methods to measure the voltages which involved oscillators measuring signal frequencies which corresponded to the wire voltages. We also looked online for some guidance on reading voltages using Arduino and found some relevant documents (1). It gave us a lot of good ideas on how to accomplish this task, such as using a diode bridge, smoothing capacitor, and voltage divider. From that point we worked on the problem of isolating the voltage in a way that the launchpad could read it.

3.2 Proposed System Block diagram



Above is an extremely basic system block diagram of our device. It will take in inputs from the three phase system and wire them to the voltage detection circuit. the wire continuity circuit will take inputs from a signal generator, detect a reflection of that input and send the reflection to the TI Launchpad. The voltage reading circuit will isolate the Launchpad from the high voltages using capacitor voltage dividers and possibly a zener diode. It will then convert the phase to phase AC waveform into a positive voltage that the arduino can read, which would be 0V-5V through the analog input pin. The wire continuity solution also isolates the Launchpad from high voltage using a switch.

3.3 Assessment of Proposed methods

There are several devices which could be used to measure 3 phase voltage, we have decided to use a TI Launchpad because it is easy to work with, does not take a lot of power, and is small. An alternative we could have used instead of an Launchpad is a raspberry pi, but for this system we would need to convert our analog signal to a digital signal while the arduino has the capability built in. There are also other microprocessors like the arduino, such as the TI Launchpad, but we decided on the arduino due to its large amount of libraries and online help.

The Launchpad can measure 0-3.3V DC through its analog input, so we will need to make sure that it is isolated from the high voltages of the 3 phase system. We have created a circuit to measure this, and it is described in detail in section 5 of the design document.

To measure wire continuity we will send a signal through a directional coupler which will be used to measure the reflection of the signal. The reflection should be different for an open circuit (fails wire continuity test) and a closed circuit (passes wire continuity test).

3.4 Validation

To validate our project we will simulate our project parts individually using programs like pspice and simulink. Next, we will build our project using lab equipment at ISU to simulate a three phase system at lower voltages and test our prototype. Validation will be complete when Grace Engineering can view our test results and is satisfied with the prototype.

4 Project Requirements/Specifications

4.1 Functional

- Product will be permanently mounted in an electrical cabinet
- Product must report the presence or absence of voltage down to a 3V minimum
- product must be able to test for wire continuity
- Product must display results locally as well as communicate via Ethernet/IP

4.2 Non-functional

- Legal: product design must not infringe on existing copyrights of similar products that are owned by other companies
- Accuracy/Reliability: product must be consistently accurate in measurements to avoid misleading technicians
- Security: certain documentation that contains sensitive data about our clients must not be available to everyone (not on our group website)

4.3 Standards

- IEEE 1801 - Unified Power Format
- 4-2013 - IEEE Standard for High-Voltage Testing Techniques

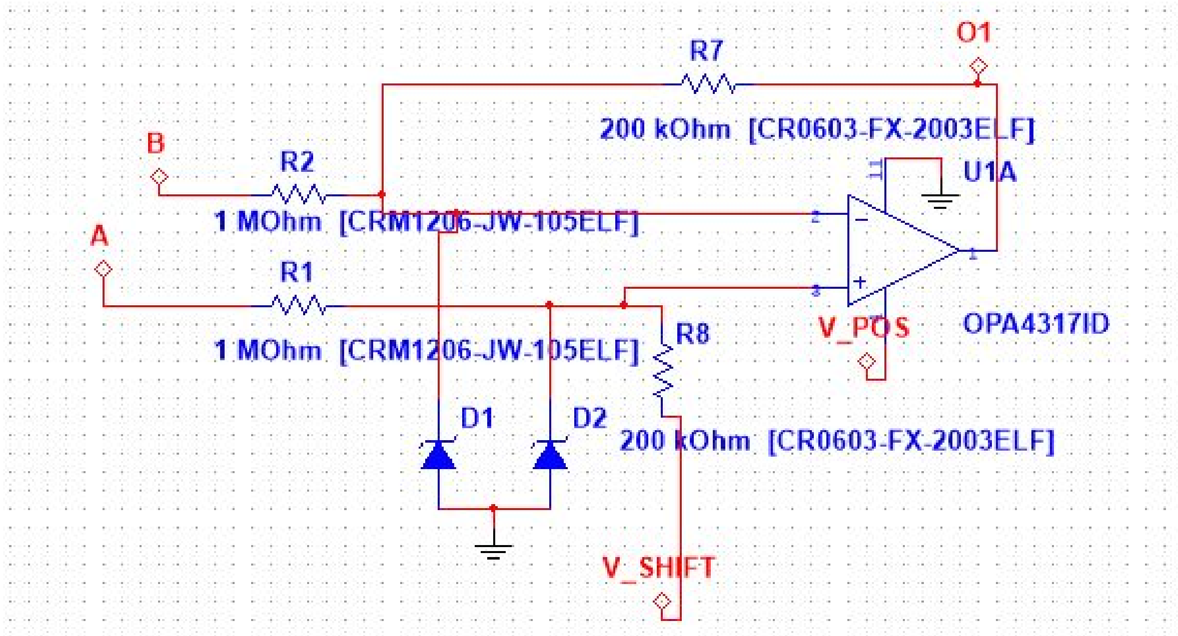
5 Implementation Details

5.1 Voltage Detection

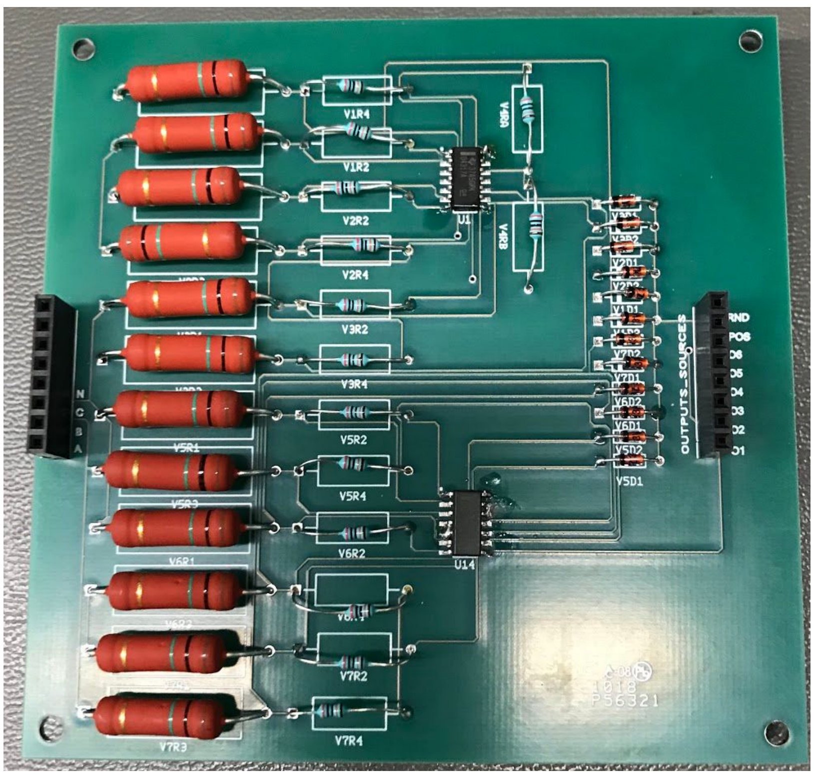
Our approach for detecting voltage involves reading the RMS voltage between every possible connection in the circuit. In a delta three phase system there are only three voltages between the phases, but in a wye there are 3 additional voltage between each of the phases and neutral for 6 total. Our chip consists of 6 sub circuits which read these voltages. Each sub circuit is implemented using resistors and an op amp. They output a voltage according to the following equation:

$$v_{out} = (v_1 - v_2)/5 \ + \ 1.65$$

The output of the difference amplifiers was given a DC offset so that negative and AC voltages could be read. Due to the nature of the op amp, it can't output lower than the negative source (which was wired to ground). The reason that the voltage difference is report with a ⅕ scaling is so that it could observe the full waveform of a 3V rms signal without clipping on the top or bottom. Our design also incorporates zener diodes wired to the inverting and non inverting terminals of the op amps. This is to protect the op amps when the voltage input becomes very large (eg hundreds of volts). We choose our specific op amp (OPA4317ID) because of its low input bias current and and because it was RRIO. Low input bias was necessary because of the large resistors that are used in our circuit (on the order of Mega ohms).



You can see the circuit diagram for a single difference amplifier. Here the inputs are phases A and B.



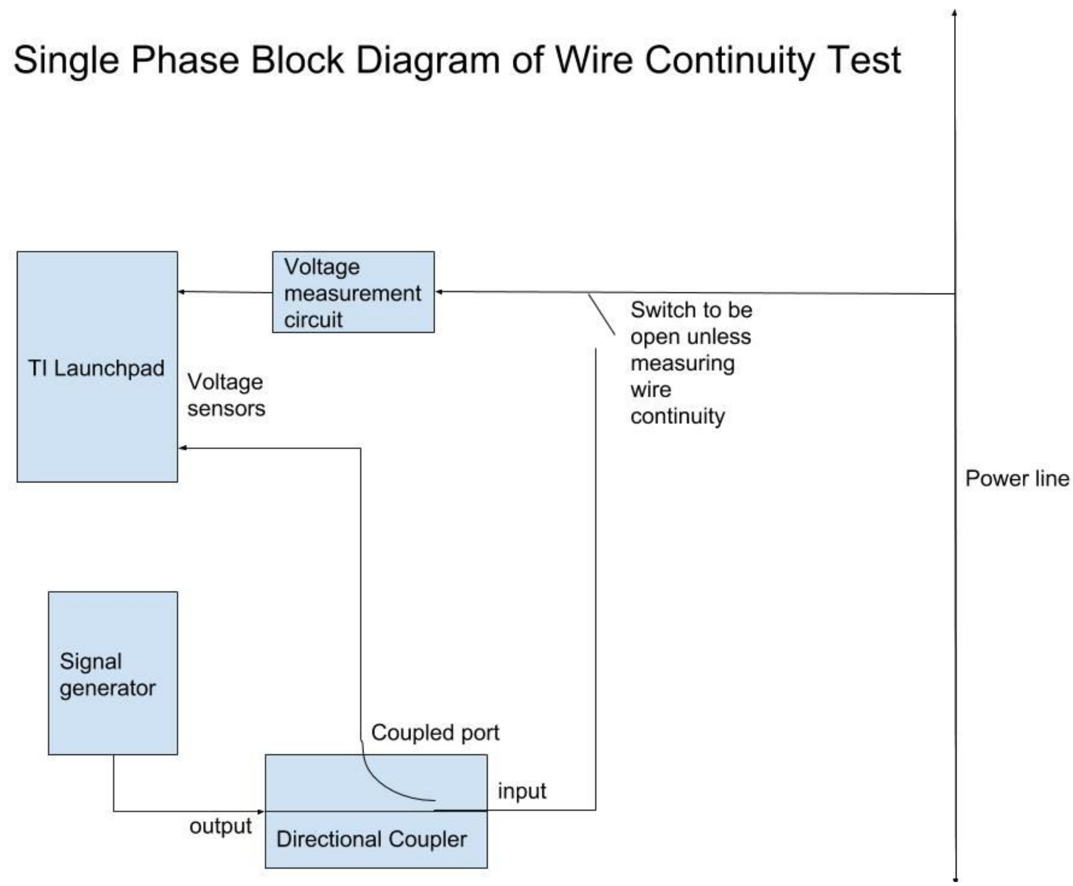
Here you can see the finished PCB. There are four inputs (A,B,C,N) and 6 outputs

5.2 Wire Continuity

Our approach for detecting wire continuity involves sending a 5V amplitude 5 MHz sine wave through a directional coupler so the reflection of the sine wave will be coupled and sent to TI Launchpad to be measured and analysed. If the broken wire is an open circuit, the load impedance will equal to 0 and therefore the reflected voltage will be equal to the input voltage. The reflected voltage of broken wire (open circuit) is 2.3V in every system. Reflected voltage amplitude of connected wires (passes test) will be different in every system because load impedance is different in every system, but load impedance will always be > 0, so the reflected voltage for connected wires will always be lower than reflected voltage of broken wires. Here is the voltage reflection equation used in the wire continuity test:

$$V_{Reflected} = V_{in}(Z_{load} - 50)/Z_{load} + 50$$

The analysis of the reflected voltage will be done through the MSP432 TI Launchpad. This is done by sampling the voltage and hence using the highest measurement to calculate in the reflected voltage equation. If the reflected voltage is higher than the threshold, an LED is lit indicates that the wire passed the continuity test.



5.3 Software

The MSP432 receives input from the voltage detection and wire continuity circuits through 9 analog pins, and provides output through 4 pins to 4 LEDs.

For voltage detection, the time needed for the software to measure a specified number of oscillations of the input wave is calculated. Then, measurements are taken at a specified frequency for that amount of time. Time between each measurement is fixed since that is a requirement for calculation of RMS. An RMS value is calculated based off of those measurements and returned to the main function. The RMS value is calculated for each of the 6 inputs. If the RMS value for any of the 6 inputs is equal to or above 3V, an LED is lit.

For wire continuity, a specified number of voltage samples are taken and the highest measurement found is returned to the main function. This is done a specified number of times, then the average of all the highest measurements found is calculated. This is done to reduce the impact of voltage spikes on the results. If this average is above a certain voltage threshold, then an LED is lit corresponding to which input is being considered.

The software was developed using Energia.

6 Testing

6.1 Voltage Detection Testing

Our testing for the voltage circuit occured in multiple phases.

1. Low DC Voltage Testing

We connected a DC voltage source from the lab to the phase inputs of the device. Using a digital multimeter to read the circuit's output we could tell that all of the 6 outputs had the correct ⅕ scaling for the voltage difference to the circuits output. However, we noticed that outputs 4 through 6 had no voltage offset so they couldn't read negative voltage. Looking back through the PCB layout we could see there was an error. Using wires we managed to repair the PCB to have the correct behavior and retested with DC voltages again. All of the outputs behaved as they should.

2. Low AC voltage Testing

We connected the function generator to each of the inputs like before and tested each of the outputs with the AC multimeter and launchpad. The launchpad provided consistent but slightly inaccurate results for the RMS values. It usually outputs 3.1V RMS when the real RMS value is 3V AC.

3. Low voltage mixed Testing

We connected 2 DC and one AC source to the chip and experimented with different combinations of voltages. The devices report high voltage on the scenarios it was expected and vice versa.

4. High Voltage AC Testing

We took a power cable, cut it in half, and connected alligator clips to the hot and neutral wire while it was unplugged. We connected the other ends of the clips to the device, plugged the power cord into a power strip, plugged in the power strip, and flicked the power on. The device outputted a 1.64VRMS square wave for all 6 outputs tested, which matched our expectation. There was no visible damage to the device for connecting it to this high voltage.

6.2 Wire Continuity Testing

We used a signal generator to send a 5V amplitude 5 MHz sine wave signal to the wire continuity circuit, then used the TI launchpad to read output and an oscilloscope to verify that the output was what we were expecting. We obtained readings from the launchpad using a broken wire, short circuit, and several different loads.

7 References

1. http://www.instructables.com/id/To-build-a-voltage-regulator-and-measure-AC-voltag/

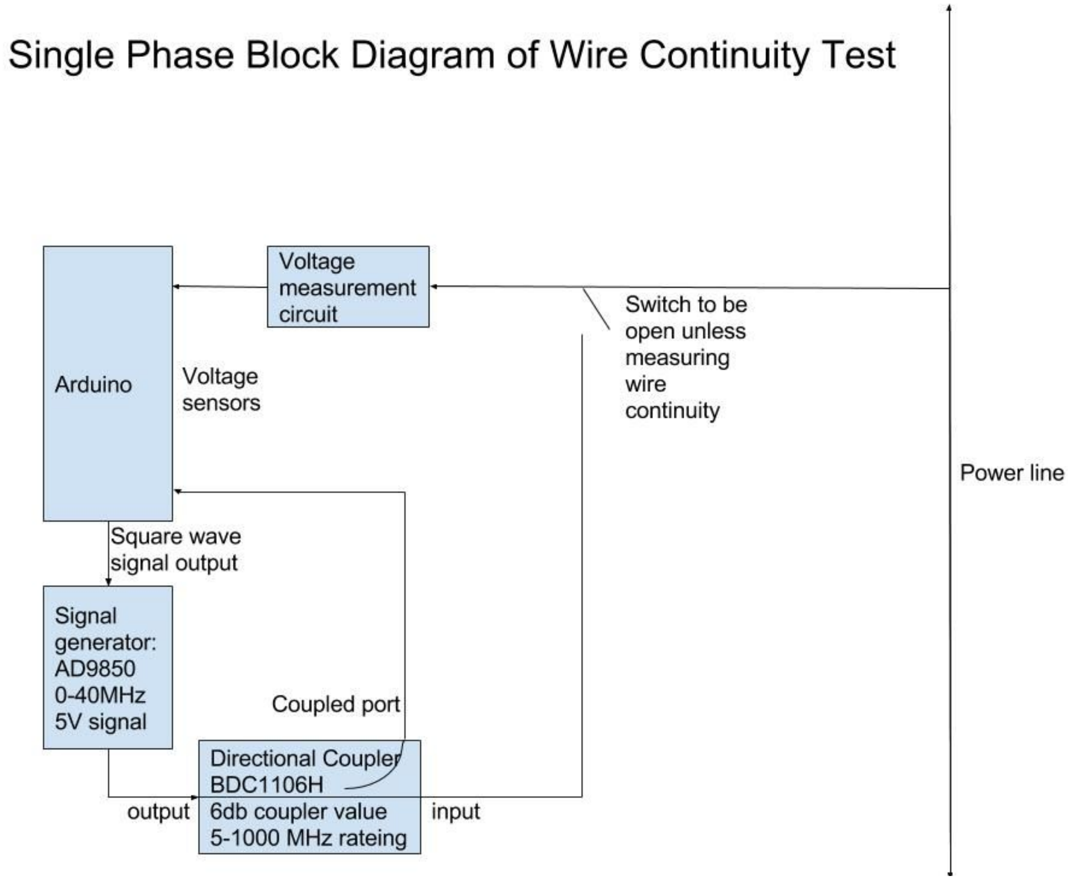
8 Appendices

8.1 Appendix 1: Operation Manual

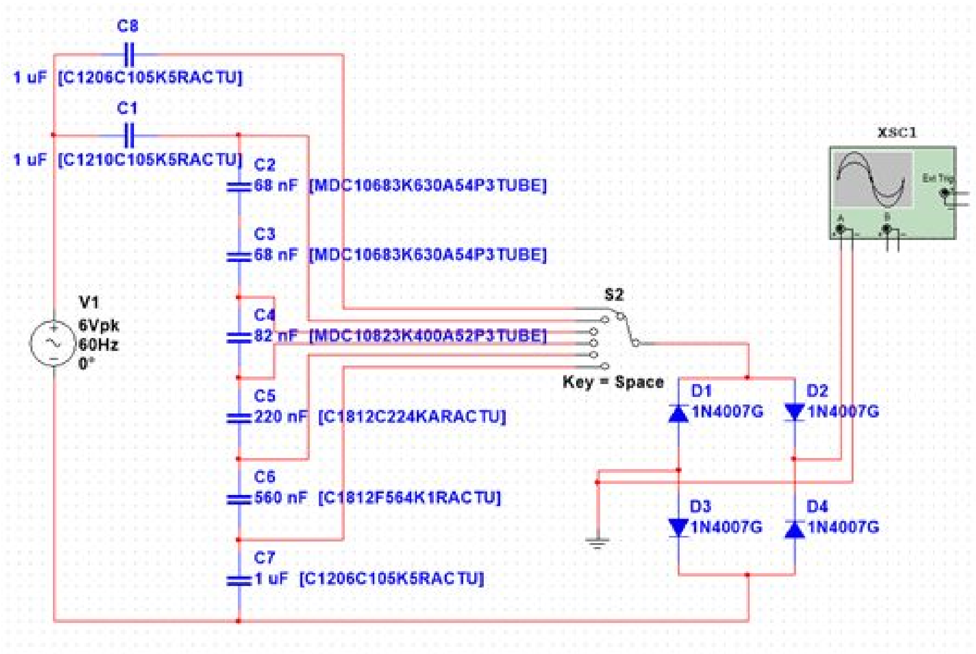
Connect 6 outputs of voltage detection circuit to the launchpad's input pins specified in the code (VOLT_IN). Connect 3 outputs of wire continuity circuit to the launchpad's input pins specified in the code (CONT_IN). Connect the launchpad's output pins specified in the code (VOLT_OUT and CONT_OUT) to LEDs. Connect the launchpad to ground. Connect the reference on the board to the V+ pin on the voltage detection circuit, and connect the phase wires A,B,C, and N (if it exists) to the corresponding input pins on the voltage detection board.

8.2 Appendix 2: Alternate Designs

Initial wire continuity design


Single Phase Block Diagram of Wire Continuity Test
Voltage measurement circuit
Arduino
Voltage sensors
Switch to be open unless measuring wire continuity
Power line
Square wave signal output
Signal generator: AD9850 0-40MHz 5V signal
Coupled port
Directional Coupler BDC1106H 6db coupler value 5-1000 MHz rateing
output
input

Capacitor divider design for stepping down voltage



Using transformers to isolate circuit from high voltage and reduce total power for measuring phase to phase AC