Testing Voltage and Wire Continuity

Design Document

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1 Introduction

1.1 Acknowledgement

This project was proposed and made possible by Grace Engineered Products.

1.2 Problem and Project Statement

The problem that we are solving is that currently when technicians are going to be working on power lines they need to test to make sure the voltage is off so they don't get electrocuted, so they use a device that measures voltage that is mounted in a substation cabinet. When the device reads zero voltage, because the power line is underground, there is no way to know if the power line is actually at zero voltage or the device has been disconnected from the power line. We need to be able to both read the voltage of a three phase system to make sure the voltage is zero, and be able to test that the device is connected to the power lines to make sure the reading of zero volts is accurate.

To do this we want to make a device that can be mounted in a substation cabinet. The device will be able to detect voltages between 3V and 600V AC and DC. The device will be connected to the power lines by wires. To make sure the voltage reading is accurate when it reads 0V the device will be able to test wire continuity. The device will be able to be powered by a battery so it can operate when the power lines are off. It will have 4 display lights. 3 of the lights will indicate which wire if any fail the wire continuity test, and the 4th will represent the presence of voltage in the power lines. If we are able to build this device, it will help technicians have safer working conditions when they are working with power lines.

1.3 operational Environment

We can guarantee that this device will be used in a protected environment. However, it must be able to handle being connected to high voltages.

1.4 Intended Users and uses

This device's intended use it to monitor a three phase voltage system and report both the presence of voltage and any disconnected wires. It will be used by trained technicians who are working with three phase systems.

1.5 Assumptions and Limitations

Our device won't need to make many assumptions about how it is used. The only assumption that exists right now is that all of the test wires for the device be connected while it is in use.

Our devices specifications have been laid out very clearly, so we have a good idea of what its limitations will be. Its maximum voltage is 600V RMS AC at 50-60Hz, and 600V DC, which is high enough to measure most three phase systems. Additionally, this device must be small enough to be mounted in a cabinet.

1.6 Expected End Product and Deliverables

Our team's goal for this project is to deliver a reliable device that can be used by Grace Engineering Products. The software team is working on developing a device, which can measure the voltage in a 3-phase system (up to 600v). Also, it would be able to detect the presence or absence of voltage (down to 3V minimum). The electrical team is working on wire continuity that determines the wires connected to the test points are not broken.

Ultimately Grace Engineered Products wants to sell a device which matches our prototype. It will not be exactly the same as what we make because we will be using an Arduino while they will print an integrated circuit with a microprocessor which meets their needs. Other arbitrary aspects of the product (cables used, chassis) will likely be different.

Deliverables:

- November 2017
  - Circuit Design for measuring voltage in three-phase system
  - Block diagram for checking wire continuity
  - Cabinet Setup
- December 2017
  - Create the conceptual solution for the device
  - The design document
- January 2018
  - Design a prototype device
  - Working on hardware
- March 2018
  - Troubleshooting/testing
- April 2018
  - Completed testing plan
- May/June 2018
  - Testing plan executed

2. Specifications and Analysis

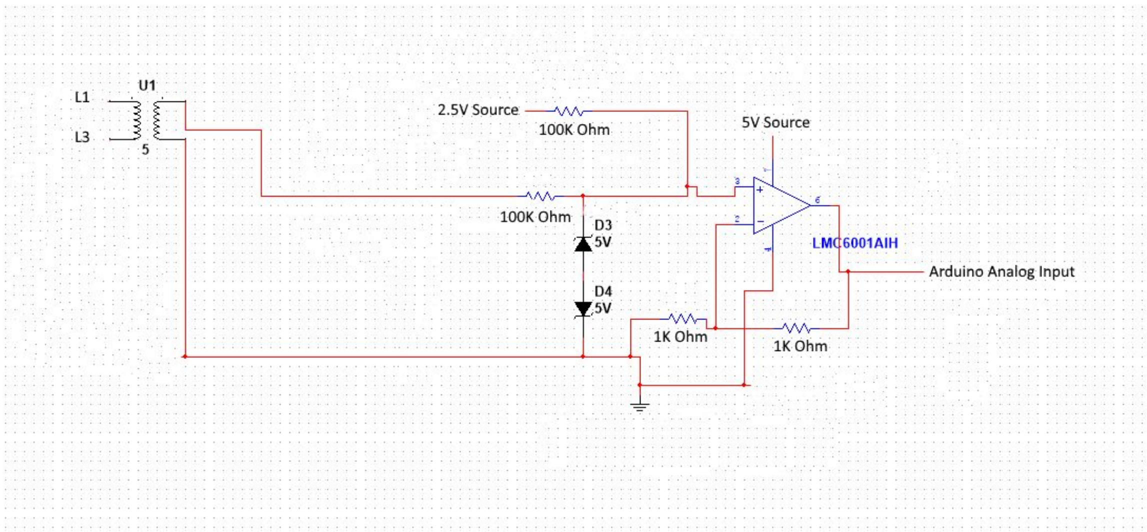
Our device shall meet the following specifications:

1. It shall be able to connect to a delta or wye three phase system.
2. It shall make no assumptions about whether the system is balanced.
3. It shall be able to detect 3V AC RMS between each phase wire and from each phase wire to neutral in a wye system.
4. It shall be able to detect 3V DC between each phase wire and from each phase wire to neutral in a wye system.
5. It shall be able to function with AC voltages as high as 600V rms.
6. It shall be able to function with DC voltages as high as 600V.
7. It shall display the presence or absence of any voltage by lightning an LED.
8. It shall be able to detect if any of the phase wires are broken when the power is turned off in the system.
9. It shall be able to detect wire breaks that occur up to 8 feet away from the test point to the load.
10. It shall display whether a wire is broken or not using three LEDs, one for each phase.
11. It shall not test for broken wires if the power is turned on.
12. It shall run on a battery and consume as little power as possible.
13. It shall be small enough to be mounted in a cabinet.

2.1 Proposed Design

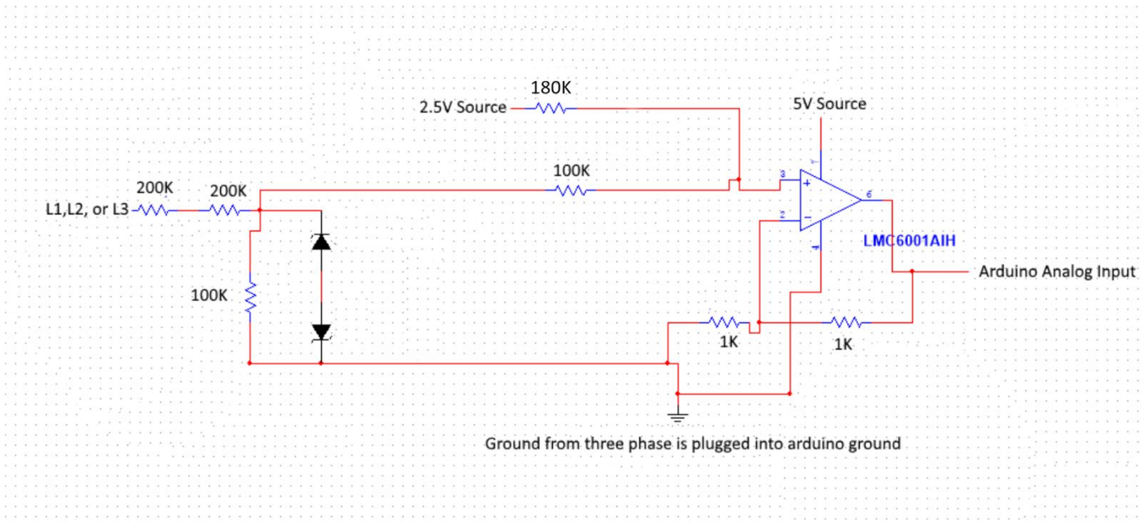
We have designed 2 circuits that can read voltage, one that can read AC voltages and one that can read DC voltages from phase to neutral in wye systems. We still need to design a circuit which can read phase to phase DC voltages or change one of the existing ones to accommodate it.

Figure 2.1



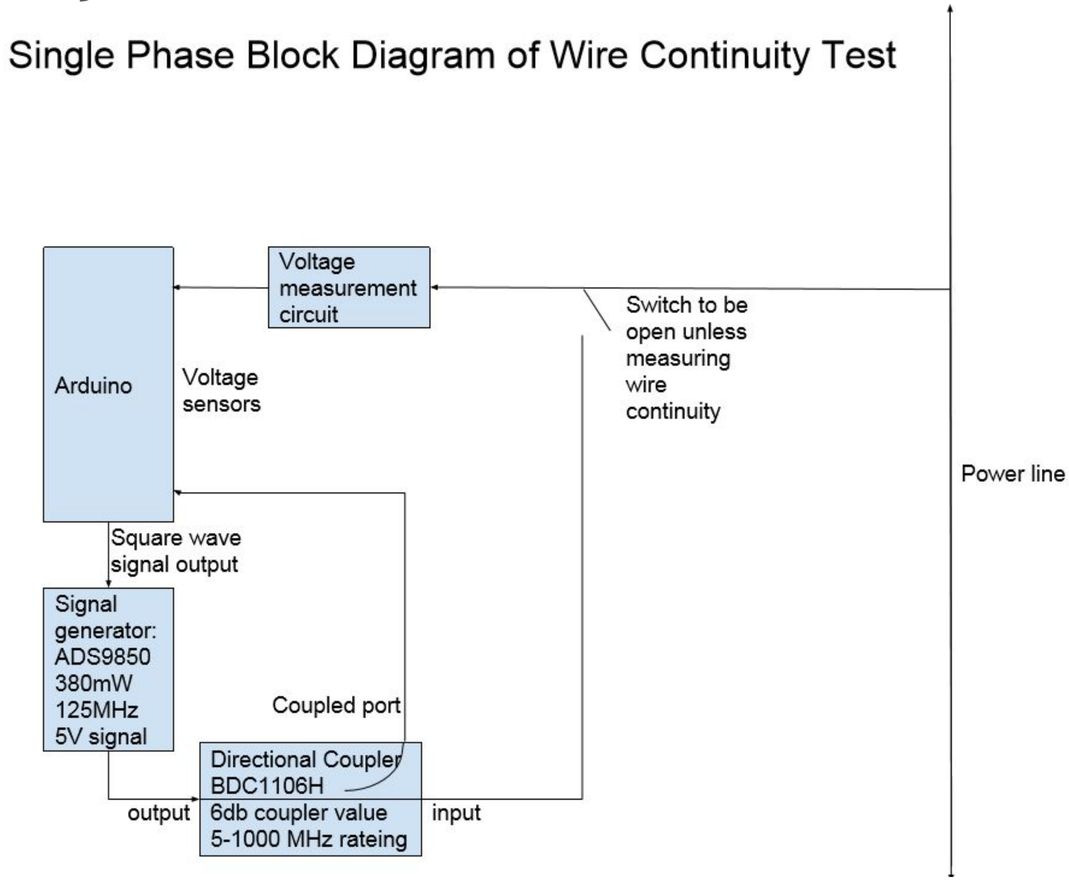
Our AC voltage measuring circuit uses three transformers to step down the phase to phase voltage by a factor of five between each of the phases (L1 to L2, L1 to L3, and L2 to L3). It clips this voltage with back to back zener diodes, and then uses a summing amplifier to shift the input up 2.5V into the 0 to 5V range that the arduino can read.

Figure 2.2



Our DC voltage measuring circuit uses a resistor divider series to step down the phase to neutral voltage by a factor of five. Then, like the AC voltage measuring circuit, it uses back to back zener diodes to clip the voltage and uses a summing amplifier to shift the reading into the arduino's range.

Figure 2.3



The wire continuity circuit uses a signal generator connected to the arduino to send a signal through the output port of a directional coupler, the input port is connected to the wire connecting our voltage measurement circuit to the power lines with a switch on the end. The switch will remain open until the voltage reads less than 3V, at that point an operator can run the wire continuity test which will close the switch and send a signal through the signal generator. The coupled port is connected to a voltage reader on the arduino.

The idea of the circuit is that a signal will be sent through the coupler, the signal will not be coupled. The signal will either pass on to the power line if it is connected or has continuity or there will be an open circuit (indicating that there is not wire continuity) if there is an open circuit the signal will be reflected and coupled in the input port to the coupled port then we can use the voltage reader to see that there was a reflection of a certain size we have yet to determine which will indicate an open circuit and fail the wire continuity test.

2.2 Design Analysis

The three phase transformer circuit behaves mostly as expected, with some non ideal behavior for higher voltages. Because of the increased impedance at higher voltages, the waveform the arduino reads shifts down as voltage increases. Because we only need to detect 3V RMS, this doesn't cause a problem.

The phase to ground circuit needed some tweaking to have the correct gain and offset, but behaves almost exactly as we expect. As with the transformer circuit, we decided to use a high impedance op amp to reduce the chance that the high input impedance could impact the circuit. The resistors that we will use will be rated for at least 1W each.

The directional coupler circuit would be able to measure a reflection which would give us insight into the health of the wires connecting our device to the power lines.

3 Testing and Implementation

Testing has occurred through simulation only. We have not started prototyping yet since we are still in the design phase of our project. Once we have agreed on acceptable designs for reading voltage and determining wire continuity, we will begin prototyping. We will have to work with our clients to determine what resources they can provide us to aid in the prototyping process, and what resources we will have to acquire ourselves. Section 3 will be filled out once we have entered the prototyping phase.

3.1 Interface Specifications

Testing our solutions for reading voltage has happened digitally through circuit simulation software. We are now making mockups for our circuits in matlab simulink, and when we finally make a circuit which should meet all of our needs we will create a simulation which accounts for as many extraneous factors as possible.

3.2 Hardware and software

3 phase voltage source

3 phase voltage source supposably available in a lab in Coover, we need to check with our advisor to make sure.

Multimeter

Useful to verify the input voltage if not from a controlled signal generator.

Arduino

Reads voltage through the analog pin, voltage interpreted by software, software will determine if LEDs should be lit.

signal generator

will be used to send a high frequency signal to check for continuity

directional coupler

will be used to measure a reflection which will determine if the wire continuity test passes or fails

3.3 Process

Testing our solutions for reading voltage began with circuit simulation software. We have been using such software to develop our proposals, and will provide results to our advisor and clients to confirm that a solution works as intended. We plan to find a working solution for reading voltage by Feb. 1st.

Once we agree on a solution that produces acceptable results for stepping down AC and DC voltages, we will acquire an arduino and the electrical components needed to build our circuit so that we can begin constructing a prototype. Receive parts and begin assembling prototype by Feb. 16th. Finish prototype assembly and ready for testing by Feb. 28th.

Once a prototype is assembled, we will test the output voltage using a multimeter to make sure the voltage has been properly stepped down to be safe for the arduino. If it is not safe, we will review our choice of components in the dividers and make appropriate changes. If it is safe, we will use the arduino's analog input pin to read the voltage and make sure that our software can properly report the voltage's presence or absence. We will record the results of our circuit for several different voltages in the range of 3V-600V, and report to our advisor and clients on how successful our prototype was and any changes needed. Report results by Mar. 9th to give time for additional prototypes and testing.

Wire continuity tests will start after break by first acquiring a directional coupler either through the ETG or online. Once we have a coupler we will run tests using a signal generator and oscilloscope to determine if a reflection can be measured, at what voltage and frequency the test works best, and will give us insight as to how we can use that data we gather from the reflection to determine if the wire has continuity or not.

Testing could take one week or several months depending on the problems we encounter, we will hope to come up with techniques for testing continuity by February - March at this point we will start putting together the full circuit. First we will test that the arduino can measure the reflection of the signal. Then we will test to make sure that the arduino can send the desired signal. Finally we will put the entire circuit together and write the code that determines if the wire continuity test passes or fails depending on the reflection we receive. We hope to have this done in early February. Finally we will put all the code together so that pushing a button runs the wire continuity test, which will turn on or not turn on the led's depending on if the wire continuity test passes or fails.

3.4 Results

We have designed a lot of voltage reading circuits that haven't met our needs, which have been described in the weekly status reports throughout the semester. The main points we have learned from these attempts are:

1. Don't use big resistors (1M Ohm or greater). High impedances will negatively impact voltage reading and op amp circuit characteristics
2. Don't use a diode bridge rectifier. If you step down voltage before using the rectifier, the forward drop will prevent you from knowing if there is 3V. If you don't, then the spacing on the PCB board will be too large
3. Be cautious of using capacitors. While they are useful because they don't produce heat, designing a circuit where they discharge properly can be challenging
4. Don't try to do logic with the circuit itself (ie use a schmitt trigger comparator to tell if there is >3 V). This is unnecessary hardware and adds a lot of complexity

5. Zener diodes are great for clipping high voltages without losing resolution at low voltages

The two voltage reading circuits that we present in this design document have mostly been behaving as expected. The transformer circuit has some non ideal characteristics when voltage increases, as the waveform can be seen shifting down on the simulation screenshot from its usual 2.5V offset. We haven't nailed down exactly what causes this to happen, it is probably related to some non ideal aspect of the transformer in the simulation. The offset of the ground to neutral measuring circuit is slightly off of what we want

Results of circuit proposals that were accepted or denied

4 Closing Material

4.1 Conclusion

Our goals in this project are to read voltage and determine wire continuity of a 3 phase system in a way that is unique from solutions of other companies. So far this semester, our team members have each learned about 3 phase systems and other relevant information so that we all now have a common knowledge base on the subject.

We met with our clients and identified several important requirements that would guide our design process. We split into two teams, addressing the voltage reading and wire continuity problems, and each team has proposed several possible solutions to our client over the past several weeks. We have received feedback from our clients and faculty advisor on each of our proposed solutions, and we are still working on refining our designs to fit exactly what our client wants. Each time we propose a solution, we take careful note of any new requirements or restrictions that are identified in order to make our next design better.

In the coming weeks, we hope to identify solutions for reading voltage and determining wire continuity that fit our client's needs, then we will work on combining both solutions into one circuit. Our current plan of action is similar to the agile methodology, since we have frequent contact with our clients and present a new product at each meeting. This is the best plan of action because our clients don't have a specific plan for the design of this product, so requirements could change rapidly. Also, our team members don't yet have as much knowledge on the topic as our clients and faculty advisor do, so frequent meetings to receive advice on our designs is a valuable asset to us.

4.2 References