EE35x1 Equipment and Software Guide

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Abstract

This document describes all of the equipment used in Electrical Engineering 3501 and 3541, as well as the accompanying software.

1 Equipment Overview

Throughout the system, the following color codes are used:

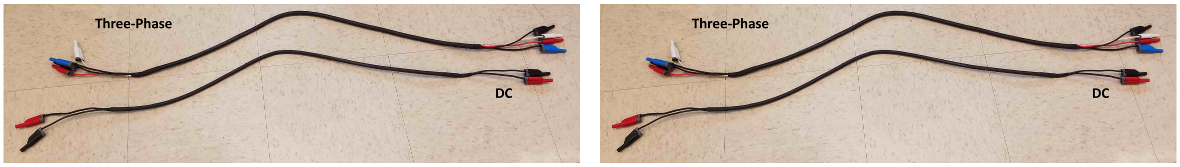
- Three-phase systems:
  - Red: Phase A
  - Black: Phase B
  - Blue: Phase C
  - White: Neutral
  - Green: Earth/Ground
- DC systems:
  - Red: Positive
  - Black: Negative

In the case of the three-phase system, "neutral" and "ground" are connected together at the service entrance, but should **not** be connected together locally, nor used interchangeably.

The main measuring and source equipment is installed in a rack (from the top):

- Fluke 8845A digital multimeters, qty 3
- Yokogawa WT333E power analyzer
- Nidec VFD
- Variac and variable dc source
- Magna-Power dc supply
- Switched three-phase mains terminals and Magna-Power terminals

Other equipment is simply on the lab bench:



(a) Safety socket only (b) Twist lock to safety socket

Figure 1: Example cables used in the lab

- A dynamometer, which has a dc machine on one side and different machines on the other
- A load box on the floor, which is wired to terminals on the bench
- Three transformers
- A TBS2074 oscilloscope, with probes:
  - P5205 differential voltage probes, which connect to the scope through TPA-BNC adapters
  - A6302 current probe, which connects to an AM503B amplifier, whose output goes to the scope through a $50\,\Omega$ terminator
- A Tenma power supply, used in place of the Magna-Power when current ratings are very low
- A handheld tachometer

Subsequent sections will detail each piece of equipment. Most equipment is operated through LabView.

You will notice that there is a mix of safety sockets and twist lock sockets. The safety sockets are compatible with standard banana plugs, or with the special plugs that have a plastic shield for safety. The twist lock sockets work with twist lock plugs: insert and twist slightly clockwise for a sure connection. Current ratings are not an issue for our purposes, but the twist lock connections are more reliable. Cables are illustrated in Figure 1. **When possible, use twist lock plugs.**

2 Rack-Mount Equipment

2.1 Fluke 8845A DMMs

The rack includes three Fluke 8845A DMMs, as shown in Figure 2. A drawing of the front panel taken from the Fluke user's manual is given in Figure 3. The items we will be concerned with are:

- Input terminals (1): to measure voltage, with HI = positive, LO = negative

Figure 2: Rack-mounted Fluke 8845A multimeters

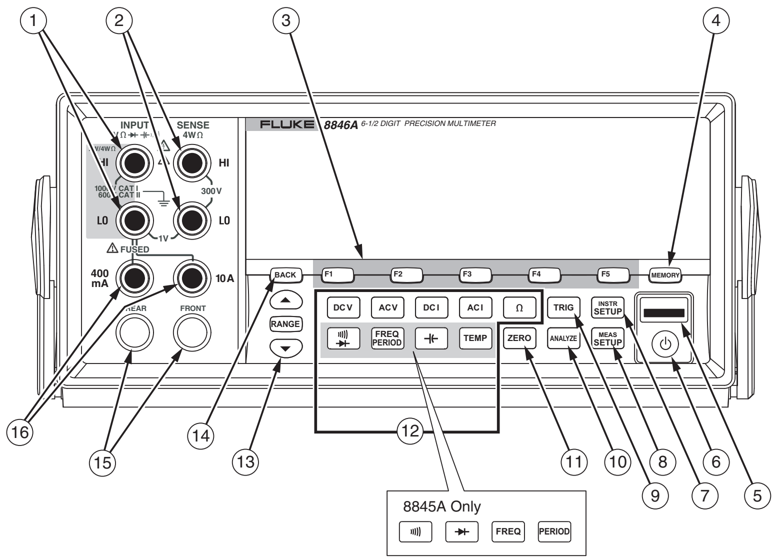


Figure 3: Fluke 8845A front panel

- Input terminals (16): to measure current, with positive current going into the appropriate terminal and out of LO; unless otherwise stated, use the "10A" terminal
- Buttons (12): to configure the measurement, if not using LabView

Throughout all your work, **the FRONT button should be pushed in** (buttons labeled (15)).

In some cases, you will want to measure current and voltage simultaneously. This may be achieved by putting the ammeter in the negative branch, since the voltage and current share the LO terminal. Be aware that this may change the sign of the voltage or current from what you would prefer.

A mapping between the physical equipment and images you might find on a schematic is given in Figure 4.

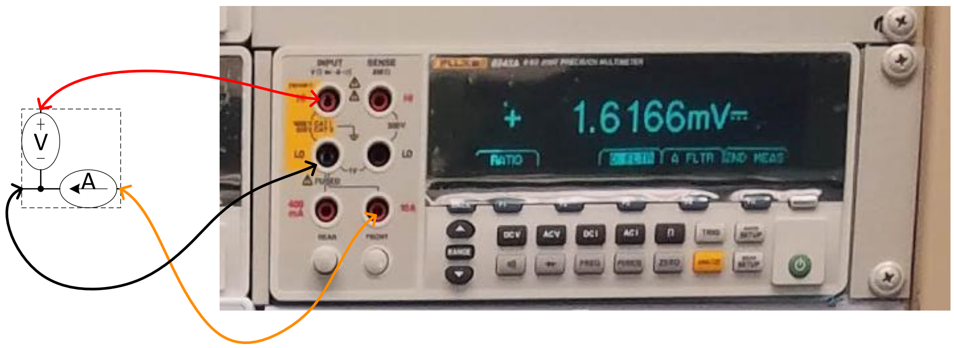


Figure 4: Mapping of Fluke 8845A terminals to schematic.

2.2 Yokogawa WT333E Power Analyzer

The WT333E provides a variety of ways to measure power in a single- or three-phase system. There are three channels, each of which measures current and voltage. In this case, the color code is slightly deceptive:

- Voltage terminals are red and black, just as for the Fluke 8845A, indicating polarity
- Current terminals are red-black-blue, but mean channels 1-2-3

As we will see in the power measurement lab, there are two ways to measure three-phase power. In the three-wattmeter method, channels 1-2-3 correspond to phases A-B-C. In the two-wattmeter method, only channels 1 and 3 are used.

A mapping between the physical equipment and images you might find on a schematic is given in Figure 5. Only channel 1 is mapped. Notice that for each channel, the current and voltage connections are separate, and the schematic will indicate two negative voltage connections although there really is only one. In essence, the Yokogawa channel is a separate voltmeter and ammeter, whereas the schematic is drawn for a two-port because that's the way it is used.

2.3 VFD

The next module of the rack contains a variable frequency drive (VFD), Nidec M751-01200065A10101AB110, along with some protection devices. Use the three-phase twist lock to connect to an induction motor or PMSM. Also use the DB15 to connect to the feedback device on the PMSM. The red-black-blue-white-green safety sockets are provided as points to probe.

As of this writing, the dc socket is not connected to anything.

The VFD may be powered on with the rotating power switch. All control occurs via LabView. A mapping between the physical equipment and images you might find on a schematic is given in Figure 6.

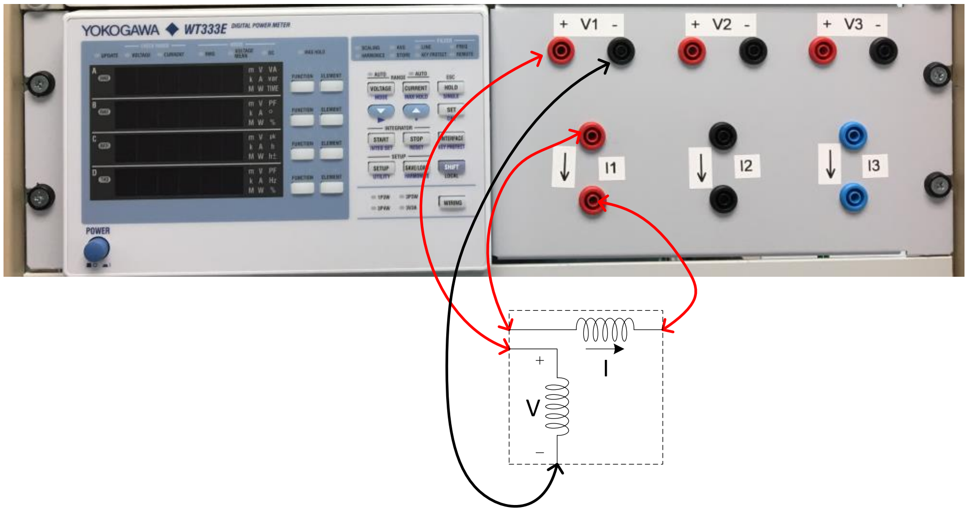


Figure 5: Mapping of channel 1 of Yokogawa to schematic

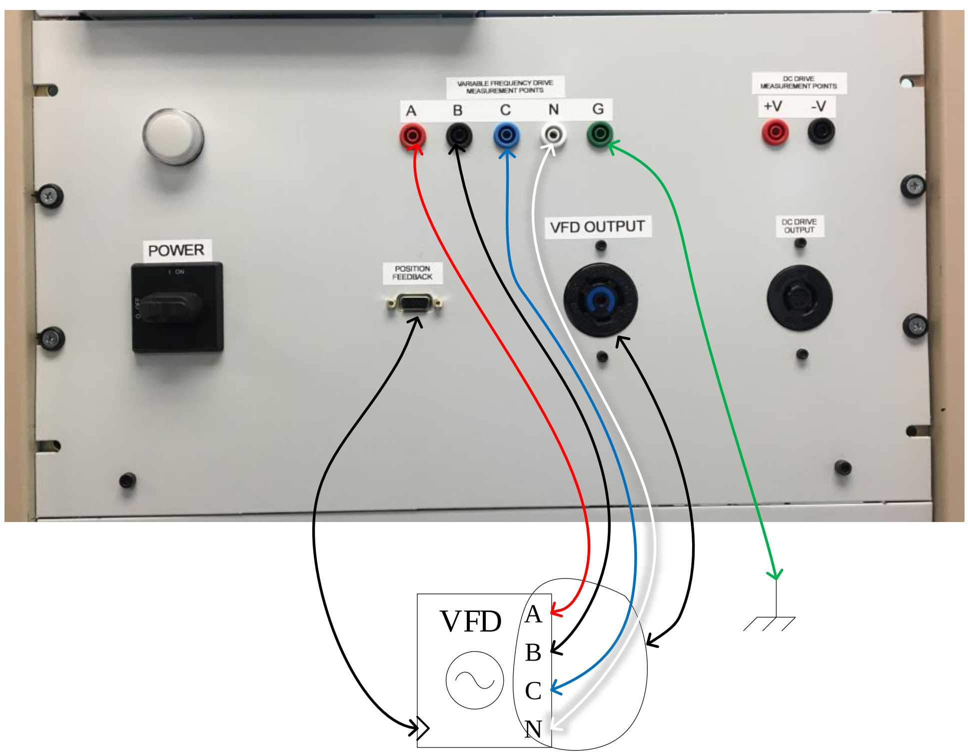


Figure 6: Mapping of VFD rack to schematic.

2.4 Variac and Variable DC Source

The next rack contains:

- Three-phase switch that activates both the variac and variable dc
- Three-phase variac, which enables the user to vary the output voltage magnitude (labeled in percentage)
- Three-phase twist lock for the output, as well as corresponding safety sockets to probe voltage
- Voltmeter for the three-phase source (after the variac), which measures line-to-line RMS
- A rectifier and capacitor to provide a variable dc source
- DC twist lock for output, as well as corresponding safety sockets to probe voltage
- Voltmeter for the variable dc source

The variable dc source is derived from the output of the variac, and will normally be around 1.4× the line-to-line RMS of the three-phase source (ranges 1.35 to 1.41). This dc source is **NOT ISOLATED**, so use with caution.

There are also breakers on the three-phase source and a fuse on the dc source. If this rack is not working, check these protection devices first.

A mapping between the physical equipment and images you might find on a schematic is given in Figure 7. Although drawn as if you were using the safety sockets, you should instead use the twist lock sockets. The green terminal is chassis ground.

2.5 Magna-Power Supply

The Magna-Power dc supply is a high-performance, isolated dc source that may be readily controlled via LabView. It is capable of providing 250 V, 40 A, 10 kW, with programmable voltage and current limiting. This is more than enough for our purposes.

2.6 Switched three-phase mains terminals and Magna-Power terminals

The last section of the rack has a switch, the three-phase source (upstream of the variac—nominally 208 V), and connections for the Magna-Power. Because of the current rating, the Magna-Power does not have front-terminal connections. Both twist lock and safety sockets are provided. A mapping between the physical equipment and images you might find on a schematic is given in Figure 8.

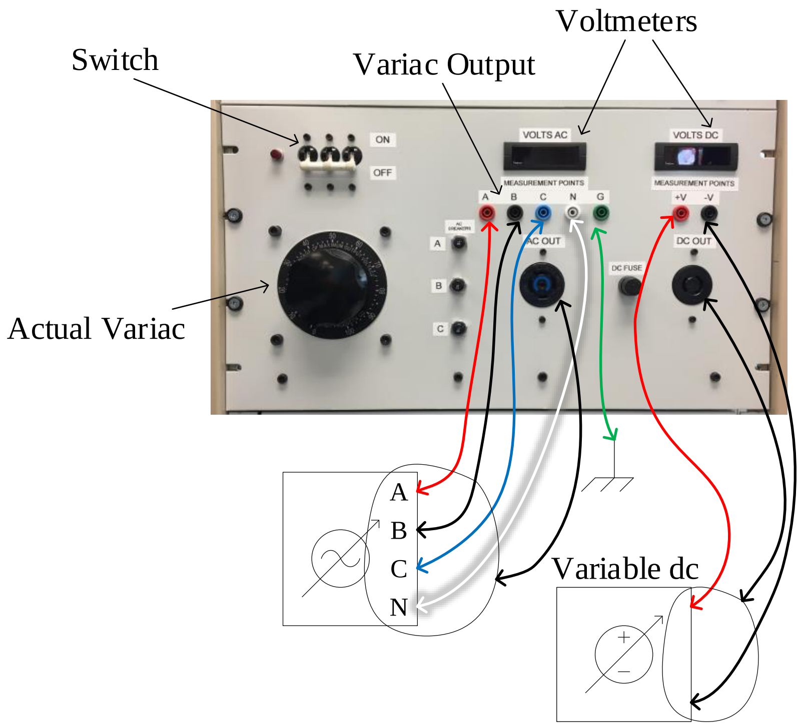


Figure 7: Mapping of variac rack to schematic; use safety sockets to probe voltage, twist lock for power flow.

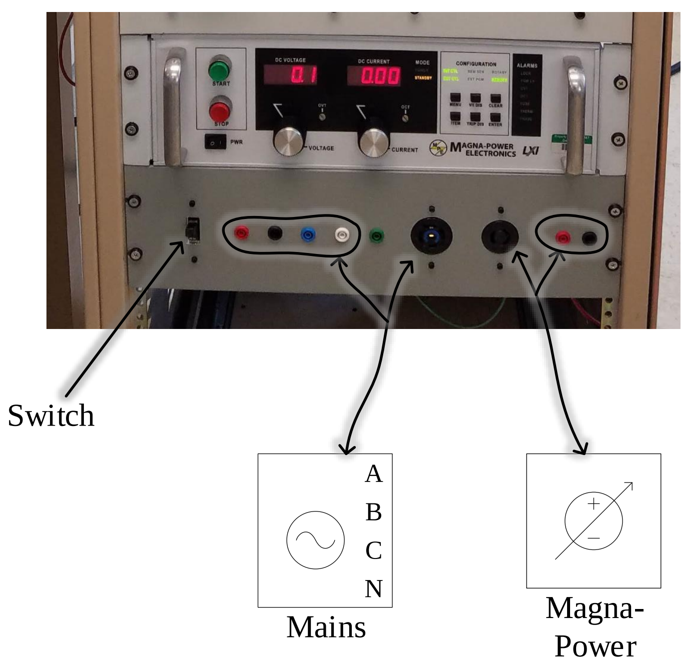


Figure 8: Mapping for three-phase mains and Magna-Power to schematic symbols

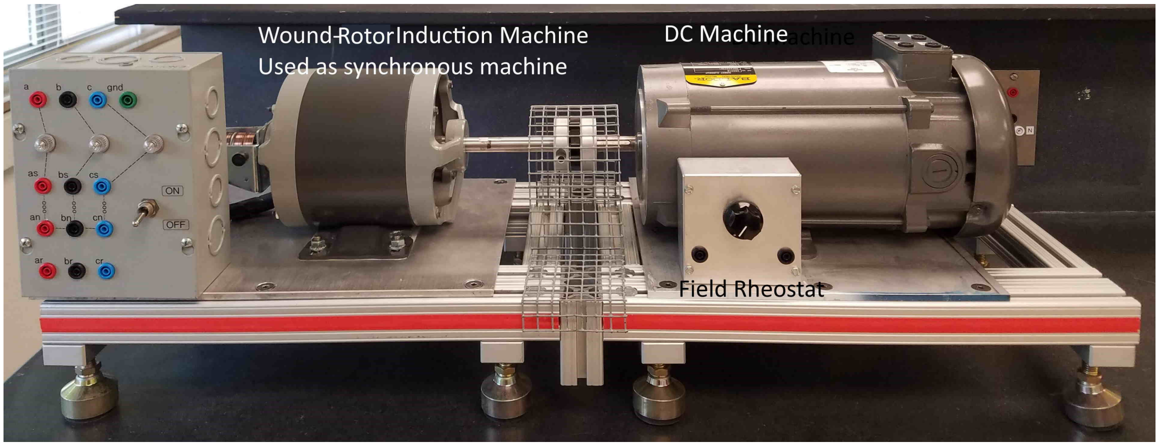


Figure 9: Dynamometer with wound-rotor induction machine (used as synchronous) connected to the dc machine.

2.7 Distinguishing Sources

In various experiments, there will be different three-phase sources used. They will be identified as:

- **VFD**—used only to drive a motor, clearly identified
- **Variac**—used when a variable ac voltage is needed; remember that there is a switch *and* a dial
- **Mains**—the connections at the bottom of the rack, which go directly to the source; there is a switch, but *no* dial; also called three-phase mains

Similarly, there will be different dc sources used, identified as:

- **Variable dc**—the dc output on the same rack as the variac; **not isolated**, easily adjusted with the dial
- **Magna-Power**—the large power supply with an output at the bottom of the rack; high power, programmable, precise
- **Tenma**—the small power supply on the bench; low power, programmable, precise

3 Benchtop Equipment

3.1 Dynamometer and Machines

The centerpiece of the bench equipment is the dynamometer (dyno), which consists of a dc machine (essentially permanent) and a second machine that varies. Figure 9 shows the dyno set up for the synchronous machine experiments. Although the actual machine is a wound-rotor induction motor, we use it as a synchronous machine.

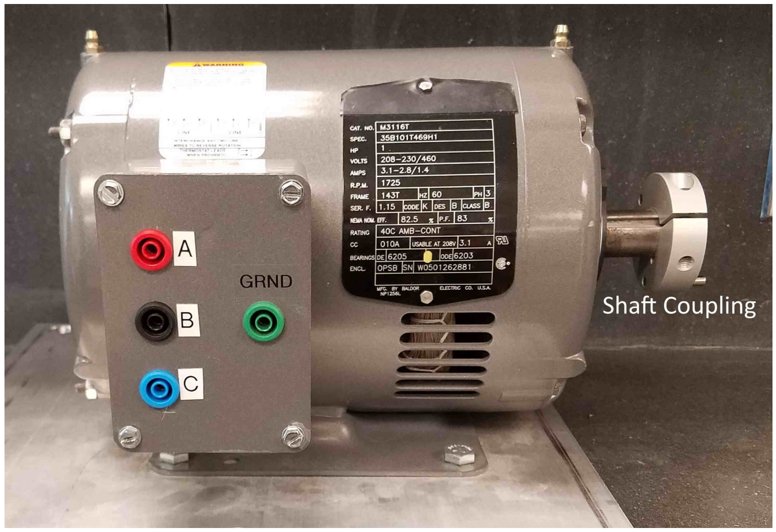


Figure 10: Induction machine

The dc machine connections are on the top, labeled A1 and A2 for the armature, F1 and F2 for the field. In some experiments, we need to vary the field resistance using the field rheostat mounted on the baseplate.

The coupling between the two machines is covered with the protective grill. However, **the spinning shaft is still dangerous!** Use caution, especially with jewelry or long hair.

The connection box for the wound-rotor induction machine includes rotor-side three-phase, stator-side three-phase plus neutral, and three phases after synchronizing lights. When operated as a synchronous machine, these lights and the switch are used to connect to the grid.

An example induction motor is shown in Figure 10. The ground terminal is usually not used, except perhaps for the VFD experiment. When performing a blocked-rotor test, a white plastic piece is placed on the shaft coupling.

A permanent-magnet synchronous machine (PMSM) is shown in Figure 11. The connection box provides access to both the stator and the feedback device (encoder).

The shaft speed needs to be measured in virtually all machine experiments. A handheld tachometer, shown in Figure 12, is used. There is a light that shines out of the top, which must be directed to the reflective tape mounted on the dc machine shaft.

3.2 Transformer

Each bench has three identical transformers, one of which is shown in Figure 13. Each transformer could be connected in various ways to achieve various voltage ratings, but has been pre-configured to support high voltage (208-277 V) on the primary and low voltage (120 V) on the secondary. The internal schematic is visible on the transformer label; the safety sockets include pre-connecting H2 to H3, X1 to X3, and X2 to X4.

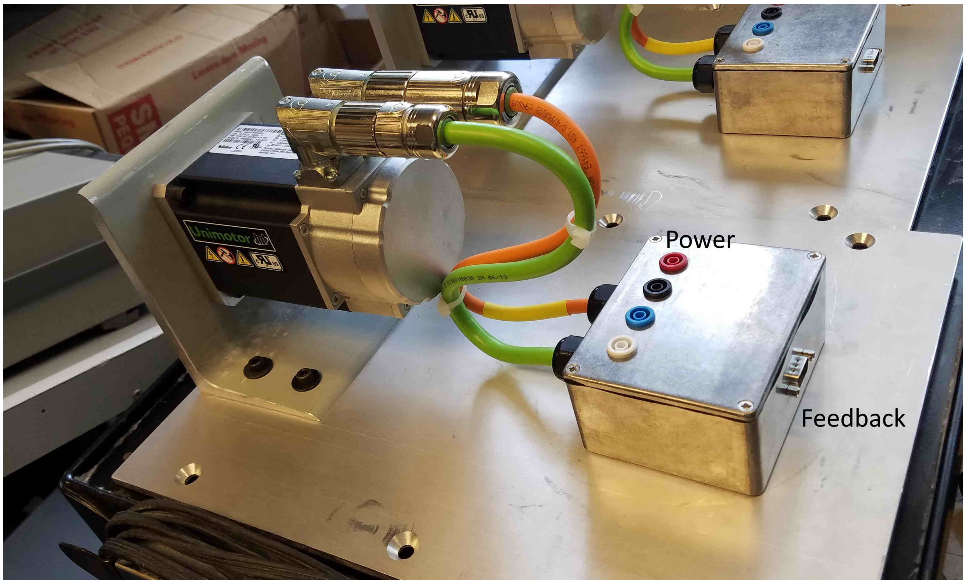


Figure 11: Permanent-magnet synchronous machine.

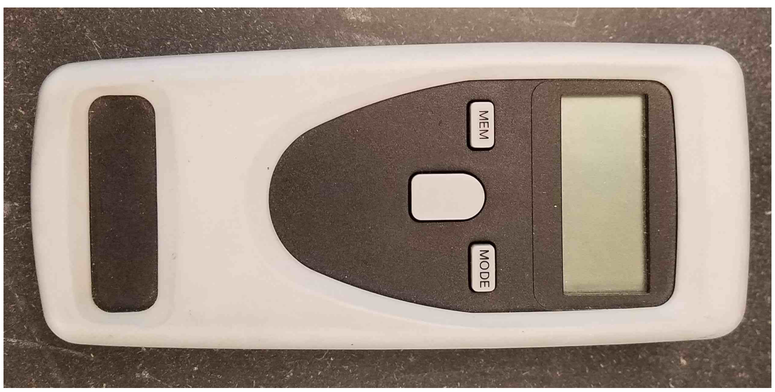


Figure 12: Handheld tachometer

Figure 13: Lab benchtop transformer

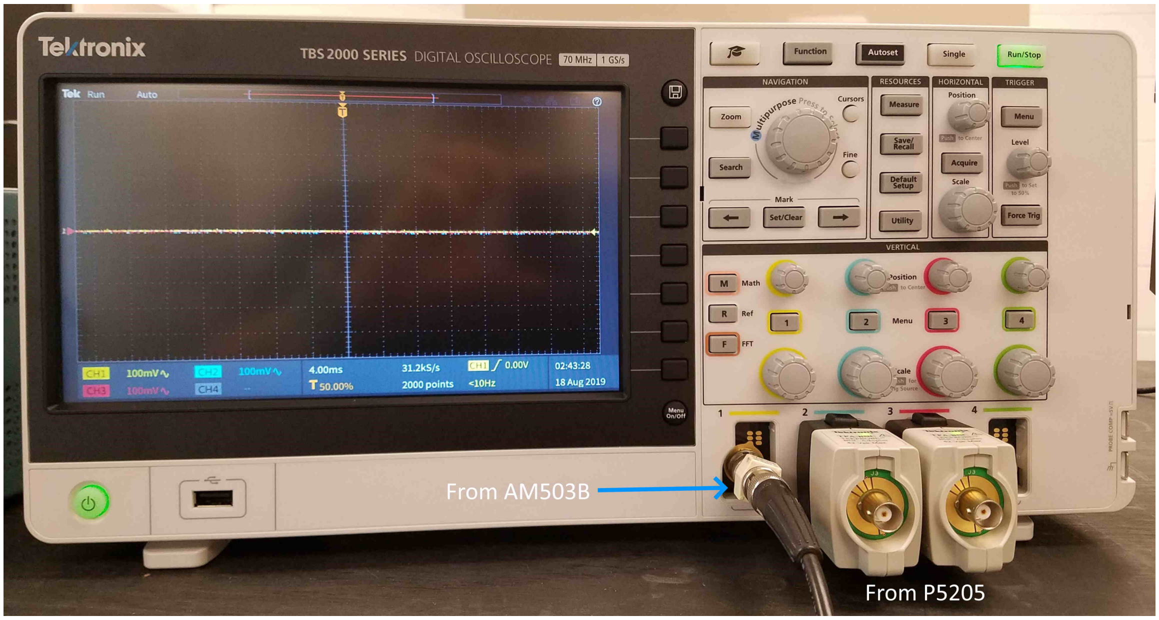


Figure 14: Tektronix TBS2074 oscilloscope, with two TPA-BNC adapters installed

3.3 Oscilloscope and Probes

Figure 14 shows the Tektronix TBS2074 oscilloscope. This is a fairly new model with four channels (of which we will only use three) intended to be used with TekVPI probes. Its analog bandwidth is 70 MHz, well beyond our needs. The LabView interface will capture the raw data rather than a screenshot, so that you may perform post-processing.

A conventional scope probe measures the voltage between the probe tip and ground. The little alligator clip is ultimately connected to the chassis, which goes to the third prong of the line cord, which goes to earth. In most circuits, this is great. In power circuits, though, this poses a huge problem. How can you measure line-to-line voltage if your probe has one lead connected to earth? If you try to do so, you will damage the scope.

Therefore, we use isolated differential probes, Tektronix P5205, shown in Figure 15. The red and black leads from the P5205 will plug directly into safety sockets. The output cable is intended to plug into a TekProbe oscilloscope. Since the TBS2074 supports only TekVPI, adapters are needed (visible in Figure 14). Also, the P5205 has a few different options. The attenuation should normally be set to 500X. The bandwidth can be limited if your signals are too noisy.

We also need to measure current, for which we use A6302 current probes, which are **FRAGILE**. A drop from as little as a few inches can irreparably damage the probe! Figure 16 illustrates the probe itself. There is a slide that opens the probe to clamp around a wire. Notice that there is a small white arrow on the part that slides, which indicates the current polarity. The black slide needs to be pushed all the way up to lock the probe.

These current probes need external amplifiers, shown in Figure 17. The amplifiers produce a signal that is most appropriately measured with the oscilloscope set to 10 mV/div. The connection between the amplifier and the scope uses a standard 50 Ω cable, which needs to be terminated for proper results. To properly use a current probe, follow these steps:

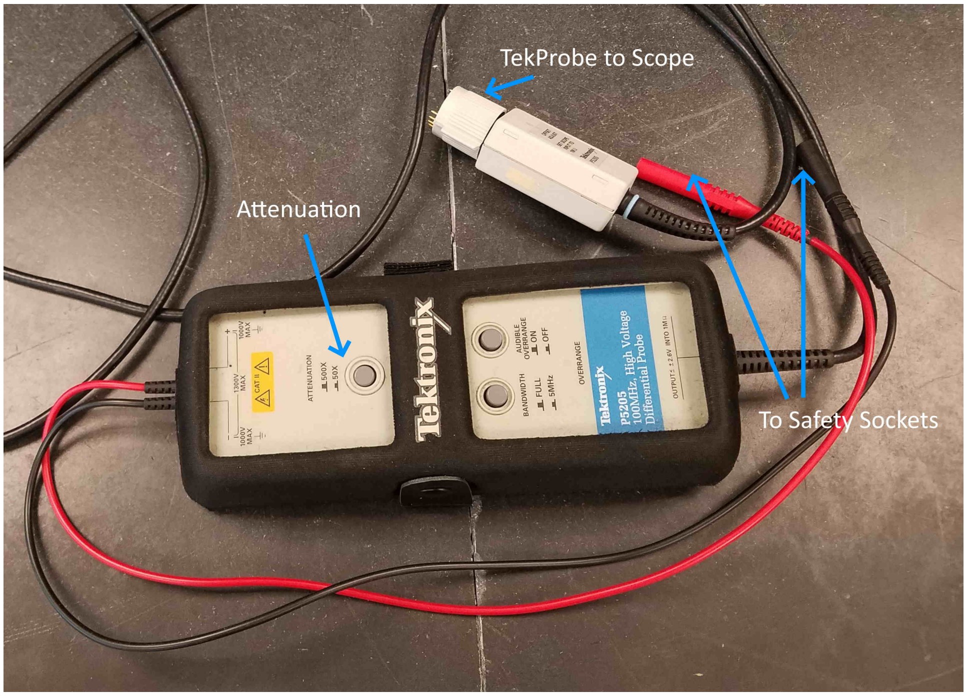


Figure 15: Tektronix P5205 differential voltage probe

(a) Profile

(b) Unlocked

(c) Locked

Figure 16: A6302 current probe

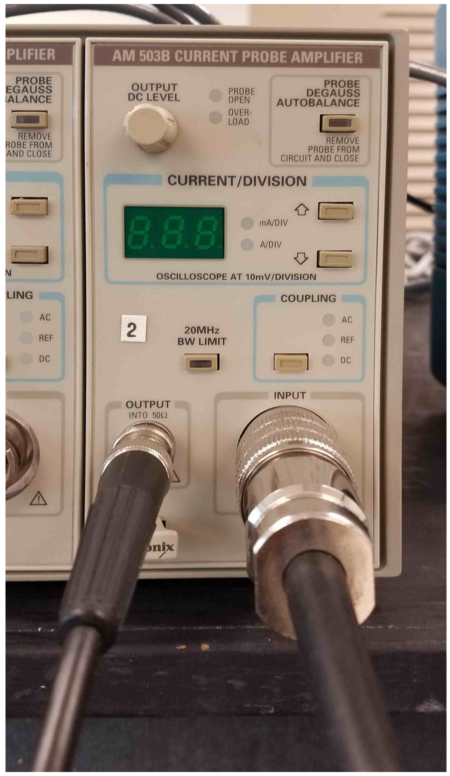


Figure 17: AM503B current probe amplifier

1. Turn on the AM503B mini-rack (switch is on the back). Allow the equipment to warm up—if you are going to be using the current probe at any point in the lab, turn it on at the beginning of the session. Also turn on the TBS2074.

2. If the AM503B is flashing an error code, press the “PROBE DEGAUSS AUTOBALANCE” button. You may need to do so multiple times.

3. Set the scope channel to 10 mV/div, dc coupled, 1X.

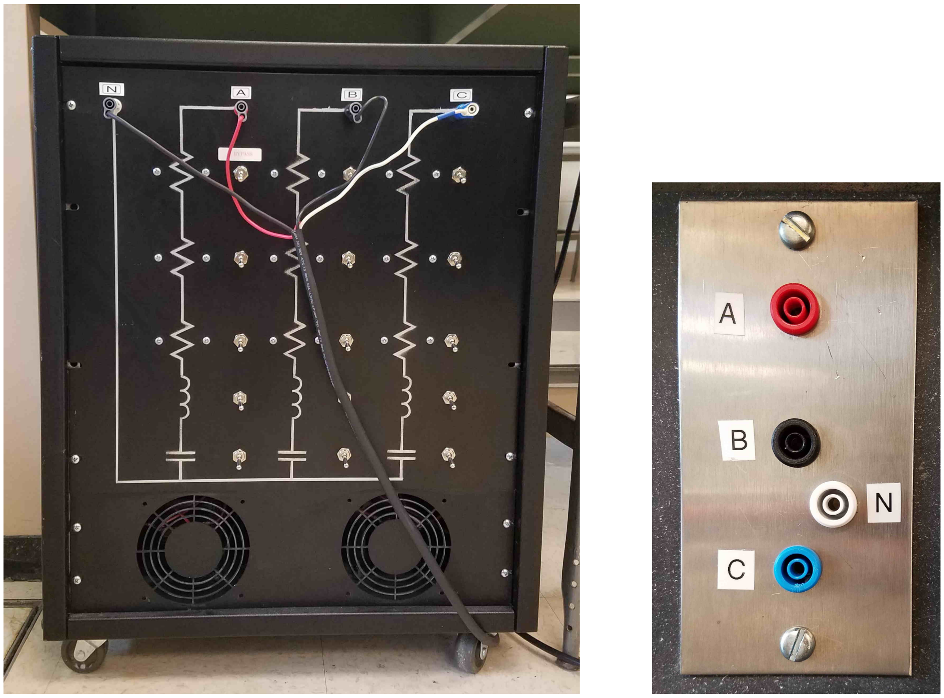
4. Set the AM503B to the appropriate current rating. Set its coupling to DC.

5. Close and lock the current probe, NOT on a circuit, just like in Figure 16c. On the AM503B, press the “PROBE DEGAUSS AUTOBALANCE” button. You will see some strange things on the scope and hear a bunch of clicking.

6. Adjust the “OUTPUT DC LEVEL” until the scope waveform is on zero. This is better than setting the scope to AC coupling for complicated reasons.

7. Put the probe on the wire whose current you wish to measure.

The signal may drift, especially its dc level, with time and temperature. Adjust the dc level periodically. If you cannot zero the level, or if the degauss light is flashing, remove the probe from the circuit and repeat the “PROBE DEGAUSS AUTOBALANCE” step.



(a) Actual Load Box (b) Bench Terminals

Figure 18: Load box and connection terminals

3.4 Load Box

The load box, shown in Figure 18a, contains a variety of loads configured in wye. For convenience, terminals are brought to the bench as shown in Figure 18b. A few cautions:

- Whenever you are using the load box, you need to turn on the fans. The fan switch is on the back of the box.
- Each phase has four different elements. Each element has a switch. If the switch is down, the element is shorted. Do not short all of the elements and try to apply power!
- When the switch is up, the element is engaged (that is, part of the circuit). Do not engage both the inductor and the capacitor at the same time! If you do, their reactances will cancel, causing resonance.

Each resistor is *nominally* $19.5\,\Omega$, though with significant variation (due mainly to connections). You will measure the inductance and capacitance in the first experiment.

3.5 Tenma

The Tenma power supply is the only other benchtop equipment you will use. (Other items are for a different course.) The front is shown in Figure 19. Do NOT use the GND terminal.

Figure 19: Tenma dc power supply

4 LabView Program

All of the instruments are connected to the lab PC and controlled using a LabView program, `C:\Users\Public\G10Lab\Labview_Project_Files\PowerLab_Main.vi`. There is one tab for each controlled device (with all three Flukes grouped together).

After opening the VI, click the "play" arrow. Any equipment that is turned on will be automatically connected. If you later want to use some additional equipment, make sure it is turned on, then click the appropriate "Connect...?" box.

There is a spot at the top to enter all lab group member names. That text will be added to reports. You can also choose a folder for saving files; use a directory on `S:\`. The station name is used to make sure the computer connects to all of the correct devices. If you click, "Generate Report," a Word document will be created with the data from all active devices. Also, every tab has a "Capture Image" button that takes a screen shot of just that tab.

When you are done, click the "STOP" button.

4.1 Oscilloscope

See Figure 20. Three oscilloscope channels are supported. For each one, you may set a gain. Voltage probe gain should be set at 1; all scaling is performed internally. Current probe gain depends on both the scope setting and the AM503B setting. For example, if the scope is set to 10 mV/div (as it should be) and the AM503B is on 0.5 A/div, the probe gain is

$$\frac{0.5}{0.010} = 50$$

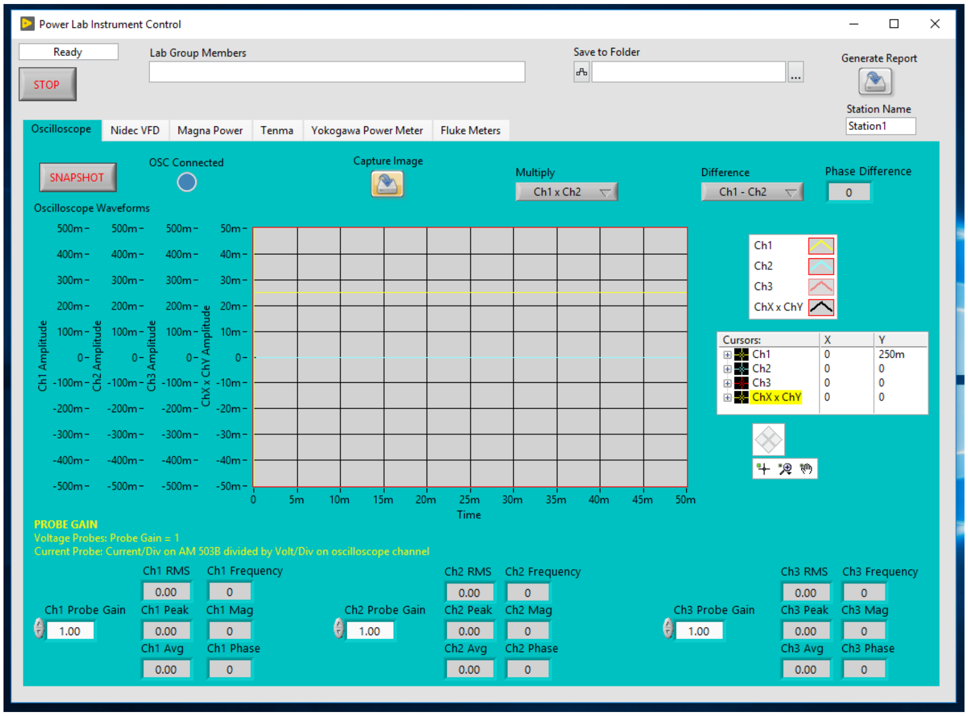


Figure 20: LabView tab for oscilloscope interface

The "Multiply" option is available to show instantaneous power; simply select which two channels correspond to current and voltage. The "Difference" option provides phase difference, e.g. between current and voltage or between primary and secondary.

When the TBS2074 is showing the waveform you want, click "SNAPSHOT" to capture the waveform. You can move cursors around the scope image. Click "Capture Image" to save a JPG of the Oscilloscope tab.

4.2 Nidec VFD

TBD

4.3 Magna-Power and Tenma

The Magna-Power and Tenma interfaces are essentially identical, as shown in Figures 22 and 23. You may set a voltage separately from setting a current. The supply will limit to the more restrictive of the two. So for example, if you give a voltage command but set the current to zero, the Magna-Power won't do anything. The current has to be slightly positive to allow some output.

4.4 Yokogawa

The Yokogawa WT333E has several operating modes, indicated as "Wiring" (see Figure 24). Regardless of the mode, data will be provided from all three channels individually. The

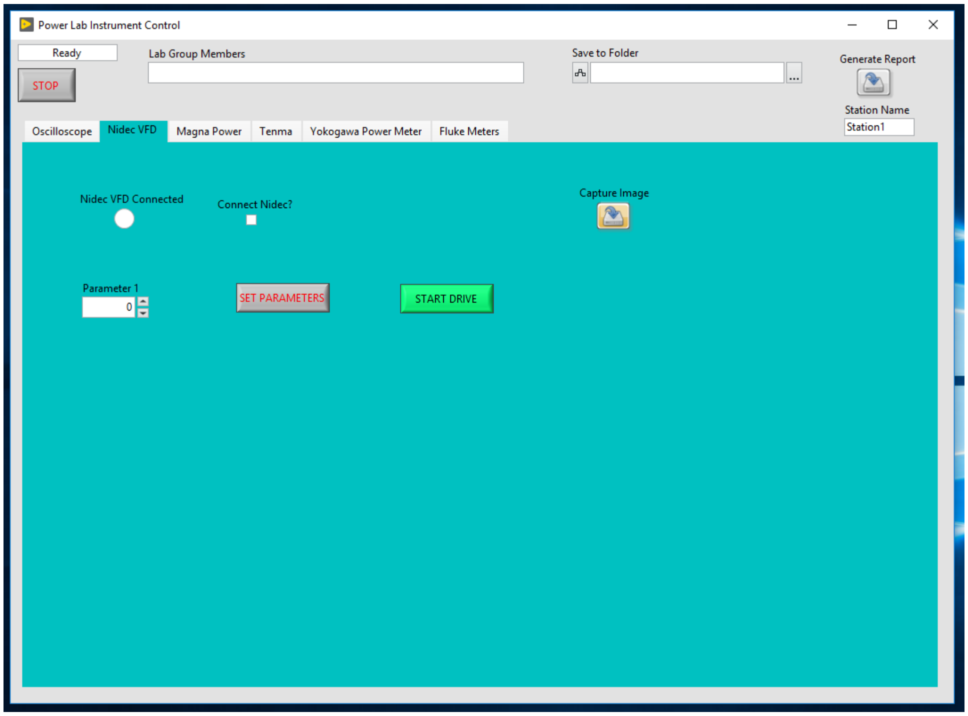


Figure 21: LabView tab for Nidec VFD interface

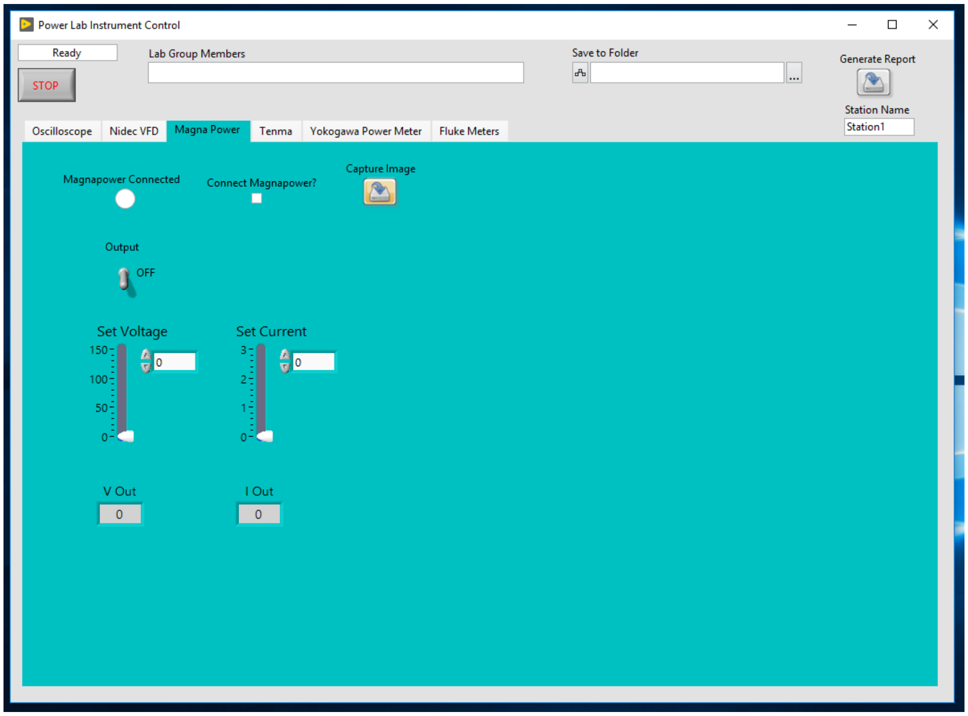


Figure 22: LabView tab for Magna-Power interface

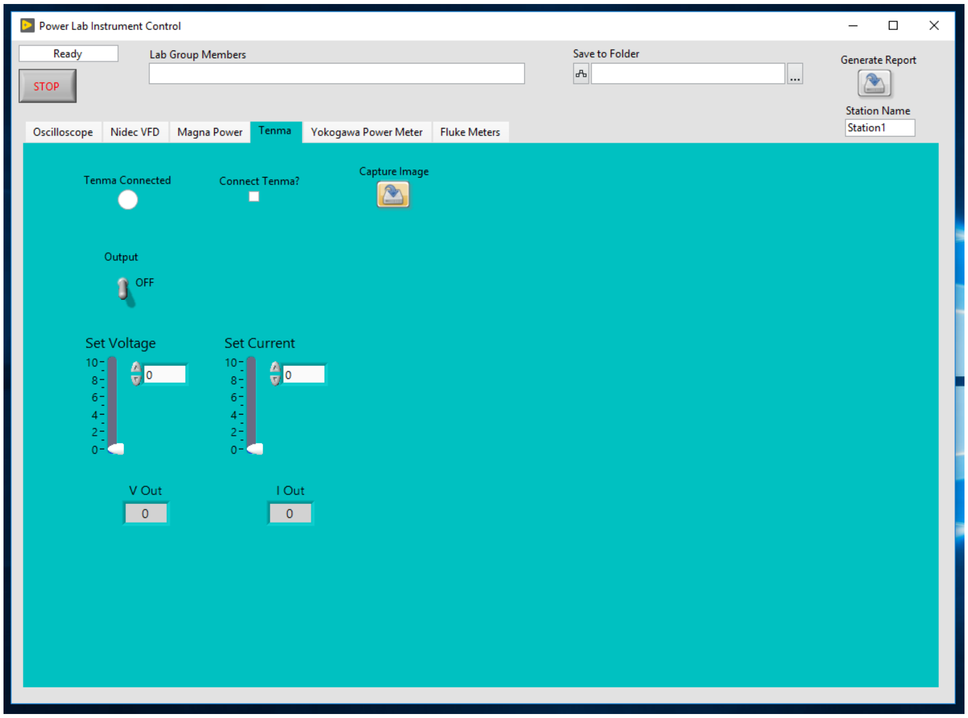


Figure 23: LabView tab for Tenma interface

last column of the table, Sigma (or on the device itself, Σ), provides the computed power. Configure the wiring to:

- 1P3W for single-phase; Sigma is not applicable
- 3P3W for two-wattmeter mode
- 3P4W for three-wattmeter mode

When you press "READ METER," all of the readings are sampled once and displayed. When you press "LOG DATA," the data will start sampling. Every second, the PC will receive the full table of readings and write it to the chosen file. When you press it again, the sampling stops.

4.5 Fluke Meters

All three Fluke 8845A digital multimeters are supported by a single tab, shown in Figure 25. All three Flukes support both primary and secondary measurements. If you only need to measure one thing on a given meter, simply choose that function (e.g. DC Voltage or DC Current). If you need to measure two things, check the secondary functions. The available secondary functions change depending on the primary. The most common combination you will use is DC Current primary, DC Voltage secondary.

When you press "GET MEAS," all of the measurements are sampled once and displayed. When you press "LOG DATA," all of the measurements will be sampled every second. When you press it again, logging stops and is saved.

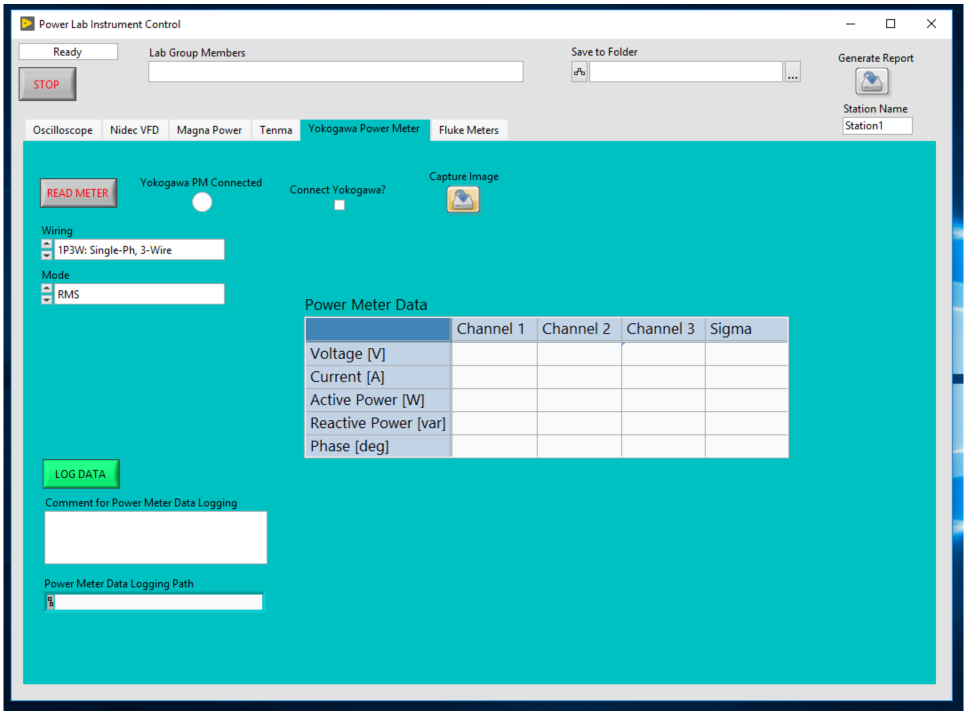


Figure 24: LabView tab for Yokogawa interface

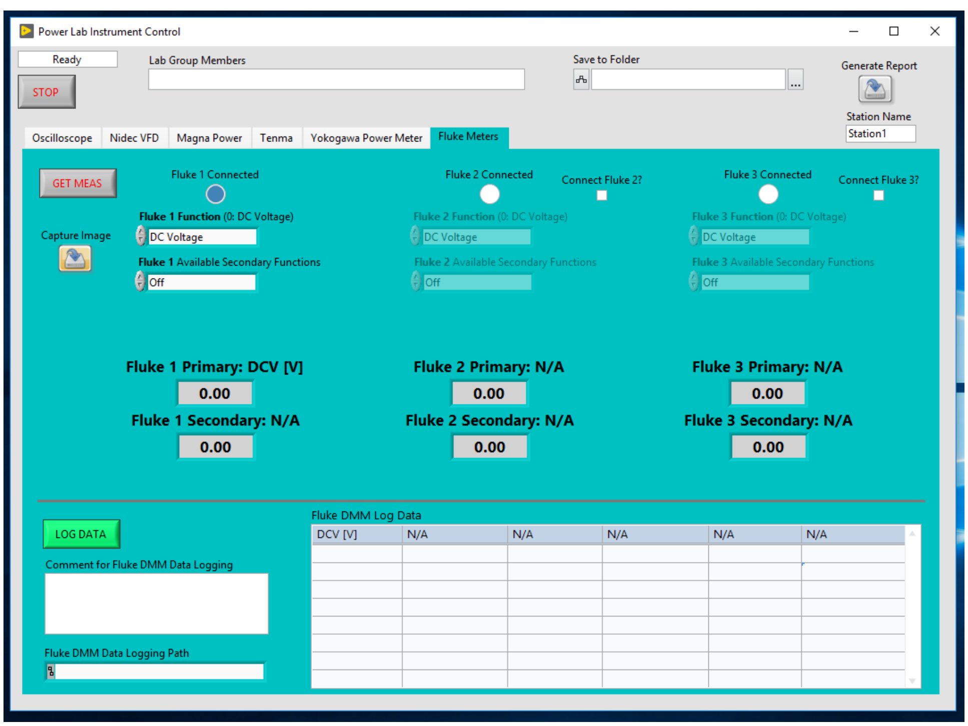


Figure 25: LabView tab for Fluke interface

4.6 Nidec Drives

The Nidec drive is described entirely in the description of Lab 7. It is important to make or break all connections *with the power turned off.* Also, there are sometimes communication issues between the drive and LabView. The first thing to try is to quit and re-start LabView. The second thing to try is to reboot the computer.

5 Typical Lab Sequence

This equipment supports two courses. They share many, but not all, experiments. For EE3501, Electromechanics Laboratory, the sequence is:

1. Power Measurements
2. Single-Phase Transformers and AC Excitation
3. Three-Phase Transformers
4. Solenoid Simulation
5. Synchronous Machines, Week 1
6. Synchronous Machines, Week 2
7. Induction Machines, Week 1
8. Induction Machines, Week 2
9. DC Machines
10. Motor Drives, Week 1 (induction)
11. PMDC Machine Simulation

For EE3541, Power Systems Laboratory, the sequence is:

1. Intro to MATLAB
2. Intro to Power World
3. Power Measurements
4. Single-Phase Transformers and AC Excitation
5. Three-Phase Transformers
6. Per Unit Calculations
7. Synchronous Machines, Week 1
8. Synchronous Machines, Week 2

9. Design with Power Flow (three-week PowerWorld experience)
12. Transmission Lines
13. Buck-Boost and Phase Shift Transformers

Notice that several experiments are common to both courses, but occur on different weeks.