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Using Industrial Test Equipment in an Undergraduate Electrical Machinery Lab Setting

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Abstract

To prepare engineers and engineering technologists for the "real world" work environment, it would be best if test equipment similar to that being used in industry was used in the laboratory. The problem with this is that most of the machines – transformers, motors, and generators – in undergraduate laboratories are considerably smaller than those in industry. Transformers are typically in the tens, or, at most, hundreds of volt-amperes and rotating machines are typically fractional horsepower. This means that in the lab the currents are usually in the milliampere range. Industrial test equipment is usually designed to measure in the kVA range. For example, the standard current probes on Fluke power meters are designed for 600 A. The smallest current probe available from Fluke that can handle both AC and DC is designed for 30 A.

This paper will discuss a method to allow industrial test equipment to be used in undergraduate labs. Our solution is to use multiple turns of wire (bobbins) in the current probes. Since these devices are not readily available, as part of the solution, an engineering design class was tasked to develop the bobbins that are used. The experiences of the students in the design of this solution are also presented. In the design process, several iterations of the bobbins were performed by one instructor/class while the bobbins were being used by another instructor/class. Finally, it is hoped that other universities can use the designs presented in their laboratories.

Tags: Industrial test equipment; undergraduate electrical machinery labs; voltage, current, and power measurements

Introduction

The driving force behind this work was the replacement of laboratory equipment that was over twenty years old and was no longer serviceable. Many other institutions are facing (and have faced) similar problems [1], [2], [3]. Two alternatives were investigated: 1) replace with similar educational-type equipment [4], or 2) reconfigure the lab with industrial-type equipment [5]. A cost comparison of these two alternatives is given in Table 1. It was found that the industrial-type equipment was $911.05 less per bench than the educational-type equipment. These values were based on the initial quotes, and with additional educational discounts directly from Fluke Corporation the final cost was $5,947.30 per bench.

In addition to costing significantly less, the industrial-type equipment also has a number of additional features not available on the educational-type equipment. The educational-type equipment was an improvement over the existing in that they were digital rather than analog meters. The industrial-type (Fluke) equipment provides waveform display and other advanced measurements in addition to digital readouts. A more complete list of features is given in the next section.

Table 1. Cost Comparison of Replacement Options

Alternative 1: Similar to Existing		
	Hampden Model ACVA-DA-100A – AC Volt/Ammeter with Digital Meters	$2,679.00
	Hampden Model DCVA-DA-100A – DC Volt/Ammeter with Digital Meters	$3,135.00
	Hampden Model ACWM-DA-100A – AC Wattmeter with Digital Meters	$2,797.00
	Total	$8,611.00
Alternative 2: Replace with Industrial-Type		
	Fluke 435 Series II Basic Power Quality and Energy Analyzer	$7,699.95

Description of the Industrial-Type Test Equipment

The Fluke 435 Series II Power Quality and Energy Analyzer (Fluke 435-II) is a standard piece of test equipment used throughout the electrical industry. The Fluke 435-II is fully compliant with the new IEC 61000-4-30 Edition 2 Class-A standard. This means that all measurements made will be consistent and reliable in accordance with the latest international standard. This device does not require traditional calibration. The measurement functions of the Fluke 435-II include:

- Voltage, Current, and Frequency
- Dips and Swells (Dips, Interruptions, Rapid Voltage Changes, and Swells)
- Harmonics
- Power and Energy
- Energy Loss Calculator
- Unbalance
- Inrush
- Event Waveform Capture
- Flicker
- Transients
- Power Inverter Efficiency

While this is an impressive feature set, and knowledge of this instrument will be very helpful to our graduates, the meter usefulness in a traditional undergraduate motors lab is suspect. The main problem is range of current measurement for the instrument. The seven current probes available for this device are given in Table 2. The smallest probe is designed to measure 30 A. This is ten times greater than the highest current typically measured in the lab. Therefore, the available current clamps are not appropriate for use in most undergraduate electrical machinery labs.

Table 2. Available Current Clamps for Fluke 435-II

MODEL NAME	DESCRIPTION	CURRENT RANGE
Fluke i30s	Fluke i30s AC/DC Current Clamp	30 mA to 30 A DC, 30 mA to 20 A AC rms
Fluke-i310s	Fluke i310s Current Probe	30 A and 300 A AC rms or ±45 A and 450 A DC
Fluke i400s	Fluke i400s AC Current Clamp	40 A Range 0.5 A to 40 A 400 A Range 5 A to 400 A
Fluke i430	Fluke i430 Flex 4 Pack	3000 A AC rms
Fluke i5S	Fluke i5S AC Current Clamp	10 mA to 6 A AC rms
Fluke i5sPQ3	Fluke i5sPQ3, 5 A AC Current Clamps, 3-pack	Same as Fluke i5S
Fluke-i6000s Flex	Fluke i6000sFlex AC Current Probe	60 A / 600 A / 6000 A AC rms

A photo of the Fluke 435 Series II Power Quality and Energy Analyzer is shown in Figure 1 below.

Figure 1. Fluke 435 Series II Power Quality and Energy Analyzer

Design of the Bobbin

In an effort to allow students to utilize industrial level equipment in their labs, we approached our CAD students to design a “bobbin” component where they could employ multiple wraps of wire. Asking second semester CAD students to design the bobbin introduced them to the design process while allowing them to experience variables that are, inevitably, part of any design project. While the electrical machinery lab instructor provided some basic design objectives, students needed to consider the ever-present constraints of time, cost, and manufacturing processes. In this respect, this design project gave students a much better experience than a static textbook problem.

While students would be using SolidWorks software to complete component and assembly files, the design process started on paper. Students were provided a basic sketch that conceptualized some of design objectives, basic shapes, and measurement ranges. They were also given an engineering drawing of the first banana jack as it was the only purchased component. Students also had access to the Fluke i30s Current Clamp as our bobbin would be used directly with this model.

Before beginning solid modeling, students needed to understand the limitations that come from utilizing a 3D printer as the primary means of manufacturing. They were instructed keep one surface on each component completely flat so that the parts could be created without the need for support material. This allowed the surface in contact with the heated bed to have better retention and surface finish.

Additive manufacturing allows the use of a wide range of materials, but being new to the 3D printing arena, students were limited to ABS and PLA. Both materials are relatively rigid, have a quality finish, and will be tolerant of human skin contact in the long term. However, ABS plastic is better prepared to handle a drop from a lab table and so students were drawn to that property. While ABS can warp near the heated bed during long print runs, the parts in this design were relatively small. In addition, having printed with PLA repeatedly, students were anxious to try ABS. In the end, students chose to do initial prints out of PLA material, while running finished products in ABS.

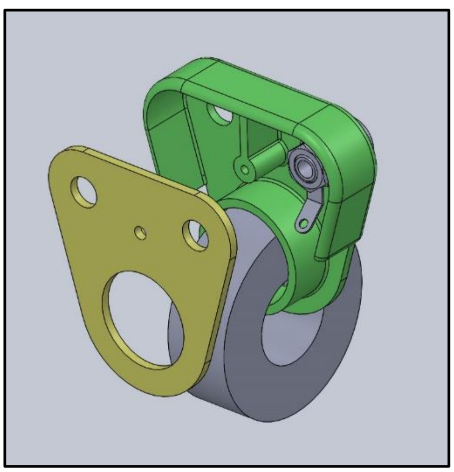

Figure 2. First Attempt with Enclosed Banana Jack

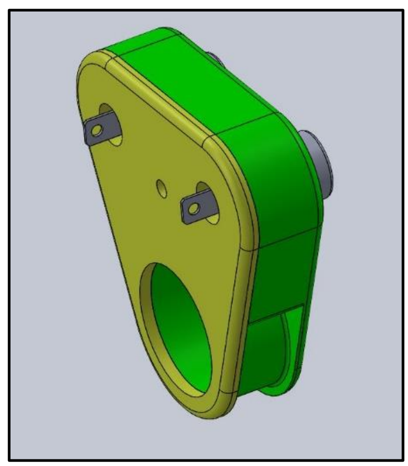

Figure 3. Second Attempt with Less Expensive Banana Jack

Before initial solid models were complete, cost considerations forced students to change to a second banana jack. This change can be seen by comparing Figure 2 and Figure 3 below. Despite eliciting groans, it was this type of “on the fly” change that made this project so valuable in terms of experience. Students learned the value of well-constructed solid model as we instituted necessary changes. Making small alterations to model geometry should be minimally disruptive during a software rebuild. This also brought up constructive discussions on real life

ECN (Engineering Change Notice) and ECO (Engineering Change Order) procedures and file management for part history. The final solid model can be seen in Figure 4.

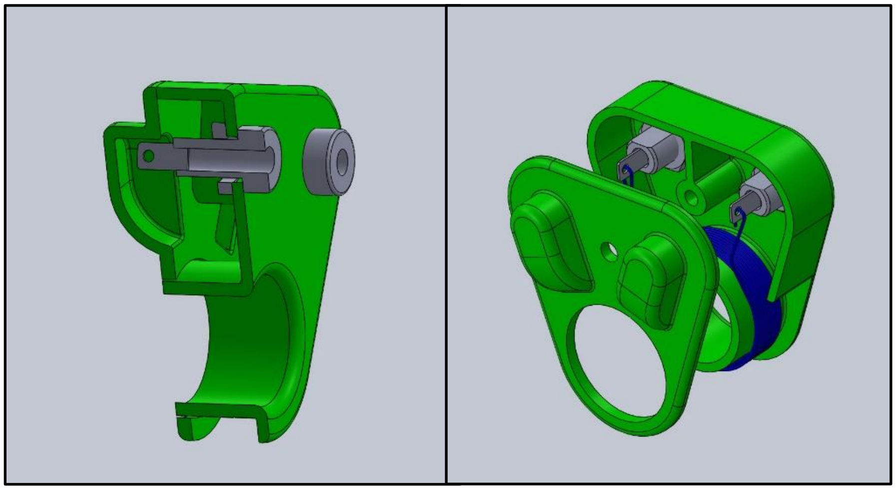

Figure 4. Final Solid Model

Initial product runs were created on two Lulzbot Taz 6 printers. These are new 3D printers for our Engineering Technology Department; consequently, students needed a few consistent prints before tolerances could be specified for the design. After each set of prints, holes and cut-outs were scrutinized and tolerances were adjusted for better fit. This reinforces the concept that a design engineer needs to know the manufacturing floor's capabilities to be an efficient and effective designer.

Figure 5. Open Completed Assembly

Figure 6. Closed Completed Assembly on Current Probe

Photos of completed assemblies can be seen in Figure 5 and Figure 6. Final assembly allowed students to verify tool clearance and view the entire assembly procedure.

Winding the Bobbins

The next step in the process was to wire the bobbins and solder the leads to the banana jacks. Since these bobbins will be used with low current, typically less than 3.0 amperes, the instructor choose a #18 AWG wire. According to NEC [6] Table 310.16, copper #18 AWG has an allowable ampacity of 14 amperes. Ten wraps easily fit on the fixture and soldering was straight forward. A completed bobbin with the wire installed is shown in Figure 7 and Figure 8. To assure that correct number of turns were used, the completed bobbins were placed on a current probe and then connected in series to compare them to a traditional ammeter.

Figure 7. Installing the Wire

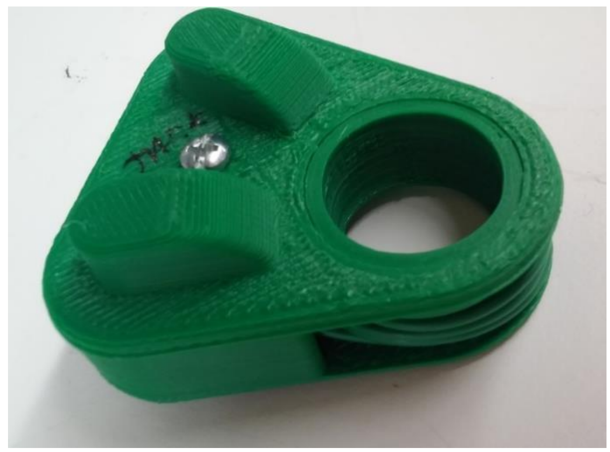

Figure 8. Completed Bobbin

Use in the Laboratory

The bobbin in use in the laboratory in shown in Figure 9. The design of the bobbin had an addition benefit that was not included in the initial specifications. The way the bobbins were designed allows for the test probe to lie flat on the bench. This makes adjusting the probe to remove offset (nulling) very easy.

In the figure measurements are being performed on a three phase induction motor. The connection for only one phase is shown in the figure for clarity. The nameplate for the motor under test in the experiment is shown in Figure 10. The rated current of the motor is 2.0 A. As noted earlier, the largest current typically measured in the lab is 3.0 amperes.

Figure 9. Completed Test Setup with Bobbin in Use in the Laboratory

Another benefit of using an instrument like the 435-II the scope feature. In addition to numerical display of voltage, current, and power, the voltage and current waveforms for up to three phases and neutral can be displayed. The phase shift between the voltage and current on the motor is clearly seen. Since many of our students are visual learnings, this aspect is very helpful.

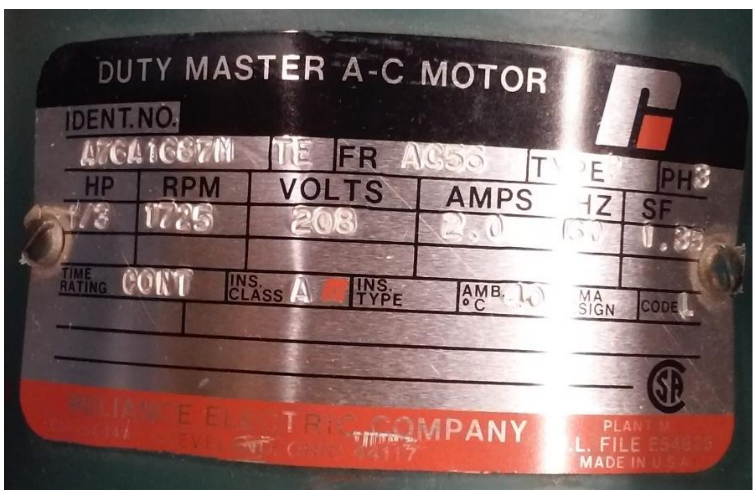

Figure 10. Three-Phase Induction Motor Nameplate

The Fluke 435-II usually displays apparent, real, and reactive power in kVA, kW, and kVAR, respectively. This makes experiments like the characterization of a transformer via open and short-circuit tests extremely difficult. When the real power is displayed as 0.01 kW, it could be anywhere from 9.50 W to 10.49 W. In this experiment the real power value is subtracted from the product of the voltage and current, which are given accurately and precisely in volts and amperes. The square root of the result is the equivalent leakage impedance. When a value of 10 W is used the calculated leakage reactance squared can often be negative! This will lead to an imaginary value for the impedance, which many students mistakenly believe is correct, since it is an inductance. With the ten-turn bobbin a ratio of 1.0 A/V is used for the current probe on the Fluke 435-II. This causes the meter to display in power in VA, W, and VAR. The students can now see the real power precisely, for example 9.65 W, allowing the calculations to be performed correctly.

The meter works on DC motor circuits in single phase mode. This is possible since a hall-effect current probe is used. With all these advantages, the Fluke 435-II with the new bobbins were a big hit with the students in the Motors Lab. No more blown fuses on their multimeter, no more imaginary values in their impedance calculations. They also appreciated that students from another class were helping to make their lab better.

CAD Course Student Feedback

The students in the CAD course were surveyed using Google Forms. The results are given below.

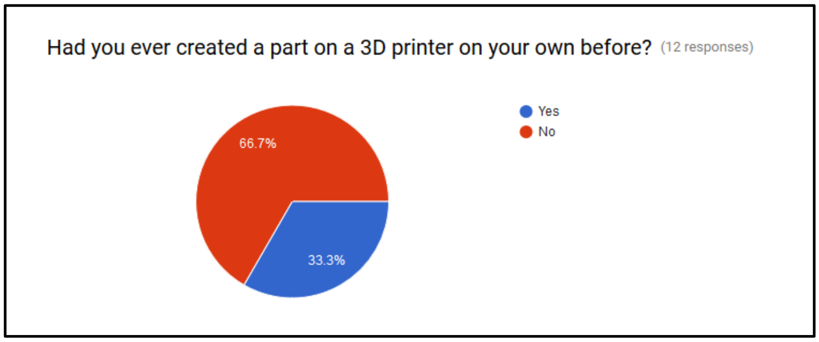

Figure 11. Survey Response on Experience with 3D Printing

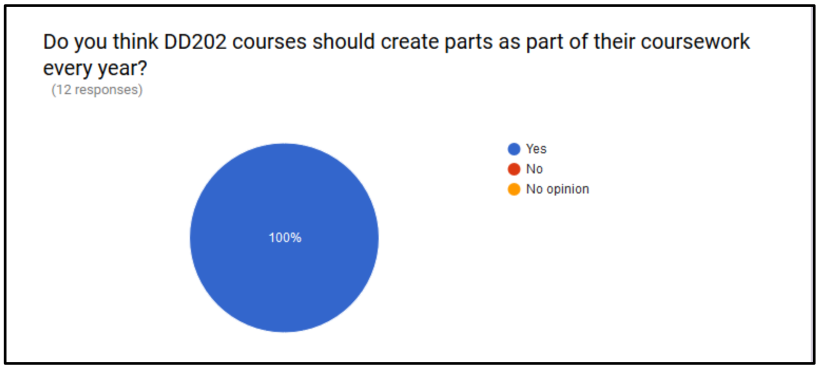

Figure 12. Survey Response to Future Similar Projects

The student responses to the prompt "If you could change/alter part of the assignment to print an object on the 3D printer, what would you change?" were:

- Possibly a more complex part
- Having more options for printing
- The only thing I would change is the option to have more available times to print
- More free form parts
- Nothing, very good first project
- I was very grateful to have the chance and would love to try some other things. It was very cool! Thank you.
- To not have the part change half way through making the part
- Make a part that will not have revisions in the future.
- None
- Maybe a part difference in fill

During class the students also stated that they were hopeful this project will lead to other similar projects as part of our Digital Drafting (DD) curriculum. Overall, the student response was extremely positive.

Conclusions

To prepare engineers and engineering technologists for the "real world" work environment, it would be best if test equipment similar to that being used in industry was used in the laboratory. The problem with this is that most of the machines – transformers, motors, and generators – in undergraduate laboratories are considerably smaller than those in industry. Transformers are typically in the tens, or, at most, hundreds of volt-amperes and rotating machines are typically fractional horsepower. This means in the lab the currents are usually in the milliampere, or at most, the ampere range. Industrial test equipment is usually designed to measure in the kVA range. For example, the standard current probes on Fluke power meters are designed for 600 A, while the smallest current probe available from Fluke that can handle both AC and DC is designed for 30 A. The test fixture described allows these meters to be used on test equipment in the laboratory. With a 1.0 V/A ratio setting for the current probe, the meter displays power in VA, W, and VAR, which allows for precise measurements.

Presenting students with real design problems can be problematic. Often a university department does not have the time or resources to finalize a solution. However, just as 3D printing has changed the face of industry and prototyping, it has changed the potential for our students. While not a large project in terms of physical size or number of items produced, this project still allowed students to create an original solution to a problem and see it through to fruition. Overall, project feedback from the students has been extremely positive. Students enjoyed the design phase and 3D printing; but also, learned the value of knowing the manufacturing process and recognized that being familiar with assembly can influence design.

References

[1] P. Gregory P. Harstine, P. Andrew E. Milks and J. A. Boley, "Low Cost Lab Equipment Implementation of a Machinery & Controls Course," in *2017 ASEE Zone 2 Conference*, San Juan, Puerto Rico, March 2 - 5, 2017.

[2] J. Park, "Design and Implementation of a Fundamental Electric Machine Laboratory Using Industrial Devices," in *ASEE Annual Conference & Exposition*, San Antonio, Texas, 2012 .

[3] E. Collins, "An Energy Conversion Laboratory Using Industrial-Grade Equipment," *IEEE Transactions on Power Systems,* vol. 24, no. 1, pp. 3-11, 2009.

[4] Hampden Engineering, "Series 100 - 1/3HP Meters," [Online]. Available: http://www.hampden.com/product-list.php?catid=206. [Accessed 17 03 2017].

[5] Fluke Inc., "Power Analyzer Fluke 435 Series II with Advanced Functions," [Online]. Available: http://en-us.fluke.com/products/power-quality-analyzers/fluke-435-ii-power-quality.html. [Accessed 22 3 2017].

[6] National Fire Protection Association, NFPA 70: National Electrical Code®, 2017.