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Teaching Power Circuit Breaker Testing to Undergraduates

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Abstract

Most educational electrical power laboratories do not have access to a working 69-kV SF_6 Puffer Circuit Breaker. At Northern Michigan University, a utility consortium has donated a Siemens SP-72.5-40, 1200 A continuous circuit breaker. The students perform travel time, insulation resistance, contact resistance, and power factor/dissipation factor testing on this breaker. This paper will discuss the problems encountered running these tests with undergraduates, including safety and power concerns. It will also discuss the student's interactions and their impressions of the testing; and look at methods to evaluate how well they learned the testing methods and the circuit breaker operational concepts. The travel time test requires that both 120 V ac (for the compressor) and 125 V dc (for the controls) be provided to the breaker. On the breaker tested, a large spring is used to open the interrupters, while a pneumatic system is used to close the breaker. A Doble TDR900 is used to perform the test. This test instrument has inputs for: 1) the linear transducer that measures the movement of the operating mechanism, 2) the status (open or close) of all three interrupters, 3) the current through the trip and open coils, and 4) the battery (or dc supply) voltage. It controls the circuit breaker tripping and closing so that trip, close, Trip-Free (CO), Reclose (O-C), C-O, O-CO, and O-C-O tests can be run. A Megger MIT525 is used to perform the insulation resistance and polarization index tests. This test also requires that the circuit breaker be powered, since the interrupters are tested in both the open and closed position. A DV Power Micro Ohmmeter RMO200G is used to perform the contact resistance test at 200 A. Finally, a Megger Delta 3000 is used to perform the power factor/dissipation factor tests at 10 kV. This test also requires that the circuit breaker be powered, since, again, the interrupters are tested in both the open and closed position. In addition to learning how to use the test equipment safely, the students must also learn the software to run the tests and collect the data. It is hoped, that this paper provides insight in testing large circuit breakers and suggestions for others that are interested in running these tests.

Travel Time Testing

The most complex test done on the circuit breaker was the travel time test. A TDR900 [1] by Doble Engineering Company was used for this test. The TDR900 controls circuit breaker trip and close commands and supports the following operations: Trip (O), Close (C), Reclose (O-0.3s-C), Tripfree (CO), O-CO, O-0.3s-CO, First Trip (O), and Slow Close (C). When performing circuit breaker timing and travel measurements, there are five primary signals that are of interest (the TDR900 records all of these values):

- Displacement (and with it Velocity)
- Contact State (Open-Resistor-Close)
- Trip Coil Current
- Auxiliary Contact State (OW-OD-C)
- Battery Voltage

The main contacts can take on three different states, OPEN, CLOSE, and RESISTOR. Some breaker applications require Pre-Insertion Resistors (PIRs). When the breaker performs a CLOSE operation, a resistor is placed across the open contacts for 8 to 12 milliseconds in order to limit potential overvoltage associated with long transmission line applications. The size of the resistor is based on the characteristic impedance of the line and the amount of line compensation. The exact amount of time the resistor is inserted before the main contacts close depends of the line length. Therefore, it is important to capture the operation, specifically, the timing of this resistor switch.

Setting up and Running the Test

The class as a whole sets up and runs the test working in teams. Only two hours is allotted for this test, so the testing cannot be done individually. (In other courses, such as ET 280 Protective Relaying, additional time is allocated so each student can do the testing individually.) The steps are as follows:

1. Check Circuit Breaker Status
    a. Check SF_6 pressure in the interrupters
    b. Check air pressure in the pneumatic system. If low, connect compressor to 120 V AC supply and allow to run until necessary pressure is reached
    c. Check battery or DC supply (see Figure 1) for proper control power

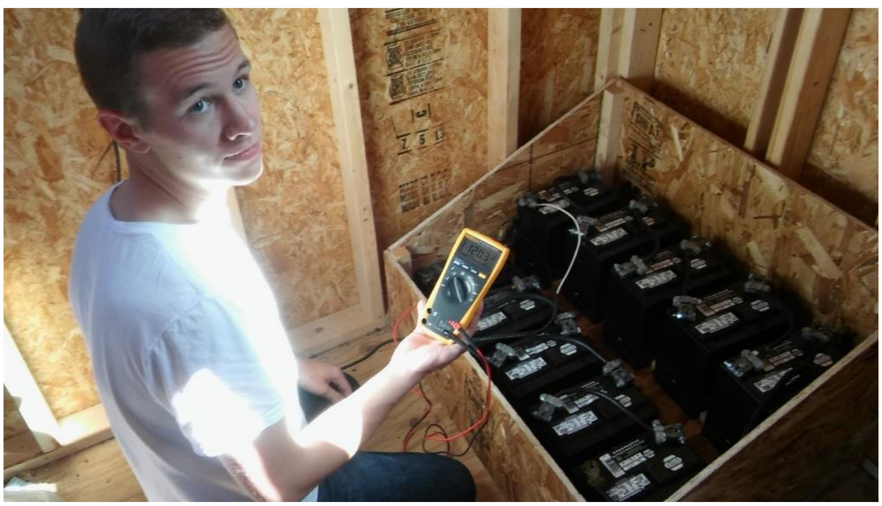

Figure 1. Student (David Wall) Checking the Battery Voltage

2. Make Grounding & Communication Connections
    a. Connect safety ground cable from the test set to the CB ground
    b. Connect the AC power supply cable from the test set to the 120 V AC supply
    c. Power up the test set. Wait two full minutes, even if the System OK LED is illuminated
    d. Connect the Ethernet crossover or USB cable from your laptop to the test set

3. Establish Communication Between Test Set and Laptop
    a. Start the T-Doble program on your laptop (students installed the software earlier)
    b. Select the Instrument tab in the T-Doble software
    c. Search for instrument, if necessary
    d. Select instrument and click Verify Connection

4. Connect Test Leads and Trip/Close Control Cable to TDR Instrument
    a. Connect cables for the circuit breaker terminals to the TDR900
    b. Connect Safety Switch to the TDR900
    c. Connect Trip/Close cable to the TDR 900

5. Make Circuit Breaker Connections
    a. Connect leads to circuit breaker high-voltage terminals (see Figure 2)
    b. Connect Trip/Close cable to control terminals inside circuit breaker cabinet

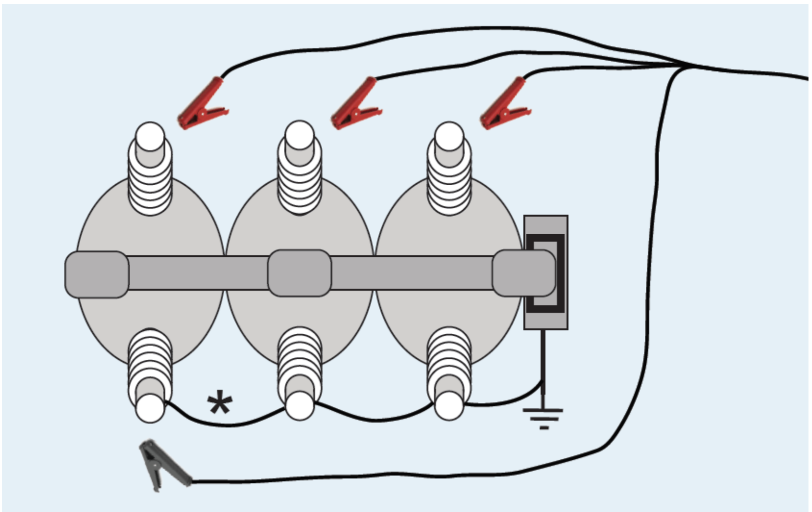

Figure 2. Circuit Breaker Connections for the Time Travel Test

6. Install Transducer (see Figure 3)
    a. Remove the clear plastic tube, open/closed indicator, and rod
    b. Screw on baseplate
    c. Attach motion transducer to bedplate with bolts and locking pliers
    d. Thread measurement rod into circuit breaker mechanism (use the threaded hole for the indictor rod)
    e. Latch the transducer rollers onto the rod

Figure 3. Displacement Transducer Mounted on Circuit Breaker with locking pliers and bolts

7. Run Test in T-Doble Software
    a. Select or create test plan.
    b. Click Run Test.
    c. When beeping begins, press and hold Safety Switch. The beeping then becomes a constant tone.
    d. When tone stops, release Safety Switch and view results.

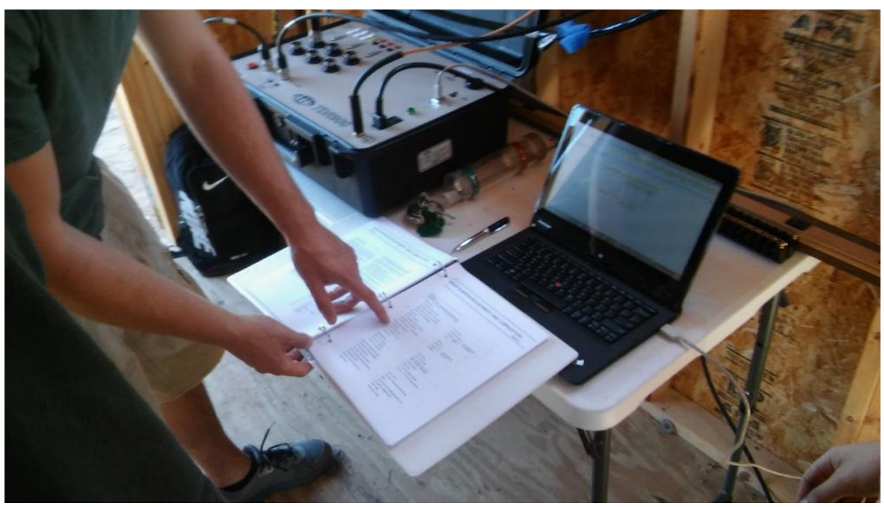

Figure 4. Students Creating the Test Plan for the Travel Time Test

Figure 5. Students (Trayton Duncan and Kevin Wood) Observing the Circuit Breaker Travel Time Test

8. Break Down
    a. Remove leads from apparatus
    b. Disconnect safety ground cable

Analyzing the Travel Time Test Results

Closing and Opening Time

According to [2] the time between when the close coil is energized and the contacts touch should be 90 to 100 milliseconds. As seen in Figure 6 and Figure 7, the time was 170.2 milliseconds.

Cursor Values

Cursors		Blue	Red
Close Command		1	0
Close Current	A	0.00	0.00
Motion-1	mm	-126.8	-24.3
Velocity-1	m/s	0.000	2.267
OCB-A	O-R-C	O	C
OCB-B	O-R-C	O	C
OCB-C	O-R-C	O	C
x-axis	ms	0.0	170.2
	samples	100	1802

Figure 6. Cursor Values from Close Operation Test

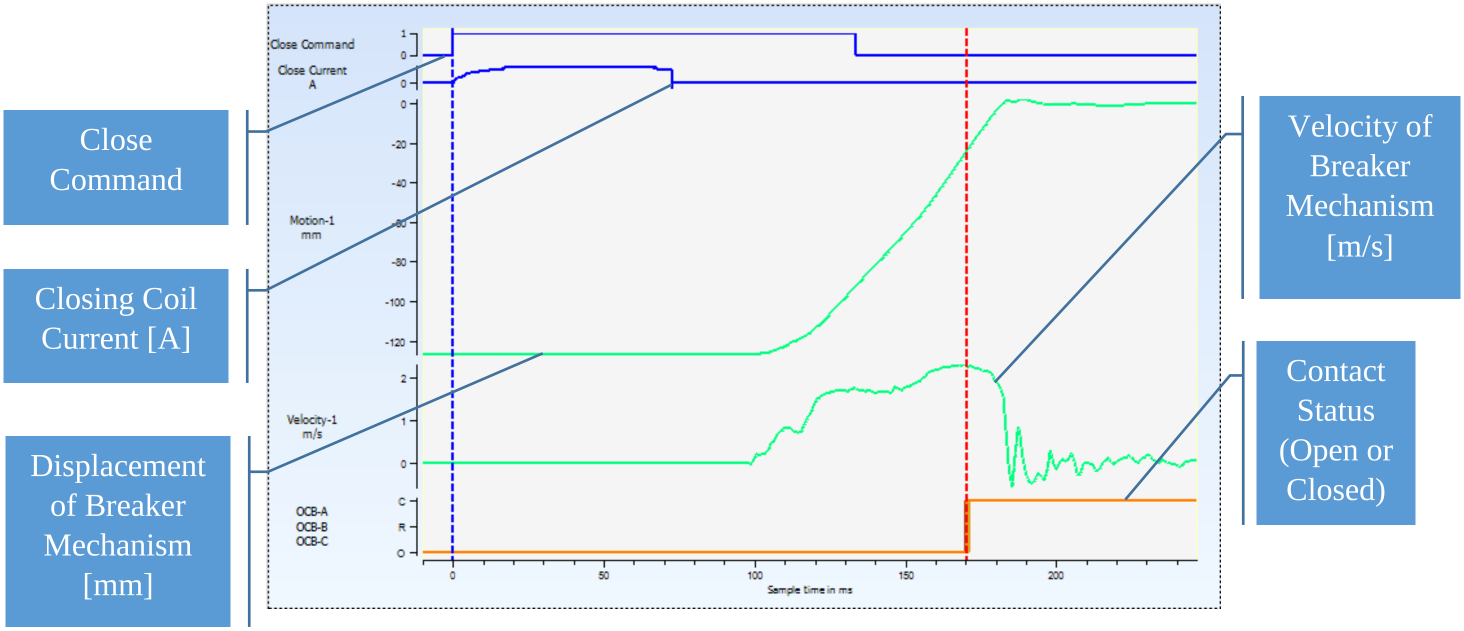

Figure 7. Data from Student Performed Close Operation Test

Opening and Closing Synchronization

The breaker opening and synchronization can be viewed as a group of openings and closings – the operation of all three phases together for a breaker open and close cycle. This information will indicate whether the breaker contacts open and close together or how far apart the three-phase contacts are relative to each other during the close and open cycle as shown in the Figure 8 for the circuit breaker closing.

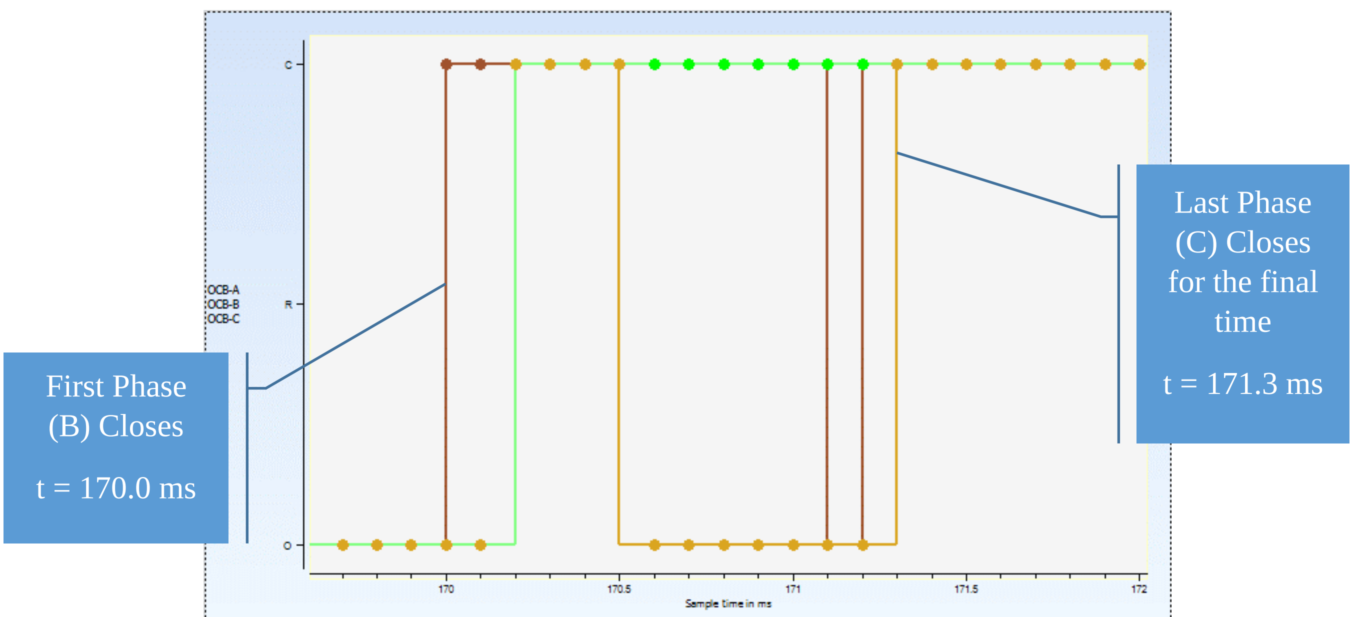

Figure 8. Contact State for All Three Phases during Closing

The normal maximum time difference between all three phases should not be more than two milliseconds for most breakers. The figure shows that the time from first phase closing to the last was 1.3 milliseconds.

Contact Bounce

Main Contacts, Resistor Switches, and Auxiliary Contacts can be analyzed for undesired bouncing. According to [3] contact bouncing is described as:

> *When a switch is actuated and contacts touch one another under the force of actuation, they are supposed to establish continuity in a single, crisp moment. Unfortunately, though, switches do not exactly achieve this goal. Due to the mass of the moving contact and any elasticity inherent in the mechanism and/or contact materials, contacts will "bounce" upon closure for a period of milliseconds before coming to a full rest and providing unbroken contact.*

Phase A in Figure 9 shows a typical contact close with no bounce. The next figure (Figure 10) illustrates bouncing of a main contact. Unusual bouncing of a main contact would be several or more bounces. If this occurs, the measurement should be repeated, and all connections should be checked. It may also be worthwhile to verify the presence of interference on the instrument cables from the circuit breaker or nearby equipment. In actual testing, if this problem is confirmed, it is recommended to follow-up with resistance measurements, both static and dynamic.

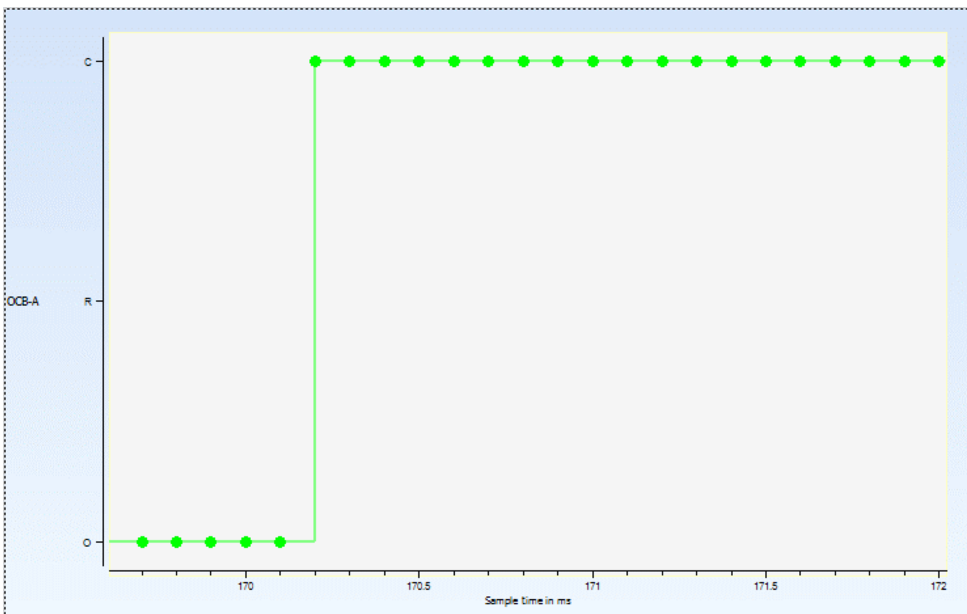

Figure 9. Example from Testing of a Typical Contact Close Operation

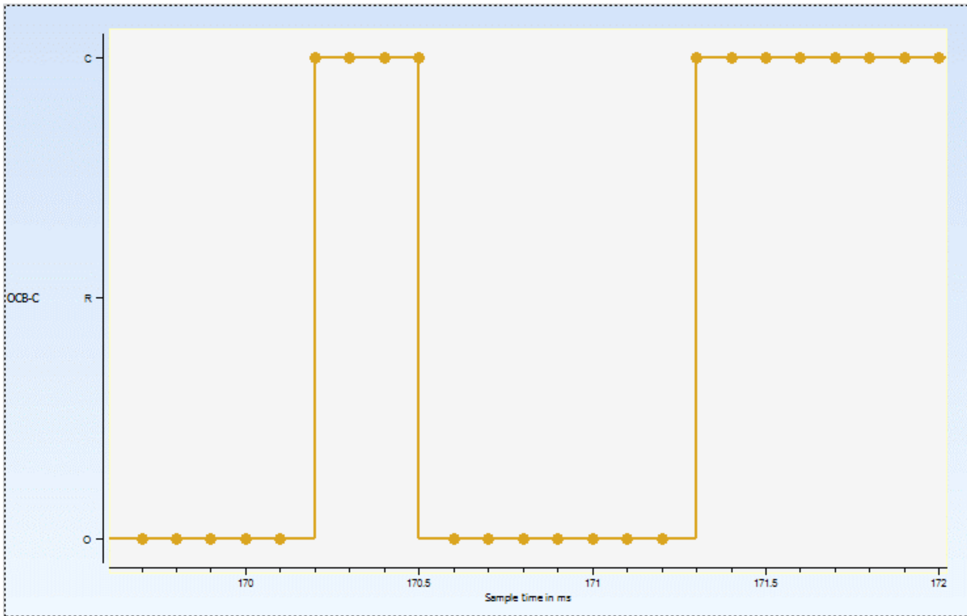

Figure 10. Example from Testing of a Contact Bounce

Insulation Resistance Testing

When testing the outdoor circuit breaker, the students work in two teams to test the insulation resistance [4] of the bushings and circuit breaker contact housing. To assure that the individual students know how to perform this test, it is also included as a required test on the tests performed by each student separately on the McGraw Edison three-phase Oil Circuit Recloser in the laboratory (the students select a one-hour timeslot in a three-week window to perform the test individually).

Figure 11. Insulation Resistance Tester Used for Testing

The test instrument the students use is a Megger MIT525 Insulation Resistance Tester [5] shown in Figure 11. One team tests the breaker with the contacts open and the second team tests the circuit breaker the contacts closed. Both teams are required to measure resistance, DAR, and current. As shown in Table 1, the second team forgot to measure the DAR this year. (DAR is the ratio of resistance at one minute to the resistance at 30 seconds.) The steps to perform these tests are as follows:

1. With circuit breaker open:
    a. Connect high-voltage lead to pole 1
    b. Ground or guard all other poles as shown in Figure 12
    c. Measure insulation resistance, DAR, and current
    d. Repeat for poles 2 through 6, in turn, with other poles grounded

2. With circuit breaker closed:
    a. Connect high-voltage lead to pole 1, with either pole of phase 2 and 3 grounded
    b. Measure insulation resistance, DAR, and current
    c. Repeat for phases 2 and 3 with other phases grounded

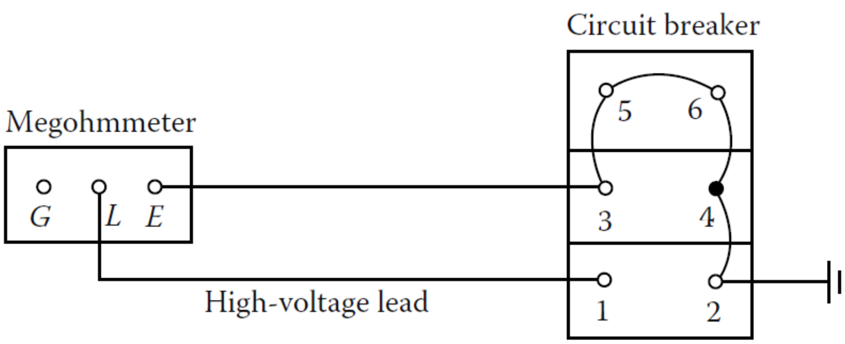

Figure 12. Wiring Diagram for the First Open-contact Insulation Resistance Test

Table 1. Values from Student Test of Bushing Insulation Resistance

Bushing (s)	Resistance	DAR	Current	Notes
1	1.09 TΩ	1.18	4.65 nA	
3	1.244 TΩ	1.74	4.11 nA	
5	1.256 TΩ	1.45	4.07 nA	
2	1.884 TΩ	1.18	2.71 nA	Bushing Chipped
4	2.96 TΩ	1.06	1.72 nA	
6	2.22 TΩ	0.92	2.30 nA	
1 & 2	940 GΩ		5.44 nA	
3 & 4	1.151 TΩ		4.44 nA	
5 & 6	1.042 TΩ		4.99 nA	

Contact Resistance Testing

The students used the RMO200G Micro Ohmmeter by IBEKO Power AB [6] for contact resistance testing. This test is straightforward: 1) attach the high current leads to the terminals of the contacts being tested, 2) attach the voltage measurement leads inside the high current leads on the terminals, and 3) press the "Start" button.

Figure 13. RMO200G Micro Ohmmeter by IBEKO Power AB

Table 2. Student Measurement of Contact Resistance

Contacts	Resistance	Maximum Resistance
Bushings 1 & 2	95.5 μΩ	135 μΩ
Bushings 3 & 4	106.1 μΩ	135 μΩ
Bushings 5 & 6	99.2 μΩ	135 μΩ

Power Factor/Dissipation Factor Testing

The students used the Megger Delta 3000 Power Factor / Dissipation Factor [7] test set to determine the power factor and capacitance of the circuit breaker bushings.

Figure 14. Megger Delta 3000 Power Factor / Dissipation Factor Test Set

Table 3. SF_6 Dead Tank Circuit Breaker Test Connections

Test No.	CB	Insulation Tested	Low Voltage Lead Configuration				Test Connections To Bushings			Remarks
			Test Mode	Measures	Grounds	Guards	Black	Red	Blue	
1	OPEN	C_{1G}	GST GND		Red & Blue		1			Bushing 2 floating
2		C_{2G}	GST GND		Red & Blue		2			Bushing 1 floating
3		C_{3G}	GST GND		Red & Blue		3			Bushing 4 floating
4		C_{4G}	GST GND		Red & Blue		4			Bushing 3 floating
5		C_{5G}	GST GND		Red & Blue		5			Bushing 6 floating
6		C_{6G}	GST GND		Red & Blue		6			Bushing 5 floating
7	OPEN	C_{12}	UST	Red	Blue		1	2		
8		C_{34}	UST	Red	Blue		3	4		
9		C_{56}	UST	Red	Blue		5	6		
10	CLOSED	$C_{1G} + C_{2G}$	GST GND		Red & Blue		1 or 2			
11		$C_{3G} + C_{4G}$	GST GND		Red & Blue		3 or 4			
12		$C_{5G} + C_{6G}$	GST GND		Red & Blue		5 or 6			

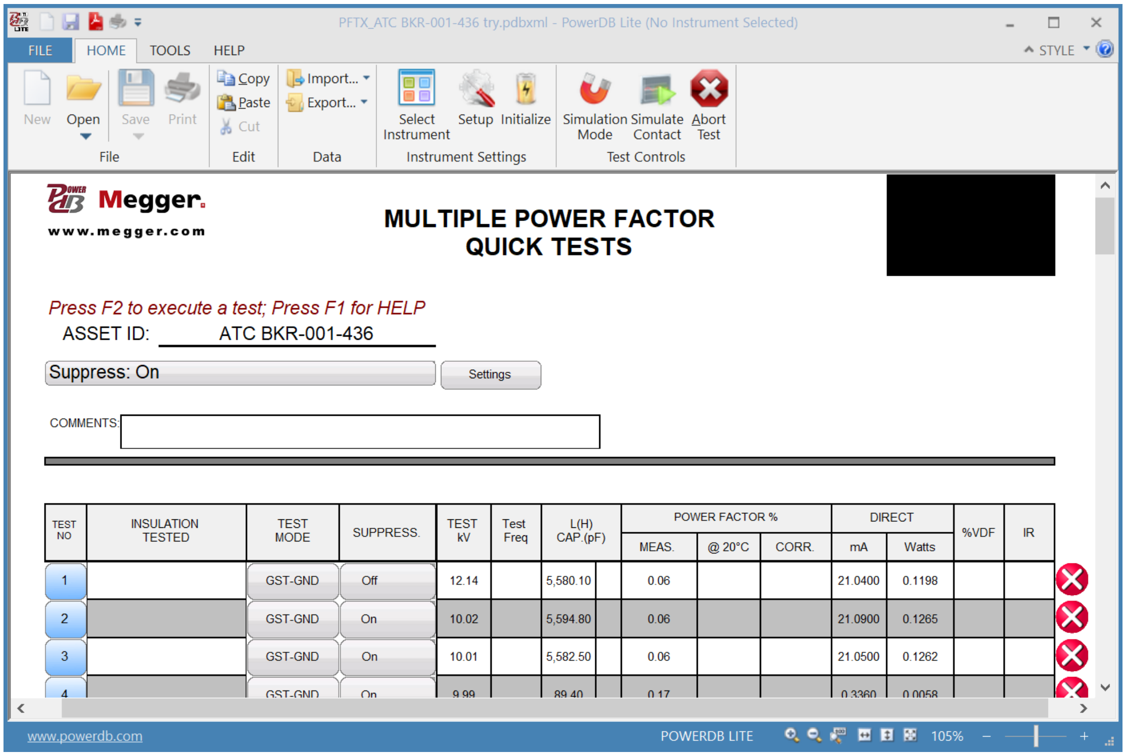

Figure 15. Student Data from PF/DF Testing Using Quick Form

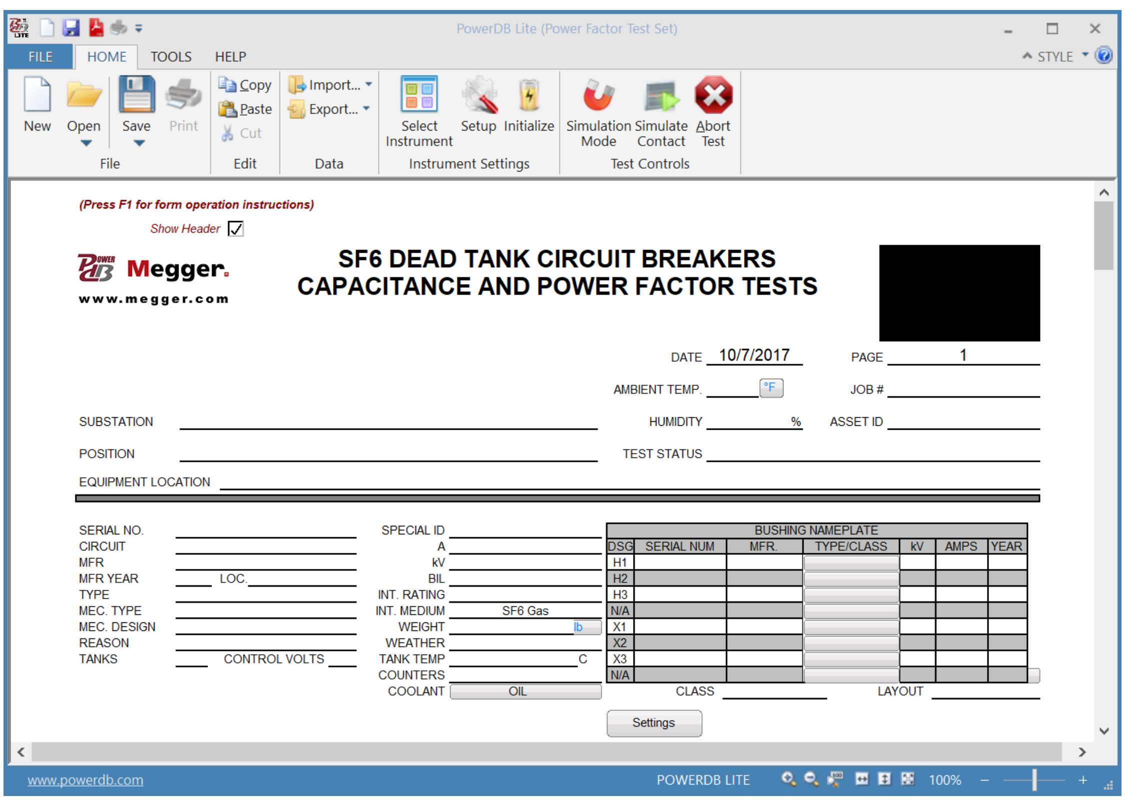

Figure 16. Suggested Form to Use for Dead-Tank SF_6 Circuit Breaker PF/DF Testing

Figure 14 shows the front panel of the test set. The students choose to use the built-in Windows CE computer to run the tests. The standard tests, the test set configurations, and connections are listed in Table 3. The students used the quick test feature and the results they obtained are shown in Figure 15. The students did not enter the insulation tested for any of the tests. In addition, the first test was repeated because the test voltage was higher than needed and noise suppression was off. It would have been better if the students had used their laptops. Templates for this and other tests are available, as shown in Figure 16.

Problems and Improvements

The main problem with these experiments is that many times the class must work in teams to perform the testing. We only have one of each of the different types of test equipment. (We do have several older pieces of test equipment, such as Insulation Resistance testers, but these are only used as backup in case the newer equipment needs repair.) A work-around for this is to have the students individually perform three of these tests on a 15 kV three-phase recloser in the laboratory. The three tests are insulation resistance, contact resistance, and dissipation factor.

When they are attaching leads to the power apparatus in the mock substation [8] we only have stepladders for them to use. It would be better if an easier method was available. In industry, a lineman would typically perform these connections. We try not to use the stepladder and use hot sticks when possible.

The mock substation is not permanently powered with either DC or AC. This causes a problem for the breaker, since the heaters inside the breaker will not be energized. One year we were not able to perform all the travel tests due to a problem with a pneumatic value. This failure was due to a lack of heating over the winter months. A group of students are currently looking for possible solutions to provide permanent power.

The first year the testing was performed there were problems with the plate for the displacement transducer. A group of students in the subsequent class designed and built the new plate that we now use. The displacement transducer is now securely mounted to the plate.

The initial 125 Vdc power supply consisted of ten car batteries. As mentioned earlier, there is no permanent power in the mock substation, so, therefore, there is no heat in the control room. The previous instructor would have the students bring the batteries out from the lab for each test. On one trip, the battery terminals touched causing significant damage. I keep the batteries in the unheated control room, so their life is significantly shortened. To fix this problem, a 125 Vdc high current power supply was installed. The remaining issue is that the temporary power in the mock substation cannot supply the current necessary to run both the dc power supply and the circuit breaker compressor at the same time.

Student Interactions and Impressions

The students have been almost unanimous in their praise of the mock substation and the circuit breaker testing. Two sample comments are:

What I liked most was the hands on aspect of the lab. The more I get to physically do something the better chance I have of learning it

The hands on work and lectures were all interesting. The whole class reinforced my love for the field.

The students realize that they are using the same software and test equipment that they will be using when they are working in the field.

The students perform each type of test as teams and then perform three tests individually. This allows assessment of each student's abilities separately. The students must schedule a two-hour block outside of class or lab time to do the testing. I am just there to observe (and to assure the students are working safely). The first time the sequence of courses were taught, I received feedback for an employer that a graduate was not comfortable around the test equipment even though he had done the tests in class. Since I have gone to the partial individual testing, I have not had any similar complaints.

Future Work

A group of five students (Joe Czernek, Mikhail P. Klebba, Troy Richardson, and Arthur Saily) are currently designing permanent wiring from control room to the circuit breaker as a directed study. One of the students has worked for several years for Systems Control, a company that manufactures electrical substation control rooms. A photo of their work in shown in Figure 17. After they complete their design, they will be installing the wiring, control, and test points.

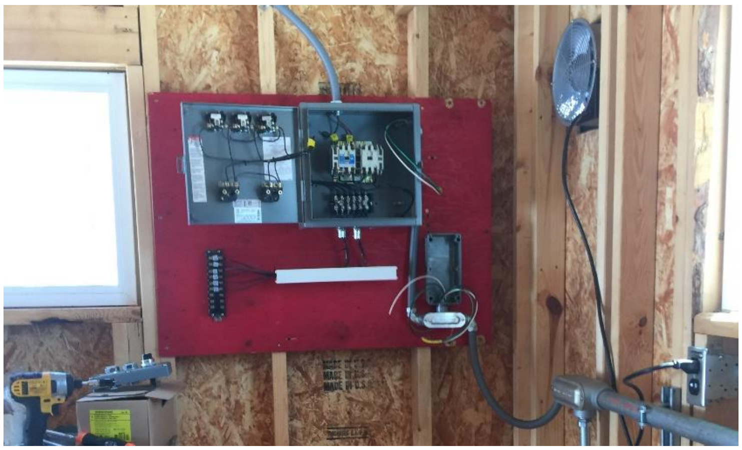

Figure 17. Work on Permanent Wiring to Circuit Breaker

Conclusions

The testing of circuit breakers is a major component of many of our Power Technician [8] degree graduate's work life. The need to obtain real-world testing conditions has driven Northern Michigan University to make significant investments in test equipment and apparatus to test. It is hope the other instructors working in this area will find this discussion helpful.

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