Evaluating Efficiency and Losses of Various Circuit Protective Devices

Abstract

Electrical system protective devices dissipate heat during normal operation. Depending on the type, rating and size of the overcurrent protective device, the magnitude of losses varies. This paper discusses a test program that quantified those losses for several typical fuses and circuit breakers. The results of this effort show that protective systems using switch and fuse were found to be less energy-efficient compared with equivalently sized circuit breakers when carrying the same load.

Introduction

Discussions of power losses within electrical power systems predominantly focus on the role of resistive (also known as "I^2R") losses as the major sources of losses. As its name suggests, resistive losses are defined as:

Equation 1: $W_{loss} = I^2R$

Where:

- W_{loss} = power loss in watts
- I = current in conductor in amperes
- R = resistance of conductor in ohms

From **Equation 1** we see that resistive power losses in a device are proportional to the resistance of the conductors within a device. For the same current flowing in both, devices with lower internal resistance will have less power loss compared with devices having a higher internal resistance.

To ensure we understood the actual losses within circuit breakers compared with both fused and unfused switches, we developed a test program to measure the losses from each of several types, brands, sizes and ratings of circuit breakers, fuses and switches.

As a result of these tests, the differences in power losses between several types of circuit breakers and fuses were noted. These differences are noted in **Table 1** in the next column:

Table 1. Percentage power loss differences between various types of circuit breakers and fuses

Comparison	Ampere Range	3-Phase Power Losses
Molded Case Breaker versus RK-5 fuses	20–600 A	Fuse dissipated, on average, 121% higher losses than MCCB of same size and rating
Molded Case Breaker versus Class J fuses	20–600 A	Fuse dissipated, on average, 91% higher losses than MCCB of same size and rating
Molded Case Breaker versus Class L fuses	800–2500 A	Fuse dissipated, on average, 226% higher losses than MCCB of same size and rating
Fixed Mounted Air Circuit Breaker versus Class L fuses	800–5000 A	Fuse dissipated, on average, 434% higher losses than Fixed Mounted Air Circuit Breaker of same size and rating
Draw-Out Air Circuit Breaker versus Class L fuses	800–5000 A	Fuse dissipated, on average, 148% higher losses than Draw-Out Air Circuit Breaker of same size and rating

When the differences highlighted in **Table 1** are viewed graphically in terms of absolute watts, the differences appear as shown in **Figures 1 and 2** on **Page 2**:
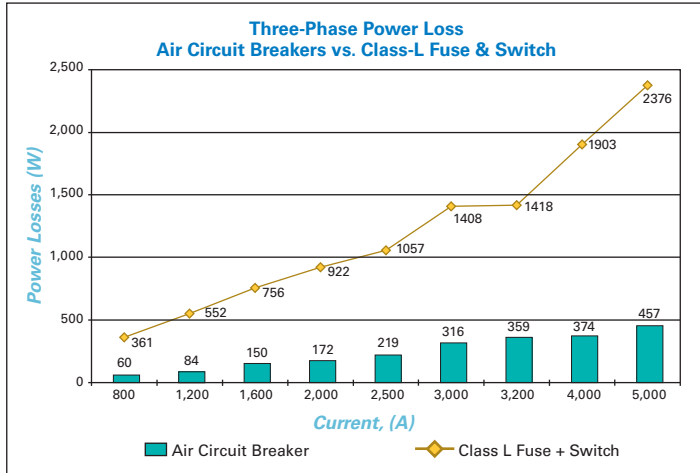
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Figure 1. Power loss comparison—Air Circuit Breaker vs. Class L Fuse & Switch
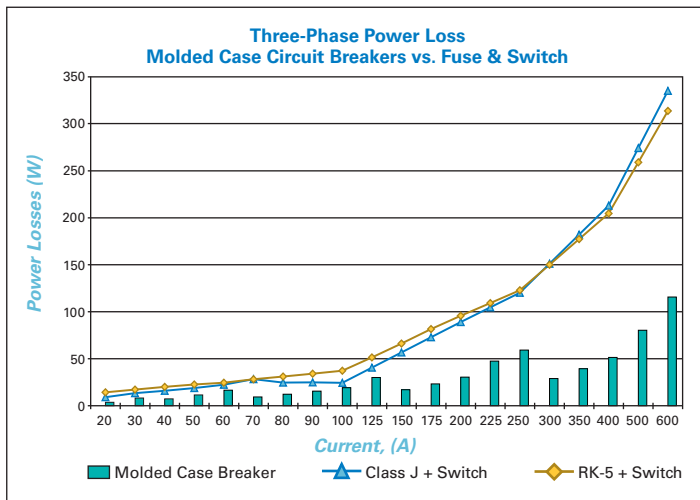

Figure 2. Power loss comparison—Molded Case Circuit Breakers vs. Class J & Class RK-5 Fuse & Switch

Details of the exact testing methodology used can be found in the Appendix.

Real-World Efficiency Differences

Extra energy consumed by a device must be purchased from some source to feed additional device losses. Reducing those extra device losses means less power must be purchased. If a more efficient device is used, the less energy wasted also means less energy is generated at the source. If that energy is generated through the burning of fossil fuels, lower energy demand means less greenhouse gases (GHG) are produced as a byproduct. At the time this paper was written, the United States did not participate in a carbon trading or carbon limit program. Therefore, today the primary monetary benefit to U.S.-based operations is the reduced energy costs. However, should carbon trading become important, or should a company attempt to reduce GHG production, the more energy-efficient product would have additional benefits to the user.

Energy Cost Calculation

Utility rate structures can be quite complex. In general, there are two components that compose the majority of the utility bill:

1. Energy (measured in kilowatt-hours)

2. Power or Demand (measured in kilowatts)

Energy is simply the summation of the average power over a time interval multiplied by the duration of that time interval.

Equation 2: $Energy = \sum_{t=0}^{x} P(t) * \Delta t$

Where:

- x = number of time intervals to sum
- P(t) = average power during the time interval
- Δt = duration of time interval

We monetize this value of energy by multiplying the quantity of energy consumed by the unit cost of that energy.

Equation 3: $Annual\ Energy\ Cost = Energy_{annual} * UnitCost_{energy}$

Power costs are monetized slightly differently. Most utility companies "ratchet" or "latch" the peak power of a demand period (what we call Δt in **Equation 2** above) used during a billing interval (e.g., 1 month). They then use this ratcheted value as the basis for billing for the whole month (and sometimes longer):

Equation 4: $Monthly\ Power\ Cost = Power_{peak}(month) * UnitCost_{power}$

Therefore, the annual power costs are the sum of the individual months' power costs:

Equation 5: $Annual\ Power\ Cost = \sum_{Month=1}^{12} Power_{peak}(month) * UnitCost_{power}$

The total cost for electricity is the sum of the energy cost plus the power cost. For example, if we assume our energy cost is $0.15/kWh and our power cost is $12.00 per kW, and if the protective devices were as shown in Table 27, we could calculate energy savings based on this data. Let's assume we are proposing to build the distribution system shown in Figure 3 and we are interested in the comparative energy and GHG savings if we used circuit breakers or if we used fuses.
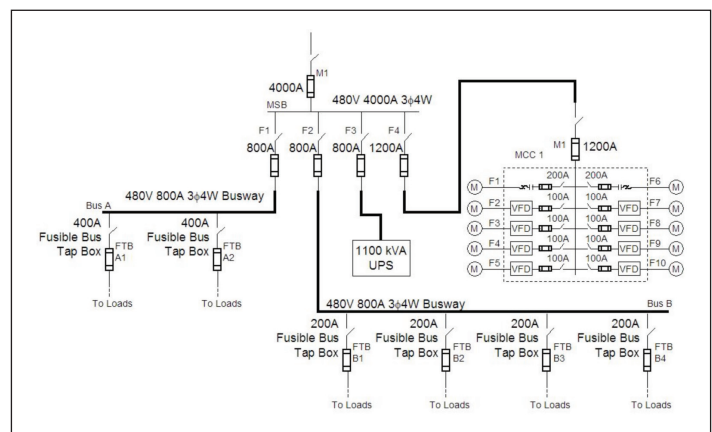

Figure 3. Example of simplified commercial office building and data center distribution system protected using fusible switches.

∗ The asterisks in the equations symbolize multiplication.

The bill of material of protective devices for this example is:

Table 2. Bill of material for distribution system in Figure 3

Group	Device	Quantity	Rating	Device Type
MSB	M1	1	4000	Class L
MCC1	M1	1	1200	Class L
MSB	F4	1	1200	Class L
MSB	F1	1	800	Class L
MSB	F2	1	800	Class L
MSB	F3	1	800	Class L
Bus A	FTB-A1	1	400	Class RK-5
Bus A	FTB-A2	1	400	Class RK-5
Bus B	FTB-B1	1	200	Class RK-5
Bus B	FTB-B2	1	200	Class RK-5
Bus B	FTB-B3	1	200	Class RK-5
Bus B	FTB-B4	1	200	Class RK-5
MCC1	F1	1	200	Class RK-5
MCC1	F6	1	200	Class RK-5
MCC1	F2	1	100	Class RK-5
MCC1	F3	1	100	Class RK-5
MCC1	F4	1	100	Class RK-5
MCC1	F5	1	100	Class RK-5
MCC1	F7	1	100	Class RK-5
MCC1	F8	1	100	Class RK-5
MCC1	F9	1	100	Class RK-5
MCC1	F10	1	100	Class RK-5
	Total	22		

Grouping devices by types and then filling in the power losses from Table 27, we calculate the power losses using these devices.

Table 3. Power losses

Rating	Type	Losses at 100% FLA [1]	Quantity	Power Loss
4000	Class L	1903	1	1903
1200	Class L	552	2	1104
800	Class L	361	3	1083
400	Class RK-5	205	2	410
200	Class RK-5	96	6	576
100	Class RK-5	37	8	296
			Total	5372

If we substituted a typical circuit breaker for each of these fuses, the losses would be reduced to:

Table 4. Reduction of power losses using circuit breakers

Rating	Type	Losses at 100% FLA	Quantity	Power Loss
4000	Magnum (fixed)	374	1	374
1200	N-Frame	210	2	420
800	N-Frame	87	3	261
400	K-Frame	51	2	102
200	F-Frame	30	6	180
100	F-Frame	19	8	152
			Total	1489

The losses are reduced by 72% from 5.4 kW to 1.5 kW, or a savings, in this example, of 3.9 kW. Converting 3.9 kW into cost of energy:

Table 5. Energy cost savings

Power Saved	Hours/Year Operation	kWh/Year Saved	Cost/kWh	kWh Cost Saved/Year
3883	8760	34,015.08	$0.10	$3,401.51

Reducing energy means that less fossil fuel must be burned. The U.S. Department of Energy publishes estimates for how much greenhouse gas is produced from each kWh generated for a variety of locations around the country. Using data for Pennsylvania, for example, we see that one kWh saved reduces CO_2 production by 2.1 pounds. When we multiply that times the actual number of kWh saved, we calculate the annual CO_2 reduction available:

Table 6. Annual CO_2 reduction available

CO_2/kWh (lbs.)	kWh/Year Saved	CO_2 Saved/Year
2.1	34,015.08	71,432 lbs.

Because of this 72% reduction with circuit breakers, reducing 3.9 kW also reduces the demand (power) charge from the utility. We include that as an additional savings:

Table 7. Demand cost savings

Power Saved	Cost/kW	Demand Savings/Month	Demand Savings/Year
3883	$12.00	$46.60	$559.15

In summary, this simplified example shows that we can annually save ($3401.51 + $559.15 = $3960.66):

Table 8. Total energy + demand savings

kWh Cost Saved/Year	Demand Savings/Year	Total Savings/Year
$3,401.51	$559.15	$3,960.66

[1] FLA is Full Load Amperes.

Assuming the project life extended to 25 years at a conservative 8% cost of money and a 2% net annual escalation cost of energy (after inflation), the net present benefit of a design using circuit breakers instead of fused switches would be:

Table 9. Net present value—circuit breakers over fused switches

NPV (Net Present Value)
$68,060

When fusible switches are added to distribution switchboards and switchgear, that fusible equipment is larger than equivalently sized circuit breaker-protected equipment, nearly always resulting in fusible equipment costing more than circuit breaker-protected equipment. Therefore, the net present value will be even higher:

Table 10. Higher net present value with smaller circuit breaker-protected equipment

NPV
$68,060 + Cost savings of smaller sized circuit breaker equipment

To simplify these energy saving calculations, Eaton® developed a Web-based calculator that evaluates the resistive power losses of selected protective devices and calculates the energy and greenhouse gas savings when using one type of protective device versus another. The greenhouse gas savings comes as a result of less energy needing to be generated when using the higher-efficiency product.

The energy and greenhouse calculator is shown in **Figure 4**. It requires 11 pieces of information:

1. Type of circuit breaker used [molded case, fixed air circuit breaker (ACB) or draw-out ACB]

2. Frame or amp rating of circuit breaker

3. Type of fuse (Class J, Class RK-5, Class L, one-time)

4. Number of circuits per type of circuit breaker/fuse

5. Average ampere load on each circuit

6. Number of poles (1 through 4)

7. Cost for each kWh of energy

8. Cost for each kW of power

9. Number of hours per year of operation for that circuit

10. Cost of money (used to discount future savings into a net present value to compare ROI calculation with solutions with variable project lives)

11. Location in the United States (different mixes of different types of generation are used in different parts of the country resulting in differing levels of greenhouse gas production for each kWh generated)

This Web-based calculator is accessible through **http://www.eaton.com/consultants**. Select "**Tools & Downloads**", then "**Calculators**" from the left navigation bar. Then in the far right navigation bar labeled "**Related Information**" under the section "**Online Calculators**" select "**Breaker Versus Fuse Green Calculator**". Alternatively you can navigate directly to the calculator by entering **http://pps2.com/b1** into your browser.

Figure 4. Data entry screen for breaker versus fuse energy and greenhouse savings calculator

Once you have entered this information, the calculator provides the following information, as shown in **Figure 5**, regarding your configuration that used circuit breakers instead of fuses:

1. Total monetary savings over 10 years resulting from using breakers instead of fuses

2. Annual energy savings (kWh)

3. Peak demand (kW) savings

4. Discounted savings over 10-year project life (spending this much additional initial cost would result in a complete payback, including cost of money, over 10 years)

5. Annual greenhouse gas (CO_2, SO_2, NO_x) savings in weight

6. Conversion of GHG savings into equivalent number of trees planted (or not cut down)

7. Conversion of GHG savings into equivalent number of autos taken off the streets

8. Breakdown by circuit, the comparison of the power loss of using breakers and of using fuses

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Watts Loss Calculator

Savings When Using Circuit Breakers   Revision date: September 08 2008 08:01:29 EDT

Calculation done for EPA Region 1.   Project Name: **Project 1**

Using breakers instead of fuses on this project would save **$50140** over 10 years.

Explanation of Benefits
We first examined each circuit and compared the watts loss for each breaker with the watts loss for each fuse. Subtracting the breaker watts loss from the fuse watts loss gave us a difference for that circuit that we then multiplied times the number of circuits of that size. We repeated this step each circuit rating where you entered a non-zero count and summed all losses into a total. The result was that total watts savings on this project when using breakers instead of fuses is **4916** watts (**4.92 kW**). Operating for **8760** hours per year, using fuses instead of breakers consumes **43061** more kWh per year than if you had used breakers. At **$0.10** per kWh, that works out to be **$4306** per year of additional cost due to kWh consumption. Based on the data you entered, each additional kW costs you **$12.00**. Since we calculated that this system would place an additional demand on the system of **4.92 kW**, each year the system will cost an extra **$708** due to additional demand charges. (monthly incremental demand **4.92 kW** x demand rate **$12.00** x 12). Combining the energy quantity cost (kWh cost) of **$4306** with the energy demand cost (kW cost) of **$708**, we have a total annual penalty of **$5014**.

Over 10 years, that would work out to be **$50140**, or discounted at your **8.00%** cost of money, the net present value of this 10 year cash flow would be **$33550**.

Greenhouse Gas Production
Based on the EPA Region you said this project is located (Region **1**), we can convert the annual kWh (**43061**) saved from using breakers and convert this into quantities of CO_2, SO_2 and NO_x, using these multipliers:

	Annual kWh		Multiplier		Annual Reduction	10-year Reduction	
CO_2	43061	x	1.73 lbs/kWh	=	37	372	tons
SO_2	43061	x	4 g/kWh	=	172	1722	kg
NO_x	43061	x	1.4 g/kWh	=	60	603	kg

Since trees consume CO_2 and automobiles produce CO_2, based on the numbers listed in the table above, we compute that using breakers instead of fuses for this project would save the equivalent of **7450 trees**[1]. That represents more than **14.9 acres**[2] of trees. That same amount of CO_2 removed from the atmosphere each year would be the same as taking **7 autos**[3] off the road.
[1]According to Tufts University, one tree consumes between 2.5 and 14 pounds of carbon dioxide per year. For this example we have assumed an average value of about 10 lbs of carbon dioxide per tree per year.
[2]Forested at an average of approximately 500 trees per acre.
[3]Auto obtaining an average of 21 MPG generates about 0.9142 lbs of carbon dioxide per mile. Driven at an average distance of 12000 miles per year, that equates to 10970 lbs of carbon dioxide produced per year.

CO_2				Saves	
74496 lbs. (37 tons)	/	10 lbs/tree/year	=	7450	trees (14.9 acres)
74496 lbs. (37 tons)	/	10970 lbs/car/year	=	7	cars

Note As discussed earlier, fuses are discarded into the environment after they operate. Fuses contain silver, a metal that bioaccumulates in living tissue. The effect of this was not included in the calculations.

Supporting Data

Amp	Frame	Fuse Type	Fuse Loss (watts)	Breaker Loss (watts)	Fuse loss - Bkr loss (in watts)	Circuits	Total Watts Saved
100	225A Series C F-frame	RK5	37.2	11.9	25.4 (68.2%)	100	2540
225	225A Series C F-frame	RK5	95.9	60.8	35.2 (36.7%)	30	1055
1200	1200A Series C N-frame	Class L	334.0	210.0	124.0 (37.1%)	3	372
4000	4000A Magnum fixed	Class L	1323.2	374.0	949.2 (71.7%)	1	949
						Total:	4915.7 (55%)

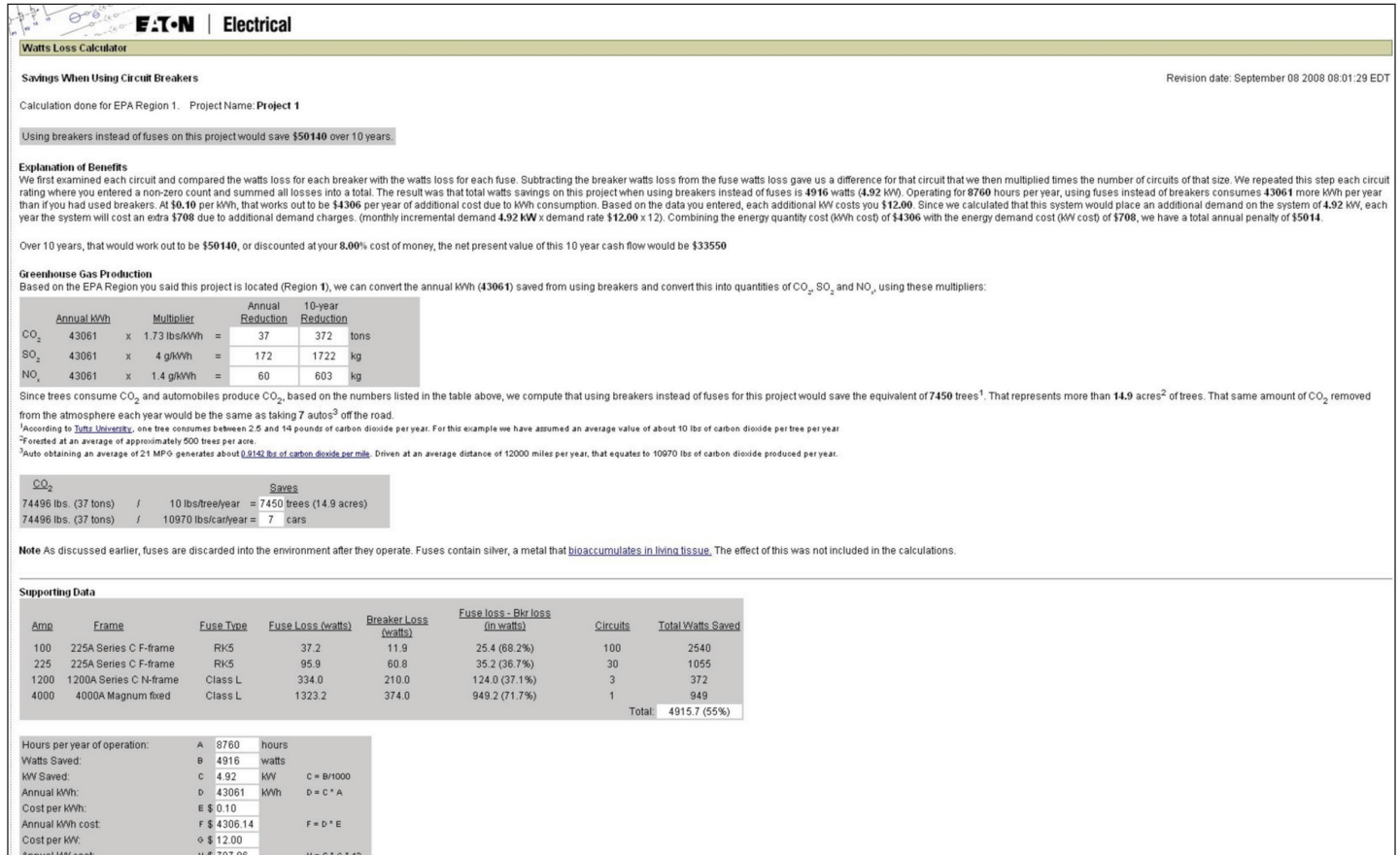|				
Hours per year of operation:	A	8760	hours	
Watts Saved:	B	4916	watts	
kW Saved:	C	4.92	kW	C = B/1000
Annual kWh:	D	43061	kWh	D = C * A
Cost per kWh:	E	$ 0.10		
Annual kWh cost:	F	$ 4306.14		F = D * E
Cost per kW:	G	$ 12.00		
Annual kW cost:	H	$ 707.96		H = C * G * 12

Figure 5. Results of breaker versus fuse energy and greenhouse gas savings calculations

Appendix

Test Method and Program

This section of the report describes the test methodology used to calculate the energy and greenhouse gas savings for breakers and fuses. While small, portable micro-ohmmeters could be used to measure the resistance through the device, we had two concerns with that method.

1. Unless the voltage generated exceeded the breakdown voltage of the oxide layers formed between pressure connections, we might see an artificially high resistance. To minimize this problem, we chose a source power supply to provide 24 volts dc. 24 volts has been shown[2] to be sufficient to penetrate the oxide layer formed on the pressure junction surfaces (contacts, fuse clips, lugs, etc.). Direct current was chosen rather than alternating current due to the problems with inductive reactance masking changes in resistance.[3]

2. Resistance of metallic conductors used in protective devices increases as the temperature of those conductors increases. It was desirable to measure voltage drop at as close to normal operating temperature as possible. Therefore an attempt was made to measure the resistance at full rated current, rather than some lower level of test current.

Figure 6. Test equipment setup and procedure—test setup for verifying power loss from various models and sizes of circuit breakers and fuses.

Referring to the schematic diagram shown in **Figure 6** above, the procedure we used to test each device was as follows:

1. Connect Device Under Test
    Connect the "Device Under Test" (protective device) to a dc power supply with sufficient current capacity to provide 100% of the protective device's ac-rated load current, up to a maximum of 500A (the limit of the test setup). Since it is the device's resistance that generates the I^2R heating losses, it is acceptable to use direct current on a device rated for ac. By definition, the heating through a resistor is the same whether you supply that resistor with direct current or with the same magnitude root mean square (rms) alternating current. However, if we had used alternating current, we would have to perform additional procedures to calculate and remove the effects of inductive (or capacitive) reactance in the test circuit and calculate voltage drop that was solely due to resistance.

2. Connect Resistive Load
    The next step was to connect resistive load to limit the current flow to 100% of the device's rated load current up to 500A. For devices rated above 500A, we used 500A as the load current. Since we used direct current, we measured the current flowing in the circuit by calculating the ratio of the voltage drop across a known resistance in series with the load current as described in **Equation 6**:

    Equation 6: $I = \dfrac{V_{drop1}}{R_S}$

3. Stabilize Temperature
    We allowed the current to flow until device temperature stabilized or one minute, whichever was shorter. (This was a compromise due to the thermal rating of the power supply chosen. 500A at 24 Vdc is 12 kW).

4. Measure
    Measure the voltage (millivolt) drop across the device under test (V_{drop2}).

5. Convert to Losses
    Convert millivolt drop and current in amps into per-phase power loss using **Equation 2**.

    Equation 7: $W_{loss\_pole} = V_{drop2} * I$

    Where:

    * W_{loss_pole} = heat loss in watts in one pole of device under test
    * V_{drop2} = voltage measured across device under test
    * I = current flowing through the device

    Substituting **Equation 6** into **Equation 7** and solving for W_{loss}:

    Equation 8: $W_{loss\_pole} = V_{drop2} * \dfrac{V_{drop1}}{R_S}$

    While **Equation 8** gives the per-pole power loss, for multi-pole devices (more than one independent current-carrying path through the device), steps 1 through 6 were repeated for each pole and the results were summed.

    Equation 9: $W_{loss\_device} = W_{loss\_pole\_1} + W_{loss\_pole\_2} + W_{loss\_pole\_3}$

    Since higher temperatures result in higher resistances, one factor that was not measured was the effect of heating between poles. This method of measuring each pole independently and then combining the results may provide lower, more conservative results in the device since effects of additional heating of each pole from the interaction of heating between multiple poles was not calculated.

∗ The asterisks in the equations symbolize multiplication.

[2] Section 5.4 of NEMA AB 4-1996 (Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers used in Commercial and Industrial Applications).

[3] For more information on this effect, refer to "Measuring Molded Case Circuit Breaker Resistance", by John Shea and John Bindas, IEEE Trans. CHMT, Vol. 16, No. 2, pp. 196-202, March 1993.
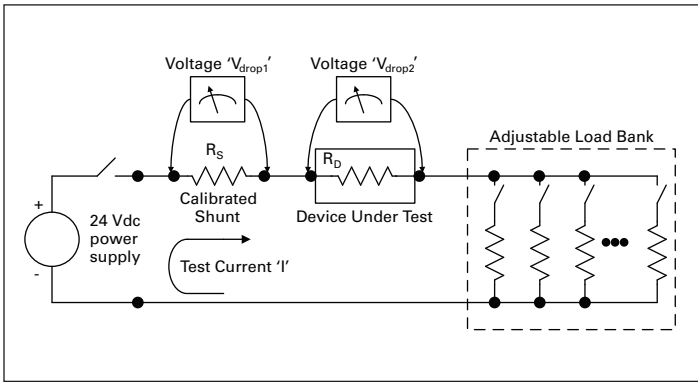
Results of Testing Program

As it would be difficult to perform experiments comparing the losses of all possible fuse sizes, types and ratings, one goal of the testing program was to test representative samples from the universe of possible devices and see if inferences could be drawn that would allow us to estimate the losses from devices not tested.

We began our tests by connecting 30A and 60A, Class J and RK-5 fuses mounted in Eaton type FDP fusible switches. The test setup described in **Figure 6** was used to measure the resistances and calculate the power losses using the methodology of **Equation 8**. Using that equation we constructed **Table 11**:

Table 11. Power loss test results using 30A and 60A Class J and Class RK-5 fuses. The last two columns of the table sum the power losses of both the 3-pole switch plus the power losses of three fuses for a total power loss of the switch and fuse. This provides the best comparison value with a circuit breaker since both are needed to duplicate the functionality of the circuit breaker.

Size	FDP Switch Measured (3-Pole)	J Fuse (1-Pole)	RK-5 Fuse (1-Pole)	J Fuse (3-Pole Switch and Fuse)④	RK-5 Fuse (3-Pole Switch and Fuse)⑤
30A	0.7 W	4.25 W	5.05 W	13.5	17.2
60A	2.9 W	6.48 W	7.19 W	22.3	24.5

We then repeated the same tests using circuit breakers of the same ratings. These results are shown in **Table 12**:

Table 12. Power loss test results for 30A and 60A Eaton EG-frame breakers.

Size	Breaker Frame	Power Loss (3-Pole)
30A	EG	8.2 W
60A	EG	16.6 W

When we compared the losses from the circuit breakers with the fuses, we see that, as a percentage, the fuse losses are quite a bit higher than the equivalently sized circuit breakers. We documented these differences, both in watts and in percent difference in **Table 13**:

Table 13. Comparison of power losses for 30A and 60A circuit breakers and Class J and RK-5 fusing. The numbers in parentheses show the percentage increase power loss for that particular switch and fuse combination versus the equivalent molded case circuit breaker.

Size	Breaker Frame	Power Loss (3-Pole)	Incremental Losses 3-Pole Class J Fuse and Switch	Incremental Losses 3-Pole Class RK-5 Fuse and Switch
30A	EG	8.2 W	+5.3 W (+65%)	+9 W (+110%)
60A	EG	16.6 W	+5.7 W (+35%)	+7.9 W (+47%)

We continued our testing with protective devices larger than 60A.

One complicating factor for doing this comparison on larger devices is that circuit breaker frame sizes are built only on certain increment intervals, (e.g., 125A, 225A, 400A, 600A, etc.). As a result, it is not always possible to get a circuit breaker frame in the exact same size as a fuse. So how do you compare losses between equivalently sized fuses and breakers when you can't buy a circuit breaker with the same frame rating as a fuse? In the real world, the user purchases a circuit breaker frame just large enough and then sets a trip unit to trip on the required (lower) circuit current rating.

As a result, we tested 100A and 200A fuses, but circuit breaker frames are rated 125A and 225A, respectively with 100A and 200A trip units. Because of the sheer number of combinations of circuit breakers and fuses, only certain sizes, ratings and current levels were tested. However, since we know that the majority of the losses within a protective device are resistive, we can calculate what the resistive losses would have been in the device at any other higher or lower current level by taking the losses at any measured current and multiplying it by a factor that is equal to the square of the ratio of the desired current divided by the measured current.

Equation 10: $Watts_{loss\_circuit} = Watts_{loss@measured\_current}\left(\dfrac{I_{circuit}}{I_{measured}}\right)^2$

For example, the tested power loss values for the 125A and 225A circuit breakers at 125A and 225A, respectively, are as shown in **Table 14**:

Table 14. Measured resistive power losses for 125A Eaton G-frame and 225A Eaton F-frame circuit breakers operating at rated load current.

Size	Breaker Frame	Power Loss (3-Pole)
125A	EG	30 W (at 125A)
225A	FDE	47.5 W (at 225A)

Using **Equation 10** we convert the 125A and 225A test data into equivalent losses when operating at 100A and 200A respectively:

Equation 11: $Watts_{loss\_actual}(100) = Watts_{loss@measured\_current}\left(\dfrac{I_{actual}}{I_{measured}}\right)^2 =$
$30\left(\dfrac{100}{125}\right)^2 = 30 * 0.64 = 19.2\ watts$

Equation 12: $Watts_{loss\_actual}(200) = Watts_{loss@measured\_current}\left(\dfrac{I_{actual}}{I_{measured}}\right)^2 =$
$47.5\left(\dfrac{200}{225}\right)^2 = 47.5 * 0.79 = 37.5\ watts$

Table 15. Summary table showing calculated power loss values for 125A and 225A circuit breakers operating at 100A and 200A loads, respectively.

Size	Breaker Frame	Power Loss (3-Pole)
125A	EG	30 W (at 125A) 19.2 W (at 100A)
225A	FDE	47.5 W (at 225A) 37.5 W (at 200A)

We next compared these circuit breaker losses with fuse losses. The tested loss values for the fuses are as shown in **Table 16**:

Table 16. Power loss results for 100A and 200A Class J and RK-5 fuses.

Size	FDP Switch Average Measured (3-Pole)	J Fuse (1-Pole)	RK-5 Fuse (1-Pole)	J Fuse (3-Pole Switch and Fuse)④	RK-5 Fuse (3-Pole Switch and Fuse)⑤
100A	5.0 W	6.46 W	10.75 W	24.4 W	37.3 W
200A	33.9 W	18.39 W	20.6 W	89.1 W	95.7 W

✱ The asterisks in the equations symbolize multiplication.

④ Equal to the sum of **switch power loss** (column 2 of chart) + **three times J Fuse power loss** (column 3 of chart).

⑤ Equal to the sum of **switch power loss** (column 2 of chart) + **three times RK-5 Fuse power loss** (column 4 of chart).

Comparing these losses with the calculated losses of the breakers operating at the same current level, we summarize the results in Table 17:

Table 17. Comparison between calculated power losses of EG and FDE frame breakers operating at 100A and 225A, respectively, with Class J and RK-5 fuses of the same rating. The values in parentheses are the increased watts and percentage increase watts of the switch and fuse combination versus the equivalent circuit breaker. Because of the somewhat arbitrary breakpoint between available fuse ratings and breaker frame sizes, these ratios will vary when looking at individual ratings. Refer instead to Table 1 and Table 28 for summary and detail tables, respectively, of the comparative power losses across the entire range of 30A–5000A.

Size	Breaker Frame	Power Loss (3-Pole)	3-Pole Class J Fuse and Switch Losses (v. Breaker)	3-Pole Class RK-5 Fuse and Switch Losses (v. Breaker)
100A	EG	19.2	24.4 W (+5.2 W, +27%)	37.3 W (+18.1 W, +94%)
225A	FDE	37.5	89.1 W (+51.6 W, +138%)	95.7 W (+58.2 W, +155%)

We consolidated the results from Table 14 (30A–60A tests) and Table 17 (100A–200A tests) into Table 18:

Table 18. Comparison of power losses of 30A–200A Eaton Series C (225A frame) and Series G (30A–125A frames) circuit breakers with Class J and RK-5 fuses.

Size	Breaker Frame	Power Loss (3-Pole)	3-Pole Class J Fuse and Switch Losses (v. Breaker)	3-Pole Class RK-5 Fuse and Switch Losses (v. Breaker)
30A	EG	8.2 W	13.5 W (+5.3 W, +65%)	17.2 W (+9 W, +110%)
60A	EG	16.6 W	22.3 W (+5.7 W, +34%)	24.5 W (+7.9 W, +48%)
100A	EG	19.2 W	24.4 W (+5.2 W, +27%)	37.3 W (+18.1 W, +94%)
225A	FDE	37.5 W	89.1 W (+51.6 W, +138%)	95.7 W (+58.2 W, +155%)

We then continued our testing above 200A.

Once we get above the 200A range, the comparison between devices becomes more complicated. There are two reasons for this:

1. While we tested circuit breakers and fuses alone up to 600A, we did not test a switch above 200A. The fuses were mounted in fuse clips, but the resistance of the switch and interconnecting conductors that are typical of a fused switch were not tested. This means our testing would indicate an artificially low value of power loss for fuses unless we found a way to compensate.

2. We did not test a fuse above 600A.

To fill in the losses from the missing sizes and ratings, we used a variety of techniques including:

• Interpolation / Curve fitting

• I²R Effect Estimates

• Corroborating Data from Third Parties

• Resistivity Temperature Coefficient Compensation

Interpolation/Curve Fitting

Interpolation is the calculation of values that fall between two tested values. For example, from Table 11 we see that 30A and 60A fuses were tested, but 40A and 50A fuses were not. To estimate the power loss values for the missing fuse values that fall within the tested range, (as shown in Figure 7) we solve for the mathematical equation that best describes the relationship between fuse size and power loss using the test data as "check" values. We then input the untested fuse sizes into this derived equation and solve for the power loss of the untested device.

Since the mathematical equation is representative of a physical piece of equipment, if that equipment is changed, the equation must be changed. This was important since different size switches and conductors were used for the different ampacities under test.

30 to 200 A curve:
$$y = 0.0005x^2 + 0.1648x + 10.797$$

200 to 600 A curve:
$$y = 3E\text{-}06x^2 + 0.2534x + 10.98$$
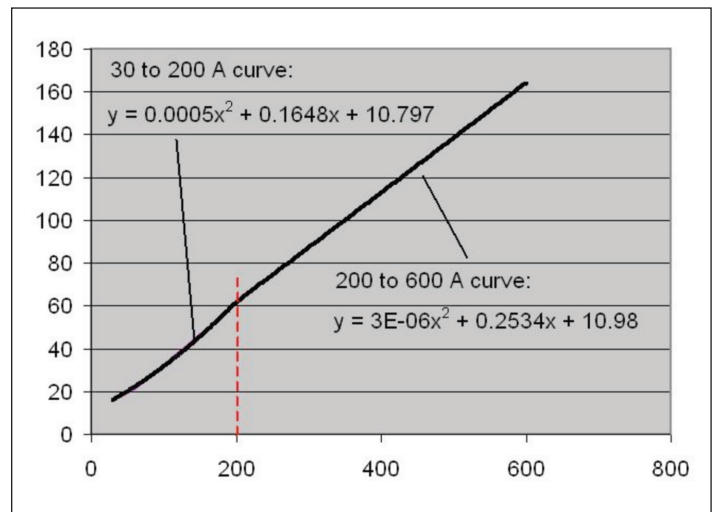
Figure 7. RK-5 measured resistive power losses and polynomial curve fit of relationship between fuse rating and power losses. To provide reasonable equations (2nd or 3rd order), we split the curve at the point of a discontinuity at 200A and developed two separate curves; one representing RK-5 fuse ratings from 30A–200A and the second from 200A–600A.

I²R Effect Estimates

As we mentioned earlier in our discussion of Equation 10, we measured power losses at the fuse's full rated current. Since we didn't test the power loss values using current values less than full load and since many circuits in practice are not fully loaded, we needed to develop a way to calculate actual power losses when less than full load current was flowing through a device.

Corroborating Data

Due to limitations of test equipment, we were not able to complete tests for fuses larger than 600A. Likewise, due to lack of available product, we could not test switches larger than 200A. It was necessary, therefore, to look for other methods to calculate losses on those larger devices.

One idea proposed was to use published resistance values from low-current micro-ohmmeter tests of those larger fuses. For example, one source of this data⑥ provided measurements of fuse resistance for fuses ranging from 200A–5000A. To verify how closely these values of resistance correlated with our tests of similar fuses at full load, we compared the measured fuse losses obtained from our testing with the calculated fuse losses obtained by multiplying the published fuse resistance in ohms times the magnitude of the current squared.

⑥ *http://www.monsterfuses.com/search/?s=class+L*

Because this data only reported the resistances of the fuses alone and not switches, we also needed to determine the additional resistance of those larger switches. After all, the total resistive losses would include both the losses of the three fuses plus the loss of the 3-pole switch and interconnecting cable or bus between the switch and the fuse clips. One solution was to create an equation that modeled the energy losses measured in smaller switches and use that equation to extrapolate the resistive power losses for the larger switch.

To obtain the resistive power losses for the smaller switches, we performed low-current (10A or less) resistance measurements of 30A, 100A, 200A and 400A safety switches and documented the results in Table 19:

Table 19. Measured resistance values for Eaton safety switches using a low-current (10A maximum) micro-ohmmeter. To convert dc resistances into resistive power losses, using Equation 1, these dc resistances were multiplied by their corresponding current rating squared, both per pole and for all three phases of a three-phase switch.

Size	Eaton Catalog Number	Safety Switch (Ω/Pole	Equivalent Watts/Pole	Equivalent Watts/3-Pole
30A	DH261UWK	120 µΩ	0.1	0.3
100A	DH363UWKWNP	180 µΩ	1.8	5.4
200A	DH364UDKW	132 µΩ	5.3	15.9
400A	DH365UDKW	87 µΩ	13.9	41.7

We did not test 800A or 1200A switches. The questions became: Could we estimate the losses of those untested switches by using the test data already collected? Does the collected test data indicate a trend? To answer that second question we plugged these values of power losses into a curve-fitting model and determined that these power losses did follow a smooth curve modeled by the equation:

Equation 13: Losses = $0.0001x^2 + 0.0663x - 1.9147$

Amp	Measured 3-Phase Watts	Est. 3-Phase Watts	% Error
30	0.3	0.2	-52%
60	2.4		
100	5.4	5.7	5%
200	15.9	15.3	-3%
400	41.7	40.6	-3%
800	115.2		
1200	221.8		
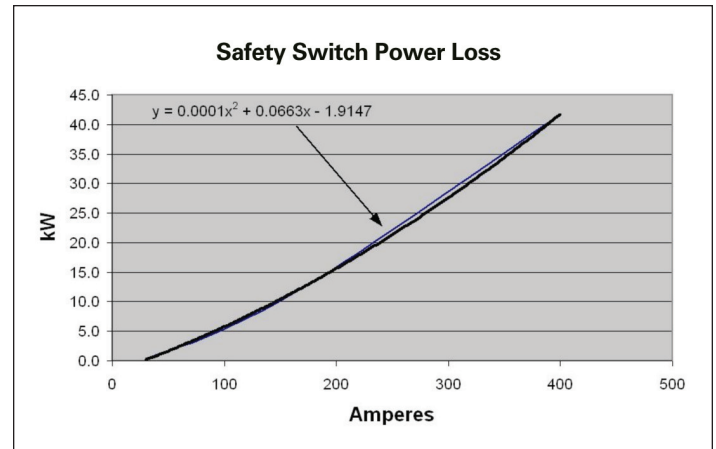
Figure 8. Measured per-pole resistances of 30A, 100A, 200A and 400A safety switches with calculated 3-phase power losses for a 3-pole device. These dc resistances were then converted to resistive power losses using Equation 8 discussed earlier in this paper. A mathematical model of the equation that best represents the curve of amps versus losses was solved using a second-order polynomial approximation. This curve fit resulted in the losses model shown by Equation 13 in the column to the left. Using this equation we could estimate the missing 60A, 800A and 1200A switches. Referring to the table at the bottom of the column to the left, the yellow background values are actual measured values. The blue background values are the calculated "missing" values derived from the mathematical equation describing the modeled relationship between switch amperes and power losses.

As you see from Figure 8 above and to the left, we used this calculated trend value to estimate the expected power loss values for the 800A and 1200A safety switch.

Calculating a model was important since, as with fuses, we did not test all possible sizes of safety switches. If the equation of the losses within the switches that were tested seemed to follow a smooth curve, we had reason to believe that the missing switch values would fall on that same curve. If the curve was marked by several discontinuities, then our belief that the missing switch loss values would fall on that curve would be less likely.

Since the curve was fairly smooth, we had reason to believe our assumptions were close to actual values. Taking this calculated model of switch losses, we next turned our attention to the third-party data of low-current resistance measurements for various fuses, including those above the ratings that we tested. These values are summarized in Table 20 on the next page.

Included in this table are fuses for various manufacturers' products. Since we had used Littelfuse fuses for the 30A–600A high-current tests in our lab, we decided to continue our analysis using that same brand above 600A as we attempted to correlate our low-current (table) and high-current (test) data with each other.

Table 20. Calculated power losses derived from direct measurements of published fuse resistance. Resistance measurements shown are in milliohms. Measured losses from lab tests (highlighted Littelfuse fuses were used in the lab tests) are used to compare with the calculated values. The "% Difference" column compares the calculated resistive losses using low-current ohmmeter measurements with the measured resistive losses using high-current voltage drop measurements. Since resistive losses increase at elevated temperatures, when comparing the Littelfuse calculated values with the Littelfuse measured values, in all cases the measured (using high-current testing) losses were higher than the calculated low-current losses.

Vendor	Type	Amp	Multiple, Repeated Tests Resistance					Ave R	Derived Losses I²R 1-Phase	I²R 3-Phase	Measured 1-Phase Watts	3-Phase Watts	% Difference
Littelfuse	Class J	100	1.087	1.096	1.098	1.081	1.121	1.097	11.0	32.9	—	—	—
Littelfuse	Class RK-1	150	0.711	0.719	0.714	0.717	0.708	0.714	16.1	48.2	—	—	—
Littelfuse	Class RK-5	150	0.709	0.719	0.715	0.708	0.714	0.713	16.0	48.1	—	—	—
Bussman	Class J fast acting	200	0.422	0.417	0.444	0.414	0.423	0.424	17.0	50.9	—	—	—
Littelfuse	Class J time delay	200	0.348	0.347	0.345	0.349	0.346	0.347	13.9	41.6	18.4	55.2	32%
Littelfuse	Class RK-5	200	0.393	0.382	—	—	—	0.388	15.5	46.5	20.6	61.8	33%
Shawmut	Class J	200	0.388	0.387	0.385	—	—	0.387	15.5	46.4	—	—	—
Bussman	Class J fast acting	250	0.339	0.340	0.336	0.345	0.338	0.340	21.2	63.7	—	—	—
Littelfuse	Class J	250	0.488	0.446	0.455	0.457	0.447	0.459	28.7	86.0	—	—	—
Littelfuse	Class RK-1	250	0.349	0.309	0.353	0.315	0.352	0.336	21.0	62.9	—	—	—
Littelfuse	Class RK-5	250	0.372	0.374	0.371	—	—	0.372	23.3	69.8	—	—	—
Bussman	Class J fast acting	300	0.289	0.299	0.301	—	—	0.296	26.7	80.0	—	—	—
Littelfuse	Class J	300	0.319	0.316	0.318	—	—	0.318	28.6	85.8	—	—	—
Littelfuse	Class RK-1	300	0.244	0.249	—	—	—	0.247	22.2	66.6	—	—	—
Littelfuse	Class RK-5	300	0.253	0.241	—	—	—	0.247	22.2	66.7	—	—	—
Bussman	Class J fast acting	350	0.225	0.222	0.221	0.215	0.241	0.225	27.5	82.6	—	—	—
Bussman	Class J fast acting	400	0.198	0.183	0.199	0.206	0.195	0.196	31.4	94.2	—	—	—
Littelfuse	Class J fast acting	400	0.213	0.216	0.213	0.214	0.217	0.215	34.3	103.0	—	—	—
Littelfuse	Class J time delay	400	0.199	0.201	0.201	0.207	0.199	0.201	32.2	96.7	40.4	121.2	25%
Littelfuse	Class RK-1	400	0.162	—	—	—	—	0.162	25.9	77.8	—	—	—
Littelfuse	Class RK-5	400	0.187	0.184	0.189	0.191	0.182	0.187	29.9	89.6	37.63	112.9	26%
Shawmut	Class J	400	0.262	0.263	0.265	0.263	0.262	0.263	42.1	126.2	—	—	—
Shawmut	Class J	400	0.189	0.191	0.191	—	—	0.190	30.5	91.4	—	—	—
Bussman	Class J fast acting	500	0.148	0.151	0.151	—	—	0.150	37.5	112.5	—	—	—
Littelfuse	Class J	500	0.167	0.164	0.166	0.163	0.164	0.165	41.2	123.6	—	—	—
Littelfuse	Class RK-5	500	0.129	0.134	0.134	—	—	0.132	33.1	99.3	—	—	—
Bussman	Class J fast acting	600	0.118	0.115	0.114	—	—	0.116	41.6	124.9	—	—	—
Littelfuse	Class J fast acting	600	0.139	0.125	0.127	0.141	0.161	0.139	49.9	149.7	—	—	—
Littelfuse	Class J time delay	600	0.124	0.123	0.123	0.129	0.121	0.124	44.6	133.9	61.87	185.6	39%
Littelfuse	Class RK-1 time delay	600	0.073	0.082	0.085	0.069	0.089	0.080	28.7	86.0	—	—	—
Littelfuse	Class RK-5 time delay	600	0.111	0.112	0.111	0.105	0.101	0.108	38.9	116.6	54.75	164.3	41%
Bussman	Class L fast acting	800	0.077	0.075	0.076	—	—	0.076	48.6	145.9	—	—	—
Littelfuse	Class L time delay	800	0.067	0.071	0.063	—	—	0.067	42.9	128.6	—	—	—
Bussman	Class L fast acting	1200	0.048	0.051	0.048	0.056	0.051	0.051	73.2	219.5	—	—	—
Bussman	Class L fast acting	1600	0.036	0.036	0.037	—	—	0.036	93.0	279.0	—	—	—
Littelfuse	Class L time delay	1600	0.034	0.034	0.035	0.035	0.035	0.035	88.6	265.7	—	—	—
Littelfuse	Class L time delay	2000	0.024	0.027	0.026	—	—	0.026	102.7	308.0	—	—	—
Bussman	Class L fast acting	2500	0.016	—	—	—	—	0.016	100.0	300.0	—	—	—
Bussman	Class L fast acting	3000	0.015	0.014	0.015	—	—	0.015	132.0	396.0	—	—	—
Littelfuse	Class L	3000	0.018	0.017	—	—	—	0.018	157.5	472.5	—	—	—
Bussman	Class L time delay	4000	0.012	0.012	0.012	—	—	0.012	192.0	576.0	—	—	—
Littelfuse	Class L	4000	0.013	0.014	0.013	—	—	0.013	214.9	644.8	—	—	—
Ferraz	Class L time delay	5000	0.009	0.009	0.009	—	—	0.009	225.0	675.0	—	—	—

Resistivity Temperature Coefficient Compensation

Why were the high-current tests of the fuses showing higher losses than the calculated losses based on the low-current resistance measurements? The electrical resistance of the metals used in fuses, switches and circuit breakers increases with higher temperatures[7]. If we only measure the resistance at a lower "room" temperature, we fail to accurately model the actual losses at operational temperatures.

"Cold" means the amount of current flowing during the test was too low to raise the temperature of the fuse above ambient temperature. "Hot" means that the current flowing did raise the temperature of the fuse element above ambient. In the special case of fuses rated 500A or less (where we could supply full-rated current), the temperature rise would be equivalent to that observed in a working system.

The internal resistance to electrical current for metals such as silver, copper and aluminum increases as the temperature of that metal increases. The temperature coefficient varies by type of metal, but for the metals common to electrical circuits, the value is approximately 0.4% increase for each degree Celsius.

Table 21. Temperature coefficients for common metals used to carry electrical current.

Metal	%R increase/ºC
Silver	0.38%
Copper	0.39%
Aluminum	0.39%

Using an average of 0.39%, we can derive an equation that predicts the percent difference in losses between "cold" (low-current) measurements and "hot" (load-current) measurements.

Equation 14: $D = T_{rise} * 0.0039$

Since fuses are regulated under UL 198 and since UL 198 allows fuses to operate at temperatures above ambient, could this explain the difference between the measured and derived values shown in Table 20?

Table 22. UL 198 maximum temperature limits for casing, ferrules and blades for Class R fuses when operating at 110% of rated current.

Maximum Acceptable Temperature Rises						
	Temperature Rise Above the Temperature of the Ambient Air					
	Casing		Ferrules		Blades	
Fuse Rating Amperes	ºC	ºF	ºC	ºF	ºC	ºF
0–30	50	90	50	90	—	—
31–60	50	90	50	90	—	—
61–100	50	90	—	—	50	90
101–200	50	90	—	—	60	108
201–400	50	90	—	—	65	117
401–600	50	90	—	—	75	135

* The asterisks in the equations symbolize multiplication.

[7] *http://en.wikipedia.org/wiki/Resistivity*

Table 23. UL 198 maximum temperature limits for casing and terminals for Class J fuses when operating at 110% of rated current. Class L fuses do not have a similar table; rather, the standard requires that the temperature rise of the terminals of a Class L fuse not exceed 65ºC.

Class J Fuses—Maximum Acceptable Temperatures Rises		
	Temperature Rise Above the Temperature of the Ambient Air	
Ampere Rating	Casing	Terminals
0–100	85ºC (153ºF)	50ºC (90ºF)
101–200	85ºC (153ºF)	60ºC (108ºF)
210–600	85ºC (153ºF)	75ºC (135ºF)

This means that at normal operating currents (100% of fuse rating), a 200A fuse may operate at some temperature less than 60ºC above ambient, a 400A fuse may operate at just under 65ºC above ambient and a 600A fuse may operate at just under 75ºC above ambient.

Using Equation 14, we solve for the predicted differences in derived versus measured losses:

Table 24. Predicted increase in measured losses when fuse is operating at 110% of rated current.

Vendor	Amp	Type	Allowable Temperature Rise	Predicted Increase
Littelfuse	200	Class J time delay	60.0	23%
Littelfuse	200	Class RK-5	60.0	23%
Littelfuse	400	Class J time delay	65.0	25%
Littelfuse	400	Class RK-5	65.0	25%
Littelfuse	600	Class J time delay	75.0	29%
Littelfuse	600	Class RK-5	75.0	29%

When we compared these calculated power loss values with the measured power loss values, we obtained the differences summarized in Table 25:

Table 25. Comparison of 3-phase Class J and RK-5 fuse power losses derived from measured resistances (see Table 20) compared with the lab-measured power losses for the same size fuse (see Table 11). These losses do not include the losses of the switch.

Vendor	Amp	Type	Calcu-lated Loss	Mea-sured Loss	Predicted Increase	Actual Increase	P to D Differ-ence
Littelfuse	200	Class J time delay	41.6	55.2	23%	33%	9%
Littelfuse	200	Class RK-5	46.5	61.8	23%	33%	10%
Littelfuse	400	Class J time delay	96.7	121.2	25%	25%	0%
Littelfuse	400	Class RK-5	89.6	112.9	25%	26%	1%
Littelfuse	600	Class J time delay	133.9	185.6	29%	39%	9%
Littelfuse	600	Class RK-5	116.6	164.3	29%	41%	12%

Several conclusions can be drawn from the results shown in Table 25:

• Since the UL 198 standard publishes a maximum temperature rise at 110% of rated current, and since our test current was always 100% or less, the predicted temperature rise will be less than shown in Table 25. Having said that:

  • 400A predicted and measured values agree very closely when we assume the increase is solely due to resistivity increases because of thermal coefficient differences. This would imply that there are additional loss mechanisms other than temperature differences that account for the increase in actual measured resistance.

  • 200A fuse resistances and power losses were measured to be higher than predicted by thermal coefficient differences alone. This implies that there are even more mechanisms at work that are raising the measured resistance above the predicted resistance.

  • 600A fuse resistance and power losses were higher still than would be predicted by differences in thermal coefficient differences alone. Recall that our test provided a maximum of 500A, meaning that the 600A fuse should not be operating anywhere near its allowable 75°C rise. Therefore, the predicted increase should not be as high as shown in Table 24 and Table 25. There are substantial additional mechanisms at work increasing the 600A fuse above the predicted values.

As we conclude from this discussion, additional (unknown) mechanisms are causing the measured resistances to be higher than the values predicted from analyzing low-current resistance. The most likely explanation is that we have two different samples of fuses. On one sample we performed low-current testing, but not high-current testing. On the second sample we performed high-current testing but not low-current testing. It is possible that aging of fuse elements, manufacturing tolerance difference or simply unpublished differences in the same fuse brand, model and size, but purchased at different times could explain the difference.

Regardless of the differences, we have a dilemma as we look at the fuse ratings above 600A. We did not perform any high-current testing on those size fuses. If the 600A fuse losses were higher than the predicted values, how will we estimate the losses for the larger fuses? Also, since Class J and RK-5 fuses stop at 600A, we will be switching to a completely different type—the Class L. Whatever the effects that were causing the lower ampere fuse losses at operating temperatures to exceed the values predicted by changes in thermal coefficient, we won't be able to estimate those increases for the Class L without stepping into the realm of speculation.

Therefore, without hard data, our decision was to remain as conservative as possible by using low-current resistances offset by an estimated 50°C temperature rise based on a temperature below the maximum allowed by UL 198.

Since the low-current resistance measurements were taken at approximately 20°C, at 50°C, the resistivity losses would need to be calculated at 70°C. Using Equation 14 we scaled the resistivity based on this higher temperature, then calculated the losses at this higher resistance using Equation 1. The results are shown in Table 26 below:

Table 26. Class L fuse resistive 3-phase power loss derived from 3rd-party measurement of resistance (see **Table 20**). Power loss values derived both at the temperature at which the fuse resistance was measured, plus a temperature 50°C higher, as permitted by UL 198 standards. The higher temperature results in higher resistive losses, but as we saw with high-current testing of Class J and RK-5 fuses, there are additional losses that cannot be accounted for from thermal coefficient effects. However, as discussed in the report, since we did not perform high-current testing, we are not assuming those additional losses are seen on Class L. Instead we chose to only describe losses that can be derived from direct measurement of physical properties. 5000A data is extrapolated from 800A–4000A data. The linear equation describing that data is (y = 0.1598x − 0.372, where y = power loss and x = amp rating of fuse).

Amperes	Power Loss at 20°C	Power Loss at 70°C
800	129	154
1600	266	318
2000	308	368
3000	473	565
4000	645	771
5000	799	954

At this point we have measured, or derived from models, for the following protective devices:

• Class J resistive power losses: 20A–600A

• Class RK-5 resistive power losses: 20A–600A

• Class L resistive power losses: 800A–5000A

• Fusible switch (less fuses): 20A–5000A

• Molded case circuit breakers, Eaton Series C: 20A–2500A

• Molded case circuit breakers, Eaton Series G: 20A–2500A[8]

• Air Circuit Breaker, Eaton Magnum DS, fixed mount: 800A–5000A

• Air Circuit Breaker, Eaton Magnum DS, draw-out: 800A–5000A

Combining all resistive power loss values, we created a consolidated data table of J, RK-5, L and circuit breaker resistive power losses from 20A–5000A.

[8] At the time of this report, Series G circuit breakers were available only up to 600A. Values shown above 600A are Series C breakers.

Table 27. Consolidated listing of measured and calculated power loss (rounded to nearest integer) for Class J, RK-5, Class L fuses and the switches controlling them along with two types of Eaton molded case circuit breakers as well as Eaton Magnum DS air circuit breakers, both fixed and draw-out chassis mounted.

	Fuses				Fuse and Switch			Molded Case Breaker		Air Circuit Breaker	
Amp	Class J	RK-5	Class L	Switch Mechanism	Class J + Switch	RK-5 + Switch	Class L + Switch	Series C	Series G	Fixed	Draw-Out
20	9	14	—	0	9	14	—	0	4	—	—
30	13	17	—	1	13	17	—	1	8	—	—
40	14	18	—	2	16	20	—	2	7	—	—
50	16	20	—	2	19	23	—	3	12	—	—
60	19	22	—	3	22	24	—	4	17	—	—
70	25	25	—	3	28	28	—	6	9	—	—
80	21	27	—	4	25	31	—	8	12	—	—
90	20	30	—	4	25	34	—	10	16	—	—
100	19	32	—	5	24	37	—	12	19	—	—
125	28	39	—	12	41	51	—	19	30	—	—
150	37	47	—	19	57	66	—	27	17	—	—
175	46	55	—	27	73	82	—	36	23	—	—
200	55	62	—	34	89	96	—	47	30	—	—
225	64	68	—	41	105	109	—	60	48	—	—
250	72	75	—	48	120	123	—	75	59	—	—
300	88	87	—	63	151	150	—	98	29	—	—
350	105	100	—	77	182	177	—	134	39	—	—
400	121	113	—	92	213	205	—	175	51	—	—
500	154	138	—	121	274	259	—	177	80	—	—
600	186	164	—	150	335	314	—	255	116	—	—
800	—	—	154	207	—	—	361	87	87	60	150
1200	—	—	229	323	—	—	552	210	210	84	185
1600	—	—	318	439	—	—	756	220	220	150	329
2000	—	—	368	554	—	—	922	270	270	172	374
2500	—	—	359	699	—	—	1057	400	400	219	439
3000	—	—	565	843	—	—	1408	—	—	316	632
3200	—	—	493	725	—	—	1218	—	—	359	719
4000	—	—	771	1132	—	—	1903	—	—	374	749
5000	—	—	955	1421	—	—	2376	—	—	457	892

Table 28. Summary of power losses percentage differences between various sizes and types of circuit breakers and fuses. As mentioned in **Table 1**, the Class RK-5, Class J and Class L fuses dissipated 121%, 91% and 226%, respectively, more losses than molded case circuit breakers. When comparing Class L fuses with fixed and draw-out air circuit breakers, the Class L fuses dissipated 434% and 148%, respectively, more losses than the equivalently sized ACB.

| Amp | Power Losses | | | | | | RK-5 v. MCB | Class J v. MCB | Class L v. MCB | Class L v. Fixed ACB | Class L v. Draw-Out ACB |
	Series G	Fixed ACB	Draw-Out ACB	RK-5	Class J	Class L					
20	—	—	—	14.3	10.486	—	—	—	—	—	—
30	8.2	—	—	17.2	13.45	—	110%	64%	—	—	—
40	—	—	—	20.6	16.412	—	—	—	—	—	—
50	—	—	—	24.0	19.375	—	—	—	—	—	—
60	16.6	—	—	24.5	22.34	—	47%	35%	—	—	—
70	—	—	—	31.0	22.85	—	—	—	—	—	—
80	—	—	—	34.7	23.36	—	—	—	—	—	—
90	—	—	—	38.5	23.87	—	—	—	—	—	—
100	—	—	—	37.3	24.38	—	—	—	—	—	—
125	30	—	—	48.0	40.5525	—	60%	35%	—	—	—
150	—	—	—	61.1	56.725	—	—	—	—	—	—
175	—	—	—	77.8	72.8975	—	—	—	—	—	—
200	—	—	—	95.7	89.07	—	—	—	—	—	—
225	47.5	—	—	137.0	104.65	—	188%	120%	—	—	—
250	59.2	—	—	145.9	120.195	—	146%	103%	—	—	—
300	—	—	—	165.4	151.21	—	—	—	—	—	—
350	—	—	—	187.4	182.125	—	—	—	—	—	—
400	—	—	—	204.6	212.9	—	—	—	—	—	—
500	—	—	—	267.8	274.27	—	—	—	—	—	—
600	115.7	—	—	313.8	335.11	—	171%	190%	—	—	—
800	87	60	150	—	—	361.455	—	—	315%	502%	141%
1200	210	—	—	—	—	551.609	—	—	163%	—	—
1600	220	150	329	—	—	756.37	—	—	244%	404%	130%
2000	270	172	374	—	—	922.16	—	—	242%	436%	147%
2500	400	—	—	—	—	1057.1	—	—	164%	—	—
3000	—	—	—	—	—	1408.34	—	—	—	—	—
3200	—	359	719	—	—	—	—	—	—	—	—
4000	—	374	749	—	—	1902.88	—	—	—	409%	154%
5000	—	456.75	891.92	—	—	2375.91	—	—	—	420%	166%
						Average					
							121%	91%	226%	434%	148%

Notes: _____

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