PDHonline Course E270U (3 PDH)

Simplified Short-Circuit Calculations (Audio Version)

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Simplified Short-Circuit Calculations

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Course Content

The Three Steps in Calculating Available Short-Circuit Current

1. Collect Field Data, utility available short-circuit current, transformer kVA and impedance, feeder type and length.

2. Run the Calcs; use a commercial system modeling tool with data library; look up transformer and cable characteristics and use the IEEE spreadsheet; look up the transformer and cable characteristics and use a manual calculating procedure; or, look up the answer on one of the tables provided in this course.

3. Apply Reasonableness Tests to the Results; Both humans and machines make mistakes. Included here are a number of easy approaches to assure that the final answer is a good answer.

The Theory Behind Calculations of Available Short-Circuit Current

Short-circuit calculations are not mysterious or difficult, just overwhelmingly tedious.

An industrial or commercial electrical distribution system can be summarized as follows:
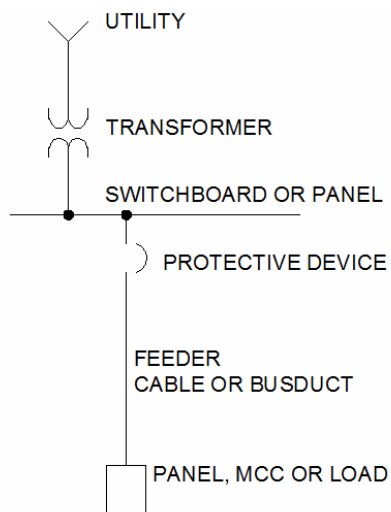
CONVENTIONAL ONE-LINE DIAGRAM
nts, TLM, 2DEC08

This is what electrical power designers see and think. Obviously, it is simplified from the equipment actually installed.   However, the simplification continues. You know that the

utility is made up of a generator somewhere, lots of cables and some transformers. We combine all of that into a single, ideal generator with all of the impedances lumped together at the service. Everything upstream, a local transformer and the service cable become just two numbers - voltage magnitude and total impedance magnitude. (There is just a little more, and we will discuss it later.)

The transformer has only two characteristics, size in kVA and impedance in %Z. (Again, there is just a little more going on here, and we will address it later.)

CAVEAT (We will have frequent warnings during this course)
This course considers only 480V, 3-phase power distribution systems. The concept of system-limiting impedance from the main transformer applies to 120V and 208V systems, and almost always yields a very low number for short-circuit amps. If you meet the short-circuit withstand at the transformer terminals, you can use this number anywhere in the system safely.

The switchboard is idealized as a lossless conductor. It is not part of the short-circuit calculations.

The protective device, circuit breaker or fuse, is idealized as a lossless conductor, as is a motor starter, if you get close to a real motor load. Not only is it lossless, but it does no protection for short-circuit calculations.

The feeder cable has three characteristics. Type, size and length. We will consider only copper conductors in steel conduit and standard copper busduct. We will talk, though, about adjustments for different types, sizes and lengths.

The panel or motor control center or load is not considered (in this course). We apply a fault at the end of the feeder, inside the load. The short-circuit-withstand rating of the load is either greater than the available short-circuit current (good) or less than the available short-circuit current (bad).

CAVEAT
You must specify or check the specification for the short-circuit withstand of the device you connect at the end of the feeder. This is the point of the NEC requirement and this course. Unfortunately, an un-fused disconnect switch is rated 10,000SCA. It is 200,000SCA if you put in a good current-limiting fuse. The warning is that an un-fused disconnect can easily be non-compliant. This also applies to motor control centers. They have no inherent short-circuit withstand. It is the capability of the main or lowest-rated bucket installed.

Manual Calculation from Field Data using Transformer Nameplate and NEC Cable Data

Back to the Conventional One-Line Diagram figure. Incorporating the simplifications discussed earlier, the drawing becomes the following:
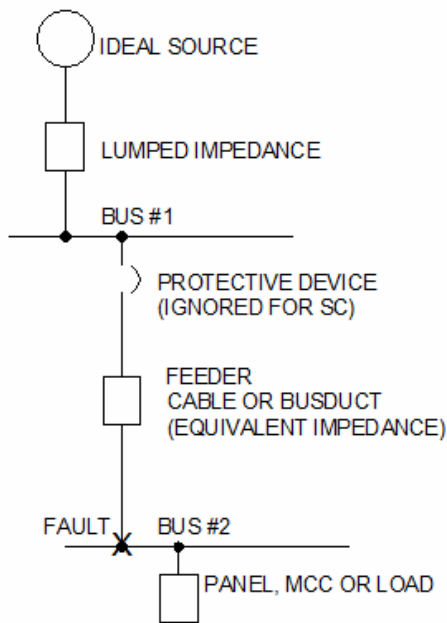
SIMPLIFIED ONE-LINE DIAGRAM
nts, TLM, 2DEC08

We first calculate the available short circuit current at Bus #1. For this example, let's use an infinite utility available short-circuit current (zero impedance), and a 1000kVA, 5.5% transformer. (These are very typical values, but, again, we will do 15 different size and impedance transformers.)

$$I(sc) = \frac{I(FL)}{\%Z} = \frac{KVA/V(L-L)/SRT(3)}{\%Z} = \frac{1000 / .48 / 1.732}{.055}$$

$$= \frac{1202\ A}{.055} = 21{,}870\ SCA$$

GOOD NEWS ! Smile. This makes life better and builds confidence in what we are doing.

First, I did some normal engineering tricks. I said "Volts", but entered kV, to keep the units consistent. Also, I said "%Z" and entered the decimal value, again, for units consistency. If this is confusing, I am sorry.

Second, I did the intermediate calculation to get the full-load current. This one of the numbers I encounter several times daily. A 1000kVA transformer has ~1200A full-load current. This provides an internal check and builds confidence that the calculator is working right (sometimes, it isn't).

Third, we got a worst-case value for required short-circuit withstand - 21,870 SCA. This is a real value and tells you what rating you need for a unit-substation distribution panel. Anything with a length of cable will have more impedance and less SCA.

This is an easy and essential calculation. It identifies the worst-case SCA. Anything we calculate with cable impedance must be less. This is our first reasonableness test.

Back to the calculations. To combine transformer impedance and cable impedance, we need both in ohms.

$$Z(TR) = \frac{V(L-N)}{I} = \frac{480}{21870} = .0219\ \text{ohms (Impedance Magnitude)}$$

$$Z(cable) = (\text{ohms} / 1000\ \text{ft}) \times \text{length} = .050 \times .2 = .010$$

Where: ohms / 1000 ft comes from NEC Table 9 for 500 kCMIL in steel conduit
length for example is 200 ft (load relatively close to transformer)

Then, $I(sc) = \dfrac{V}{Z(tot)} = \dfrac{480}{.0219 + .010} = \dfrac{480}{.0319} = 15{,}047$ SCA

CAVEAT

This numeric value is bogus. You remember that impedance has both a magnitude and direction. We are considering only the magnitude. The transformer and conduit-encased cable will have different impedance directions. Also, we may not be using the NEC Table correctly.

However, the concept is valid. Adding cable impedance reduces the available short-circuit current. When we run the computer simulations, using commercial software, we can use these numbers for reasonableness tests.

Short-Circuit Modeling Software

An industrial or commercial electrical distribution system can be graphically represented as follows:

Typical Short Circuit Model EasyPower 8.0.2.303b -2Dec08
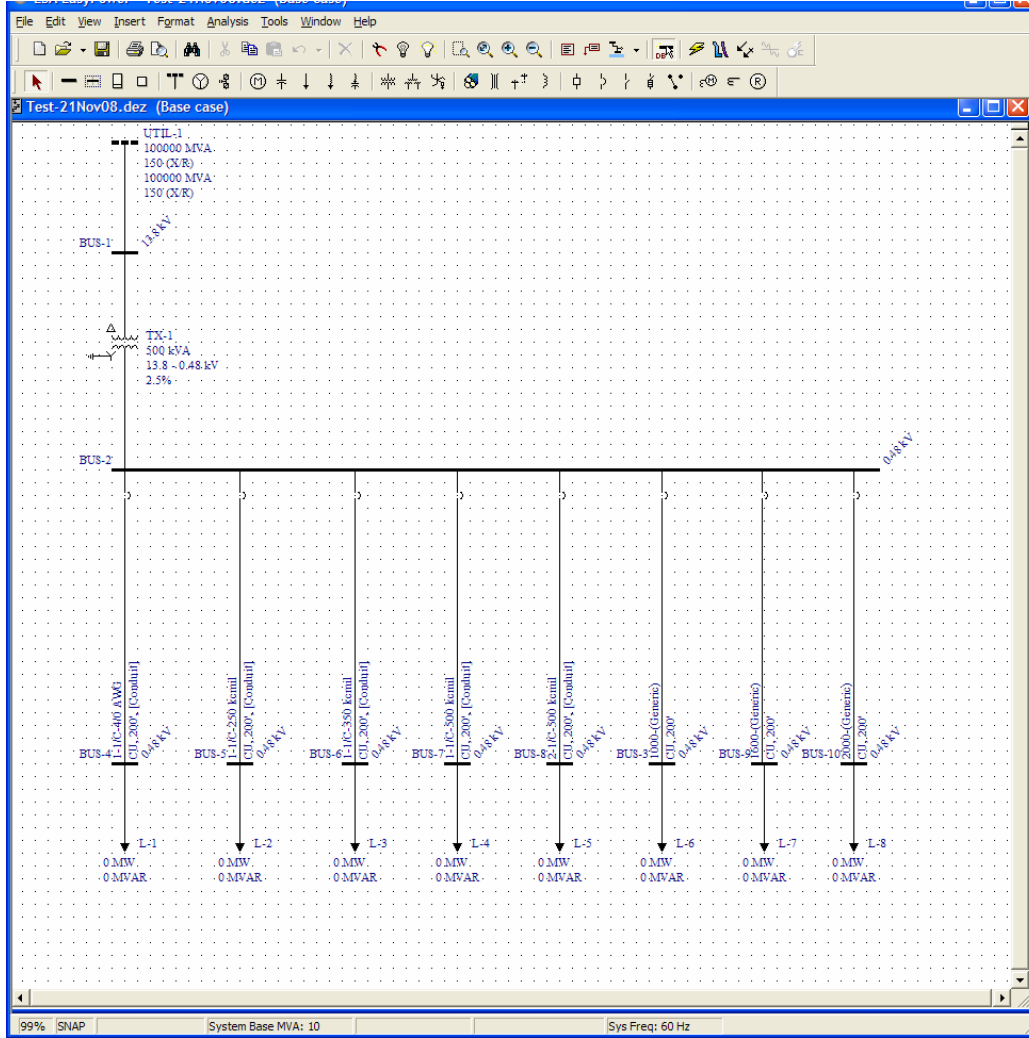
This is the actual model run for one of the table entries. Let's examine what it reports on the internal database used for calculations.

UTIL-1, 100,000MVA, 150(X/R)

This is the software equivalent of infinite available utility source short-circuit current. Note that the software permits you to enter actual utility available short-circuit current magnitude and direction.

CAVEAT
It is difficult and dangerous to enter actual utility available short-circuit current. It is difficult because it is very hard to make contact with a utility technical person these days. It is difficult because, when you do, the technical person doesn't want to commit the utility to a particular delivery structure. He knows they will re-configure, as needed and will upgrade (reduce impedance) in the future. If you make contact with the technical person and keep reminding him/her, it normally takes 3-6 months to get a numeric value. Using infinite source is conservative - produces results less likely to blow up initially or later.

BUS-1, 13.8kV

The software needs a bus (node) to connect the transformer. I chose 13.8 kV because it is extremely common. With an infinite utility source, the delivery voltage value does not enter the calculations.

With a provided utility available short-circuit current, the software needs to delivery voltage to do conversions to a common voltage base.

TX-1, 500kVA, 13.8 – 0.48 kV, 2.5%

This is the transformer rating used for one of the last runs used to create the tables. A 500kVA transformer is the smallest power transformer I have run into. 2.5% is the lowest tranformer impedance I have seen. The tables run from 500-2500kVA and 2.5%-7.5%.

BUS-2, 0.48V

This is a real bus, inside the distribution switchboard or panel. It is where we test the transformer available short-circuit current for the table and check against our reasonableness test.

Unlabeled Circuit Breakers

As mentioned previously, standard short-circuit calculations ignore protective devices, but I put them in because it doesn't look like a one-line diagram without them. In all of the major system modeling software packages, you use a single set of data entry to perform short-circuit modeling, load-flow modeling and time-current-coordination modeling. It is right to load the protective devices, even though the settings have no effect on the short-circuit calculations.

Eight Feeders, 1/C, 4/0 AWG, Cu, 200', (steel) [Conduit] 0.480V
        to 2000A Generic Busduct, Cu, 200', 0.480V

As indicated previously, the tables for this course have eight columns, for eight different feeders. This part of the computer graphic shows the eight feeders.

1/C means one conductor per phase. That sounds implied, but for power runs, it is common to use 2/C or 3/C per phase or more. This is usually done with multiple conduits, not more than 3 current-carrying conductors per conduit, or in cable tray.

4/0 AWG is the wire size. Again, I did runs for the smallest power conductor I have used (4/0 AWG) to the largest power conductor (2/C 500kCMIL) and the smallest busduct I have used (1,000A) to the largest (2,000A).

Cu means copper conductors. I have never installed aluminum conductors for feeders. I understand that the result is totally reliable - when done by skilled tradesmen - and substantial cost savings are available. This is a selection in the software, but not included in this course.

200' is the feeder length for this computer run. I initially planned to do 0' (transformer terminals) to 2 miles, in roughly logarythmic progression. After I started recording data, I discovered that about 1/3 of the values in this set are not meaningful. I did not completely fill out the tables.

[Conduit] means that the software will look up the impedance magnitude and direction for copper conductors in steel conduit. There will be different results for aluminum conduit or PVC or cable tray. The software can handle this.

(Generic) means old-style busduct. Newer, proprietary designs have lower feeder impedance. Even when installing new, I have purchased old-style busduct for compatibility, so I have no experience or reasonableness tests to apply to the new, compact styles.

BUS-3 to BUS-10
These are names of the ends of the feeders. Note that they are out of order. This is a common problem with power modeling software. It believes what you tell it and when you add more, it adds more, with new numbers after the original numbers. I made the mistake of entering BUS-3, then more in front of, rather than behind #3. When I added the larger busducts, I added them after #3. This looks funny and is a little awkward when modifying the database for additional runs. There may be a hidden function to re-number busses, but I couldn't find it.

L-1, 0 MW, 0 MVAR to L-8, 0 MW, 0 MVAR
These are the loads on the feeders. I used zero values because the tables report simplified conditions. Most loads, other than motors, do not affect short-circuit current values. Motors do. Just as they have an inrush at starting, they have an outrush when the terminals are shorted. The outrush is limited by motor characteristics to about 600% full-load amps. It must be included for large motor loads. Just add in the amps.

CAVEAT
Please notice each of the simplifications listed above. The table results are good reasonableness values for preliminary design. They are good numeric values when the assumptions are met. They are bogus for substantial utility impedance, voltages other than 480, aluminum conductors, raceway other than steel, modern busduct or distances other than the table values.

Look at One Table, 500kVA, 5.5%

Available Short Circuit Kilo-Amps Using EasyPower ™ ver. 8.0.2.303, ESA								
SC kA	480V, 500 kVA, 5.5%							
	Cable					Busduct		
	4/0	250	350	500	2@500	1200A	1600A	2000A
Feet	10.934							
0								
10								
20	10.551	10.556	10.579	10.597	10.763	10.831	10.879	10.890
50	10.005	10.021	10.081	10.125	10.515	10.667	10.798	10.824
100	9.093	9.143	9.282	9.383	10.103	10.424	10.663	10.715
200	7.746	7.881	8.098	8.251	9.419	9.931	10.394	10.500
500						8.594	9.614	9.878
1000								
2000								
5000								
10000	0.421	0.453	0.529	0.595	1.124			

This is the first table in the set and carries the sheet name, "Available Short Circuit Kilo-Amps Using EasyPower™ ver. 8.0.2.303, ESA.

Values are in kA because that is the standard term used in specifications and catalogs.

The tables were derived from results produced by EasyPower™, ver. 8.0.2.303. This is a commercial product of ESA (EasyPower.com). The work was done using their 6-month trial version, which is identical to the commercial version, but lacking SAVE and PRINT functions. I copied the results from the screen to a spreadsheet and didn't turn off my computer for the three days I was doing computer runs. The sales representative was very happy to have me use it for this course.

GOOD NEWS !

EasyPower™ is an excellent product with a near-intuitive user interface, excellent on-line manual, superb technical support and great reputation in the industry.

It is the intent of ESA that users sell the results they produce and there can be no copyright on data.

Other modeling software products with good reputations are SKM (skm.com) and ETAP(etap.com). It is the intent of this course to get demo programs of each and duplicate a few of the runs to validate the consistency of results among the programs. Stay tuned for future releases of this course.

The notation SC kA in the upper right corner indicates that the cell values are short-circuit kilo-amps at the end of the feeder.

Cable 4/0 to 2@500
These are column heading for the feeders examined. An interesting quirk of MicroSoft Excel™ is that it forces values containing @ to be email addresses and does not permit editing or change of the cell borders.

Busduct 1200A to 2000A
These are the busduct sizes that I have used. When you look at the tables, you will clearly see the pattern.

Feet   10.934
When I started out, I planned to calculate the available short-circuit current at the transformer terminals and for each feeder. The 10.934 is the available at the terminals. Obviously, this is the same as any feeder at 0-feet. I left the 0-feet because the table seemed truncated without it.

Feet 20   10.551 … 10.890
This row displays the available short-circuit current for each feeder if 20-ft long. Note that all are above the 10kA value for cheap molded case circuit breakers or unfused switches.

CAVEAT

I was surprised by this and hope that you, also can learn from it. Even a small transformer can blow up gear connected by short feeders.

Feet 100   9.093 … 10.715
This row displays the available short-circuit current for each feeder if 100-ft long. The big "X" indicates that available short-circuit current is less than 10,000A. This means that standard industrial gear does not need special attention for short-circuit rating.

I stopped using the big "X" after the first table, but left it on the sheet to explain use of the table.

I kept doing computer runs because I started at 100-ft for all of them and continued until I got below 10,000 SCA. I didn't do the 10-ft runs because the 20-ft runs were so close to the transformer terminal value that the calculation provided no value.

GOOD NEWS ! (kinda)
If you are 20-ft away from the transformer, or less, you can usually use the transformer terminal SCA and not worry about feeder impedance or direction. This isn't very good news because it is expensive at the transformer terminals. A utility service run of more than 50-ft is a good thing, though.

10,000-ft 0.421 … 1.124
This row displays the available short-circuit current for each feeder if 2-miles long. I have done several remote pump stations, for municipal water utilities and industrials. The 2-mile value is real-world.

Note that the available short-circuit current is just slightly more than the rated full-load capacity of the feeder. This means that 1,124 amps will flow for quite a while before the protective device recognizes an overload. It won't know it is a bolted fault. A single line-to-ground fault might not exceed the overload setting and might not escalate into a line-to-line fault.

CAVEAT
Worry about this if you have any remote pump stations or guard shacks. Ground fault protection works on feeders below 1,000A, even though not required.

Look at Another Table, 2500kVA, 5.5%

SC kA	480V, 2500 kVA, 5.5%							
						Busduct		
	4/0	250	350	500	2@500	1200A	1600A	2000A
Feet	54.649							
0								
10								
20	45.863	46.059	46.652	47.078	50.607	52.102	53.294	53.653
50	36.132	36.053	37.920	38.811	45.480	48.447	51.287	52.171
100	25.767	26.557	28.344	29.654	38.566	42.957	48.057	49.753
200	16.546	17.313	19.043	20.349	29.877	34.348	42.217	45.214
500	7.762	8.260	9.410	10.349	17.532	20.602	29.815	34.474
1000	4.102	4.398	5.091	5.670	10.339	12.089	19.376	23.904
2000	2.109	2.271	2.652	2.977	5.670	6.564	11.190	14.474
5000						2.758	4.885	6.524
10000	0.431	0.460	0.548	0.620	1.219			

The last table in the 5.5% set is 2500kVA.

We know how to read the table from the first example. The differences are that 5.5% of 2500kVA is a lot less ohms. Therefore, we see much higher SCA at the transformer terminals and on each of the feeders.

The feeder impedance doesn't start to have significant effect until we get above 200-ft and we can't use standard industrial gear on busduct until we get in the 2,000-ft distance. When I was doing work for a large US auto company, the standard 480V transformer was 2500kVA and we used 2000A busduct. The transformers were on mezzanines above the center of the plant and we never exceeded 2,000 on a busduct run.

At the 2-mile distance, the feeder impedance is controlling and, again, we have short-circuit currents just a little above overload protection threshold.

Look at Another Table, 500kVA, 2.5%

SC kA	480V, 500 kVA, 2.5%							
	Cable					Busduct		
	4/0	250	350	500	2@500	1200A	1600A	2000A
Feet	24.052							
0								
10								
20	22.244	22.273	22.387	22.473	23.238	23.238	22.820	23.858
50	19.844	19.942	20.227	20.432	22.107	22.820	23.396	23.569
100	16.631	16.836	17.344	17.707	30.434	21.634	22.747	23.090
200	12.255	12.584	13.333	13.872	17.656	19.452	21.484	22.148
500	6.775	7.104	7.848	8.414	12.564	14.504	18.113	19.522
1000	3.824	4.061	4.609	5.047	8.414	9.880	13.981	15.969
2000						5.911	9.237	11.380
5000								5.895
10000	0.428	0.462	0.542	0.612	1.187			

Error

We now examine the effect of low transformer impedance. The example is a small, 500kVA unit. Such transformers are presently installed and not too rare.

You would expect low transformer impedance to produce higher short-circuit currents, but the magnitude is not intuitive, to me. Available short-circuit current at the terminals is 24kA, emphasizing the economy of a separate transformer and distribution panel some distance away. Full load current is kVA/V(L-L)/SRT(3) = 500/.48/1.732 = 601A, so we might try to get the main distribution panel ~100-ft away to get down to a reasonable interrupting rating.

It doesn't make sense to buy a transformer and main, then run cables to a distribution panel, in most circumstances, but it is cheaper and may use production space more economically. Again, looking at the table, running 2/C, 500kCMIL for 100-ft identifies an error in the published table. That 32kA isn't right. I will fix it in the main table, but left it here to emphasize that both humans and machines make mistakes and it requires some vigilance to get proper results from either. (This mistake is clearly mine.)

The other case where this occurs is where the utility provides a padmount or pole-mounted cans outside and you put your service panel inside. 100-ft produces a cost reduction and safety improvement.

Since we can only deliver 600A, it doesn't make sense to look at 1000A or larger busduct. Note, however, that the software didn't complain. You must apply reasonableness tests.

CAVEAT

A special problem is upsizing feeders to reduce voltage drop. That isn't the focus of this course, but it is a consideration and is related.
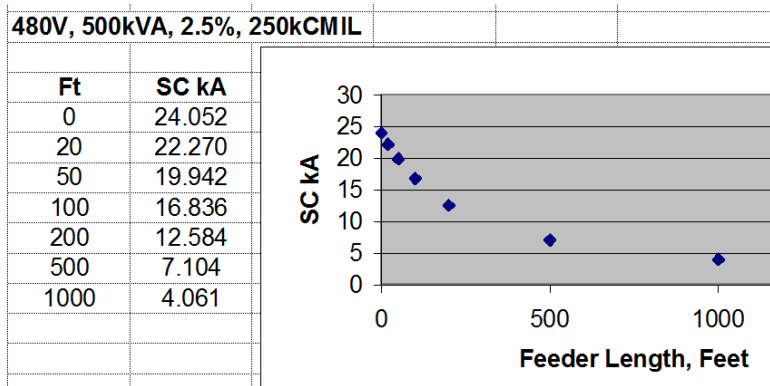
I recently joined a project during the construction phase. The consulting engineer had specified 3/C, 500kCMIL for an 800A run with expected load of 500A. His run was 500-ft. He didn't look at the fact that a tenant was hooking up another 500-ft of 2/C, 4/0 AWG for the remainder of the run. (He didn't know that the tenant was hooking up another 500-ft of 2/C, 4/0 AWG for the remainder of the run.)

This is a little silly, but not a problem. Until, the consultant called for an unfused disconnect switch and kWH meter at the tenant connection. As noted earlier, an unfused switch has 10,000 AIC rating. We had 18,000 A available at the switch, mostly because of the over-sized feeder.

There was a happy ending, though. The contractor bought a fused disconnect switch and provided 500A fuses with no additional cost.

(Quirky detail: How can 3/C, 500 kCMIL be replaced with 2/C, 4/0 AWG ? Easy, the 3/C was XHHW in steel conduit and the 2/C was 90-degree RHW / DTO / P-123 MSHA open conductors, laying on the ground. I don't think the tenant was worrying about voltage drop.)

From the table, available short-circuit current drops to 10kA somewhere between 200-ft and 500-ft from the transformer. The data points are "hard". That is, they are actual commercial software result values. Any interpolation must be done with care. Let's look at the curve, using MicroSoft Excel™.

480V, 500kVA, 2.5%, 250kCMIL

Ft	SC kA
0	24.052
20	22.270
50	19.942
100	16.836
200	12.584
500	7.104
1000	4.061

The region between 200-ft and 500-ft looks acceptably linear to me.

$$\text{Slope is} \quad \frac{12.584 - 7.104}{200 - 500} = \frac{5.48}{300} = 0.01827 \text{ kA/Ft}$$

Predicted cross-over is at $200 + 2.584/.01827 = 200 + 141 = 341$ Ft

Check   500 – (10 - 7.104) / .01827

                                  = 500 – 2.896 / .01827

                                  = 500 – 159 = 341 Ft

(This is the most manual algebra I have done since I can't remember when, certainly the last century.)

In fact, since we are doing reasonableness tests, I would look at a better plot and mark a point at the 10 kA crossing, then read the distance axis.

Using the pathetic Excel™ chart, 341-ft looks about right.

CAVEAT ?
This looks like good engineering to me, not WAG. If you do not have a comfort level with the result, then you are a good candidate to buy the commercial software package or hire a PE who has it. My comfort level comes from the numerous reasonableness tests we have performed to get here.

Look at Another Table, 2500kVA, 2.5%

SC kA	480V, 2500 kVA, 2.5%							
						Busduct		
	4/0	250	350	500	2@500	1200A	1600A	2000A
Feet	120.164							
0								
10								
20	83.111	84.138	86.690	88.485	102.093	108.097	113.360	115.365
50	54.415	56.127	59.990	62.794	82.897	92.270	104.306	108.363
100	33.869	35.515	39.233	42.060	62.794	72.489	90.516	97.550
200	19.051	20.239	22.974	25.173	41.922	49.390	68.879	79.809
500	8.246	8.847	10.256	11.439	21.016	24.541	39.759	49.433
1000	4.230	4.555	5.324	5.982	11.439	13.227	22.679	29.472
2000	2.142	2.311	2.713	3.061	5.982	6.864	12.115	16.134
5000						2.807	5.039	6.810
10000	0.433	0.468	0.551	0.624	1.233			

This is a large, low impedance transformer. We would expect huge available short-circuit current, but, again, it is not intuitive how much distance we need to get down to general purpose, 10 kA gear.

As expected, the available short-circuit current at the terminals is huge - 120 kA - above the rating of a lot of current-limiting fuses and circuit breakers with fuse protectors.

200 kA protective devices are available, but recognize the expected problem when you have to replace one of the fuses. If it goes, a big part of your plant is down until the fuse is replaced.

You have to get beyond 500-ft to use 10 kA gear. If you have a transformer like this in your plant, it would be prudent to start checking the interrupting capacity of all protective devices and be very wary of any unfused disconnects.

REASONABLENESS TEST

The embedded caveat above was that great care is required in the ratings of all distribution devices if you have a 2500kVA, 2.5% transformer. Is this reasonable ?

Short-circuit studies ignore the operation of protective devices. If you have a 200kA current-limiting fuse on your transformer main, do you really need to worry about feeder breakers, downstream panels and disconnect switches ?

YES! For four reasons. First, it is the law. When you start intentionally violating the National Electric Code, you are buying grief for yourself and your employer. This is persuasive to me.

Second, protective devices fail. I have high confidence in current-limiting fuses, operating in their current limiting range. I have less confidence in relay-driven power circuit breakers. I have been part of accident investigations where the circuit breaker didn't open when needed.

Third, I have high confidence in current-limiting fuses, operating in their current limiting range.   This transformer has full-load current of 2500/.480/1.732 = 3,000 A. A reasonable main fuse might be 4,000 A. A 4,000 A current limiting fuse doesn't go into its current-limiting mode until something like 40 kA, depending on the fuse. Can you foresee situations where a distant fault or weak nearby fault looks to the fuse like overload instead of a short ? You don't get the fractional-cycle operation and the field device gets the full hit.

Fourth, if the field device opens before the main device it doesn't matter what the main device is rated at. The field device gets the full hit. Sometimes there is an intentional delay placed on the main for protective coordination reasons or in error. In this case, the field device gets no benefit from the upstream rating. I am talking here about relaying that is set incorrectly or enjoying a spider's web, not the breaker failure in the second worry. The success rate on relaying tests is directly proportional to the maintenance care they have received. If yours haven't been checked in 20-years, it is another reason to get fully rated field gear.

Is there any reason to look at the 7.5% cases ?

The only reason I can conceive is if you have one or more 7.5% transformers in use and didn't want to read the discussions of 5.5% and 2.5% transformers. There is nothing special about 7.5% units except that they have smaller available fault currents, at the terminals and after a feeder.

Look at the table for your unit and see if you have existing or prospective problems.

Is there any reason to make tables for 3.5%, 4.5% and 6.5% transformers ?

We demonstrated interpolation of the distance column previously. The same method can be applied to an impedance value between 5.5% and 7.5% or between 2.5% and 5.5%. Because we have three values to use in the interpolation, you can easily see how linear or curved the section is that you are interpolating. Again, I recommend graphic interpolation, as it incorporates visual reasonableness tests. There is some slick technical software out there to do algebra for you, too.

Parting Words

Please use the COMMENTS section following the quiz. Tell me what was confusing or not clear. Tell me if you got the promised value. Tell me if you would like a similar course on simplified time-current-coordination.

[eof]