Short Circuit

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Short Circuit Calculations – Transformer and Source Impedance

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An infinite bus short circuit calculation can be used to determine the maximum short circuit current on the secondary side of a transformer using only transformer nameplate data. This is a good (and simple) method for determining the worst case short circuit current through the transformer since it ignores the source/utility impedance. Ignoring the source impedance means you are assuming an infinite short circuit current available at the primary of the transformer.

In another article, we used the infinite bus method to calculated the maximum worst case short circuit current at the 480 Volt secondary of a 1500/2000 kVA transformer. What if you are evaluating the adequacy of a panel on the secondary that has a short circuit rating of 30,000 Amps? Using the "infinite bus" or "worst case" approach indicated an available short circuit current of 31,374 Amps which would mean the panel has an inadequate interrupting rating.

Based on this simplified worst case approach, you might think the panel needs replaced with a panel of a higher interrupting rating. This could be an expensive conclusion based on assumed (infinite primary) data.

Let's see how we can include the effect of the actual source short circuit current the equivalent source impedance. To factor in the effect of the actual source impedance, we can use the same formula that was introduced last month and add a few more steps to account for the source impedance. Last month we were introduced to the following infinite bus formula that is based on transformer impedance only and ignores the source impedance:

$$SCA_{secondary} = x\ (FLA_{secondary} \times 100)\ /\ (\%Z_{transformer})$$

Source and Transformer Impedance

The actual short circuit current available at a transformer's secondary terminals is not just a function of transformer impedance, but it is also dependant on how strong the source is at the primary of the transformer. A transformer connected to a strong source such as close to a major utility substation, will have a greater secondary short circuit current than if the same transformer was connected to a weak source such as a long distribution line in a rural area.

To factor in the strength / weakness of the source impedance we only need to add one extra variable, $\% Z_{source}$ to our previous formula. The new formula would be:

$$SCA_{secondary} = (FLA_{secondary} \times 100)\ /\ (\%Z_{transformer} + \%Z_{source})$$

By adding $\%Z_{source}$ to $\%Z_{transformer}$ we are now factoring in the strength of the source. A stronger source will have a lower $\%Z_{source}$ and a weaker source will have a higher $\%Z_{source}$

This calculation procedure is similar to the infinite bus calculation from last month, but we now have to add the additional step of calculating the source impedance:

Step 1 – To calculate the equivalent source impedance:

$$\%Z_{source} = (kVA_{transformer}\ /\ kVA_{short\ circuit}) \times 100$$

where:

$$kVA_{short\ circuit} = kV_{L-L} \times Sqrt\ (3) \times SCA_{primary}$$

This seems simple enough but where do you obtain the $SCA_{primary}$? Great question! If the transformer is going to be connected to the utility system, the utility company is usually the source of this information. It is best to start out by determining who is the utility account representative and they can either provide you with the information or direct you to someone that might have the information.

If the transformer is not directly connected to the utility but is further down stream in a power distribution system, you will need to obtain short circuit calculations for the upstream part of the system. This means someone (perhaps you) will have to perform short circuit calculations from the utility down through the power distribution system.

If you are unable to determine any of this information, and you are concerned about worst case highest magnitude short circuits, you can always default to the simpler and generally more conservative infinite bus calculation.

You must be careful! Infinite bus calculations are good for the evaluation of the maximum worst case short circuit current through the transformer (excluding motor contribution

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and impedance tolerances for transformers not yet delivered/tested). However, if you are interested in minimum short circuit currents for analysis such as voltage flicker or harmonic resonance, an infinite bus calculation is *not* the way to go.

Derivation of Step 1

The formula for calculating the source impedance may seem a little odd the first time you see it. Dividing two kVA's might seem puzzling however, it has its origin with the Per Unit System. The $\%Z_{source}$ is actually the true primary source impedance of the source in ohms, divided by the transformer base impedance in ohms. Her is how the derivation of step 1 works:

$$\%Z_{source} = (Z_{source\ ohms} / Z_{transformer\ base}) \times 100$$

$$\%Z_{source} = (kV_{L\text{-}L2}/MVA_{short\ circuit}) / (kV_{L\text{-}L2}/MVA_{transformer)}) \times 100$$

where:

$$Z_{source\ ohms} = kV_{L\text{-}L2}/MVA_{short\ circuit}$$

$$Z_{transformer\ base} = kV_{L\text{-}L2}/MVA_{transformer}$$

The $kV_{L\text{-}L2}$ in the numerator and denominator cancel each other and you are left with:

$$\%Z_{source} = [\ (1 / MVA_{short\ circuit}) / (1 / MVA_{transformer})\ ] \times 100$$

which becomes:

$$\%Z_{source} = (\ MVA_{transformer} / MVA_{short\ circuit}) \times 100$$

or in our case we use Kilo instead of Mega so our numbers are scaled by 1000:

$$\%Z_{source} = (\ kVA_{transformer} / kVA_{short\ circuit}) \times 100$$

Step 2 – Calculate the secondary full load current rating of the transformer:

$$FLA_{secondary} = kVA_{3phase} / (\ kV_{L\text{-}L} \times \text{Sqrt}(3))$$

Step 3 – Calculate the short circuit current on the transformer secondary bus, but this time we use the transformer impedance AND the source impedance.

$$SCA_{secondary} = (\ FLA_{secondary} \times 100\ ) / (\%\ Z_{transformer} + \%Z_{source})$$

Here is an example of the calculation:

Let's say we have a transformer rated 1500/2000 kVA with a secondary voltage of 480Y/277V, a primary voltage of 13.2 $kV_{L\text{-}L}$ and an impedance of 5.75%. The base rating is 1500 kVA and the fan cooled rating is 2000 kVA. Suppose the utility informs us that their maximum short circuit current available at the transformer's primary is 6,740 Amps at 13.2 kV.

Step 1 – Calculate the source impedance:

$$kVA_{short\ circuit} = 6{,}740 \text{ Amps} \times 13.2\ kV_{L\text{-}L} \times \text{sqrt}(3)$$

$$kVA_{short\ circuit} = 154{,}097 \text{ kVA}$$

(some utility companies might refer to this as 154 MVA)

$$\%\ Z_{source} = (\ 1500 \text{ kVA} / 154{,}097 \text{ kVA}\ ) \times 100$$

$$\%\ Z_{source} = 0.97\%$$

Step 2 – Just like last month, calculate the secondary full load current rating of the transformer.

$$FLA_{secondary} = 1500 \text{ kVA} / (0.48\ kV_{L\text{-}L} \times \text{Sqrt}(3))$$

$$FLA_{secondary} = 1804 \text{ Amps}$$

Step 3 – Calculate the short circuit current on the transformer secondary bus.

$$SCA_{secondary} = 1804 \text{ Amps} \times 100 / (5.75\% + 0.97\%)$$

SCAsecondary = 26,845 Amps

If this calculation ignored the source and assumed it was infinite, the short circuit current at the secondary would be

$$SCA_{secondary} = 31{,}374 \text{ Amps}$$

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When we factor in the effect of the source, the short circuit current drops to:

$SCA_{secondary}$ = 26,845 Amps

You can see that factoring in the source impedance (source strength) has a significant effect on the magnitude of short circuit current at the transformer secondary terminals.
All of the variables listed above are:

$FLA_{secondary}$	= Secondary Full Load Amps
kV_{L-L}	= Secondary voltage in kV
kVA_{3phase}	= Transformer three phase $kVA_{self\ cooled}$
Sqrt (3)	= Square root of three (1.73)
$\% Z_{transformer}$	= Transformer percent impedance
$\% Z_{source}$	= Source percent impedance referenced to the transformer base
$kVA_{short\ circuit}$	= Short circuit power
$SCA_{secondary}$	= 3 Phase Short Circuit Amps at the secondary bus
$SCA_{primary}$	= 3 Phase Short Circuit Amps at the primary bus

A few words of caution!: The impedance of a transformer must be the actual nameplate and not an assumed value. Impedances of transformers that have not yet been built or tested can vary by + / - 7.5% of the specified impedance.
The above calculation does not include something called motor contribution that I will discuss in later issues.
Adding the source and transformer impedances like we just did is good for a close approximation but it is not perfect. If your calculated short circuit current is close a device's interrupting rating, you will want to be even more precise.
Next month I will be discussing the effect of the X/R ratio which should also be factored into the calculation for greater precision. The X/R ratio is a dimensionless value that indicates how much of the impedance Z is resistive R and how much is inductive X. This is ratio is important for a more precise addition of impedances.

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