Beware of Simplistic Fault Current Calculations

Specifying and installing underrated equipment can undermine your power distribution design

AIC calculations for this roof-mounted distribution panel must include motor contribution factor.

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Fault current calculations are a critical piece of the electrical design/engineering puzzle for electrical distribution systems in commercial and industrial installations. A fault current calculation determines the maximum available current that will be available at a given node, or location, in the system. Once the fault currents have been calculated, you can then select overcurrent protection equipment, breakers, and fuses with a fault current rating equal to or greater than those values (NEC 110.9). If a breaker or fuse isn't rated to handle the maximum available fault current it might see, it may not operate properly and its internal parts could fuse together or the device may blow up under the destructive stresses of a fault condition, which can cause serious injury and or property damage.

Fault current calculations are based on Ohm's Law (V=I×R). To determine the maximum current available at any given point in a distribution system, the equation is rearranged to solve for current (I=V÷R). In a short circuit condition, resistance (R) gets very small and is essentially based on the total resistance in the electrical distribution system, from the derived source of power to the point of the fault.

As noted above, basic point-to-point fault current calculations are derived using Ohm's Law. System characteristics like voltage, conductor length, conductor constants, available short circuit values at the beginning of the circuit, and transformer percentage impedance are used to find the fault current at various locations within the system.

These calculations become more complicated when you consider that the resistance (R), should actually be replaced with an impedance value (Z). Impedance is calculated using the formula $Z=\sqrt{(R^2+X^2)}$. For instance, instead of utilizing the percentage impedance for transformers, percent Z, percent X, and percent R are used and converted to X and R values on a per unit basis. And instead of using a defined constant for conductors, the impedance for conductors within the electrical system are also broken down into X and R components of the impedance.

The ratio of reactance to resistance, or X/R, determines the peak asymmetric fault current. The total asymmetric current is a measure of the total DC component and the symmetrical component. The DC component causes the short circuit current to be asymmetrical. The asymmetrical component decays with time and will cause the first cycle of a fault current to be larger in magnitude than the steady-state fault current.

In addition, the decay of the DC component depends on the X/R ratio of the circuit between the source and the fault. If the fault comprises all reactive components, then the resistance value of the X/R ratio is zero and the DC component will never decay. If the reactive component of the impedance is zero, then the DC component decays immediately. In the real world, impedance is neither all resistive nor all reactive. It's a combination of both.

As you can see, calculating asymmetric current can be very difficult. Accurate calculations require you to know the rate of change of all reactive components in the system. However, multipliers, based on the actual calculated X/R ratios, have been developed to somewhat simplify this process. They're used in conjunction with the symmetric fault current calculation to provide an asymmetric fault current, which includes the DC offset component.

The issue becomes more confusing based on the fact that all low-voltage protective devices are tested at predetermined X/R ratios (Table on page C39). If the calculated X/R ratio at any given point in the electrical distribution system exceeds the tested X/R ratio of the overcurrent protective device, then you must derate the effective rating of the gear.

This can be a very critical issue if your fault current calculation doesn't include the X/R ratio or the peak asymmetric fault current. A fault condition with a high reactive component can potentially require a de-rating of the gear to below the symmetric fault current value calculated at the gear. Replacing installed gear that has been undersized because these asymmetric calculations haven't been provided could certainly ruin your day.

In addition, induction motors can contribute short circuit current back into the system during a fault condition. The motor can act as a generator and contribute "back EMF" from the inertia of the load and the rotor driving the motor after the fault occurs. Because the flux is produced from the induction from the stator and not the field windings, the motor contribution is quickly reduced and will only last for a few cycles. The total motor contribution depends on many factors, including motor horsepower, voltage, the reactance of the systems at the point of the fault, and the reactance of the motor.

This 4,000A service switchgear requires AIC bracing and overcurrent protection in excess of 65,000AIC.

The following example illustrates a potential problem of installing underrated electrical equipment if X/R ratios and motor contribution aren't considered in the initial design.

Example design criteria:

- Utility transformer rating: 2,500kVA
- Utility transformer % impedance: 4.775%
- Service conductors: 10 sets of 600 MCM copper
- Available fault current at utility transformer secondary: 63,000A
- X/R ratio at the utility transformer secondary: 11
- Motor contribution: 400 hp
- Ampacity of service conductors: 4,000A
- Service gear tested X/R ratio: 4.9

A fault current of 62,321A is calculated at the switchgear. This value is based on the 2,500kVA utility transformer with 4.775% impedance and minimal impedance from the service conductors (11 feet of 10 sets of 600 MCM copper).

The simple form of this calculation, based on infinite bus theory, is indicated below:

2,500kVA $\div$ ($\sqrt{3}\times$480V) $\div$ 0.04775 = 62,975, or 63,000AIC at the utility transformer secondary

However, the AIC is further reduced at the service to 62,321A, based on the impedance of the service conductors. This assumes no contribution from the motors in the system or from the asymmetric component.

X/R Ratios	
Device	**Tested X/R Ratio**
Molded case circuit breakers (rated $\leqslant$ 10kAIC)	1.7
Molded case circuit breakers (10kA $<$ rated $<$ 20kA)	3.2
Fuses, insulated case circuit breakers, molded case circuit breakers (rated $\geqslant$ 20kA)	4.9

All low-voltage protective devices are tested at pre-determined X/R ratios.

If the switchgear is rated based on this information only (i.e. no X/R or motor contribution), the switchgear could have easily been specified as 65,000AIC.

In this example, we're looking at a total contribution of 400 hp for the motor and an X/R ratio of 11 at the secondary side of the utility transformer. The X/R ratio at the switchgear is calculated at 10.37 based on the X/R ratio at the service transformer provided by the utility and the contribution of resistance from the service conductors and the reactance from the motors in the system. The electrical service equipment has been tested and rated at an X/R ratio of 4.9. The calculation of this X/R value can be performed using sophisticated software, electronic spreadsheets, or by long per-unit handwritten calculations. However, this work is beyond the scope of this article.

The motor adds a total of approximately 2,406A of fault current over the first half cycle. The motor contribution is based on the characteristics of the individual motors, but can be estimated by taking the total horsepower contribution, multiplying it by 5, and then converting this number to amps.

The high X/R ratio requires the de-rating of the gear by a factor of 1.139. The 1.139 is a multiplier factor equal to the asymmetric current at the calculated X/R ratio divided by the asymmetric current at the tested X/R ratio.

In addition, the following formula can be used to calculate the multiplier factor based on the caculated X/R ratio and the test X/R ratio for a given overcurrent protection device:

$$\frac{\sqrt{2}\times 1+e^{\frac{-\pi}{\text{X/R Ratio}}}\ \text{(Calculated)}}{\sqrt{2}\times 1+e^{\frac{-\pi}{\text{X/R Ratio}}}\ \text{(Tested)}}$$

In this case, the total fault current available, including the motor contribution, would be 64,727A.

62,321A (symmetric fault current) + 2,406A (motor contribution) = 64,727A

The gear, based on asymmetric de-rating, would be rated at 57,068A.

65,000A (gear rating) $\div$ 1.139 (X/R derating factor) = 57,068A

Assuming that the simplistic form of fault current calculations was initially used to size and install the main switchboard, the switchgear would have a fault current rating lower than the maximum available short circuit current and would therefore have to be replaced.

More complicated issues can arise if closed transition paralleling (utility and generator) gear, parallel redundant UPS systems with closed transition bypass, or high-impedance grounding systems are used. In many cases you should rely on a qualified professional and the use of advanced software to ensure that electrical gear is properly rated to provide protection for personnel and property. EC&M

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