Tech Note:

The Effective Value of Source Impedance

Impedance vs. Percent Impedance

Impedance is defined, in the Standard Handbook for Electrical Engineers, as "the apparent resistance of an alternating current circuit or path… the vector sum of the resistance and reactance of the path." Impedance may be comprised of resistance, capacitive reactance and inductive reactance, and is expressed in ohms. From the perspective of a load, the total input impedance may include the impedance of the upstream generator, transformer, line reactor and conductors. The power system impedance is useful for estimating the available short circuit current.

Sample calculations for a three-phase transformer rated 500kVA, 4160:480, 60Hz, 6% impedance.
Transformer reactance $X_t = (kV^2/MVA) \times \%Z/100 = (0.48^2 / 0.5) \times 0.06 = 0.027648$ ohms.
Approximate available short circuit current = 480/(1.732 x 0.027648) = 10,023.7 amps.

Equipment Nameplate impedance

Transformers and line reactors typically have nameplate ratings expressed as percent impedance. This rating indicates the internal voltage drop, based on the reactance in ohms, at full load operating conditions relative to the rated load and rated voltage. A five percent impedance line reactor will cause a five percent drop in voltage when rated current flows through the circuit. Voltage drop across impedance reduces as circuit current is reduced.

Sample calculations for a three phase transformer rated 500kVA, 4160:480, 60Hz, 6% impedance.
Transformer reactance $X_t = (kV^2/MVA) \times \%Z/100 = (0.48^2 / 0.5) \times 0.06 = 0.027648$ ohms.
Rated secondary current = 500,000 / (480 x 1.732) = 601.4 amps.
Voltage drop at full load = 601.4 x 1.732 x 0.027648 = 28.8 volts (28.8 / 480 = 0.06, or 6% of 480 volts).

Effective Percent Impedance

Effective impedance is the relative impedance of a reactor or transformer under actual operating conditions. Since smaller (kVA) loads have higher impedance and thus draw lower current than larger (kVA) loads, the internal ohms of a reactor or transformer represent a smaller percentage of the load impedance for a small (kVA) load than for a large load. The value in ohms will cause a lower voltage drop when less than rated reactor or transformer current is flowing. If the load is only one half the rated current, then the voltage drop across the impedance will be one- half of the rated voltage drop.

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Rated secondary current = 500,000 / (480 x 1.732) = 601.4 amps.
Actual Load current = 300 amps
Voltage drop at actual load = 300 x 1.732 x 0.027648 = 14.36 volts (14.36 / 480 = 0.0299, or 3% of 480 volts).
Effective percent impedance = 6% x (300 / 601.4) = 2.99%.

The effective percent impedance of a transformer or reactor is useful for estimating the harmonic current distortion that will be caused by the addition of non-linear loads (assume 6-pulse rectifiers here).

Source Impedance =	0.5% Z	1.0% Z	2% Z	3% Z	5% Z
Approximate Current Distortion	~100% THD-I	~75% THD-I	~55% THD-I	~45% THD-I	~35% THD-I

Generally, the higher the effective impedance, upstream of a non-linear load, the lower the harmonic current distortion will be. However, the transformer or reactor nameplate ratings do not accurately define the expected harmonic distortion. Although a 1000kVA transformer may have a nameplate impedance rating of 5%, the effective impedance relative to a 100kVA load is only one-fifth of 5% or 0.5%. This transformer represents a stiff power source to this smaller load and the resultant harmonic current distortion will be approximately 100% THD-I. In contrast, if a 5% line reactor is sized correctly for this 100kVA load, then current distortion will only be about 35% at full load. Notice however, that at 60% load, the effective impedance of a 5% line reactor is only 3% and therefore expected harmonic current distortion at 60% load is 45% THD-I, not 35%.