Application Guidance Notes: Technical Information from Cummins Generator Technologies

AGN 168 - Short Circuit Ratio (X/R)

OVERVIEW

Understanding a distribution system's fault discrimination requirements, characteristics and protection capability is complex. Such studies require appropriate technical data, including the identification of that system's various Impedance values.

Understanding a specific system's Impedance (Z) will require qualification of all the involved power distribution equipment in terms of X and R components. Such a process involving the identification of the fundamental elements is sometimes referred to as 'complex Impedance' or 'polar notation'.

DESCRIPTION

Complex Impedance values can be considered by graphical representation, where R is on the horizontal axis and X is on the vertical, thereby plotting Z as the resultant; in fact the hypotenuse of the Vector triangle.

The X/R ratio is the amount of reactance X divided by the amount of resistance R, which also happens to be the Tangent of an angle created by reactance and resistance in a circuit. The provision of X/R data for components incorporated within the scope of the distribution system can usually be provided by the appropriate manufacturer.

In the case of a transformer, there being no dynamic closed loop control system, a fixed value for X/R can usually be obtained from the transformer manufacturer, or a 'typical' value be obtained from an appropriate reference book. The identification of X/R values for the power source, either a utility supply or an a.c. generator (alternator) can be a far more difficult task.

Consider now the power source being a synchronous, brushless, ac generator (alternator). The manufacturer will be able to supply a Decrement Curve graphically, displaying the short circuit current levels, for conditions of: 3ph, 2ph, or 1ph short circuit conditions and the supplied information will include guidance regarding the duration for the sub-transient, transient, and steady state regions.

The Short Circuit Decrement Curve displays the alternator's behaviour from:

1. Time zero moment; and the result of imposed sub-transient behavioural dynamic excitation.
2. The transient period associated with appropriate reactance and appropriate time constants.
3. The 'push' resulting from actual (direct) positive excitation to the point of AVR ceiling voltage and resulting exciter and main rotor magnetic saturation.

The Decrement Curve displays Symmetrical and Asymmetrical behaviour at time zero through to the point where positive excitation takes over. Refer to AGN 005 – Fault Currents and Short Circuit Decrement Curves, for more detailed information.

The following information will offer an explanation; why the above described 'regions' result in a complex answer associated when providing an X/R ratio for an alternator. Text books will offer typical values, and one example recently found advised that a 13.2kV system, based on an alternator rated at some 200MW, may have an X/R ratio of between 12 and 20.

TECHNICAL DISCUSSION

Technical discussions regarding the supply of an X/R value result in the conclusion that several methods are available to identify a value, each producing an answer, which begs further clarification.

Method 1

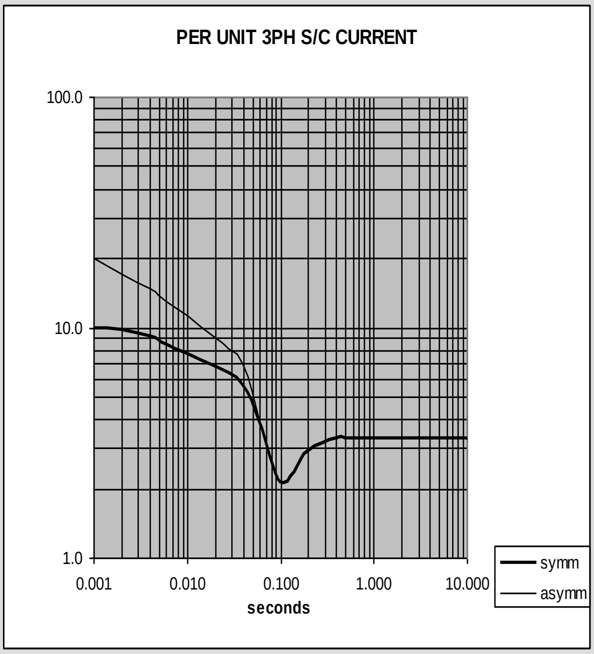
The example below provides an indication of the dynamic ratio associated with the alternator's internal reactance (X) against a per-unit value of R, based on the stator winding L-N Ohmic resistance converted in to per-unit terms.

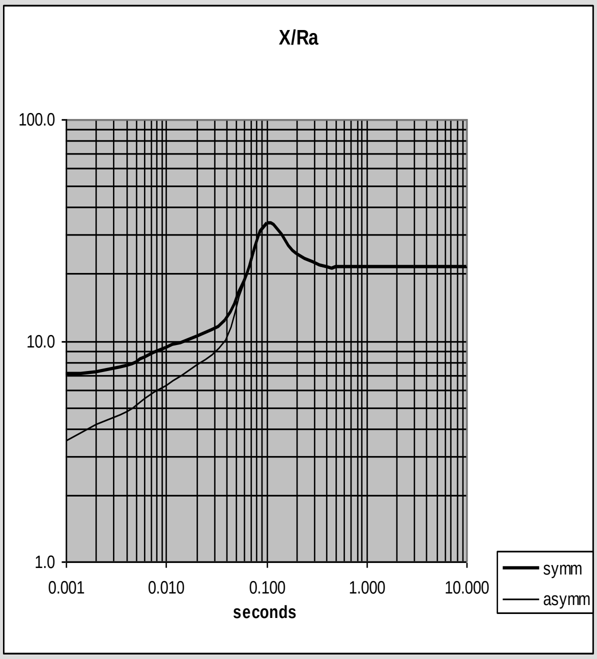
As the below example displays, the X/R ratio varies over the sub-transient and transient regions, resulting in a curve, which is the inverse of a Decrement Curve.

3-PH SHORT-CCT CURRENT DECREMENT & X/Ra

Frame and Core	HC5E	wdg17	
kVA	725	kVA	
Voltage (L-L)	600	volts	
Frequency	60	Hz	
Xd"	0.1	per unit	
Ra	0.007	ohms	(resistance of stator winding single phase L-N)

Rated current	698	amps	
Base Impedance [1 p.u. res]	0.496552	ohms	(V_{L-L}^2) / (rated kVA x 1000)
R. p.u.	0.014097	per unit	Ra / Base Impedance





For above L-L-L short circuit condition.

- Note that, across the dynamic Sub-Transient and Transient regions – considering both the Symmetrical and Asymmetrical extremes – X/Ra varies from 2.5 to 35, before the steady state condition of 22 is established. Distribution system over current protection should have operated at close to time zero, but certainly within the time period associated with the above dynamic behaviour.

Method 2

Using the same alternator considered for the example used in above Method 1.

IEC60034-4 identifies the method for identification of the following (and many more) parameters.

This calculation method for X/R uses Positive Sequence components for both the R and X components.

The positive sequence resistance:

Available technical data identifies R_1 at 0.00875 ohms. This Ohmic value needs to be converted into per-unit terms, and now becomes r_1

r_1 = 0.00875 / Base Impedance calculated in above Method as 0.496

$r_1 = 0.0176$ p.u.

The positive sequence reactance, X_1

Available technical data identifies X_1 at 0.3

$$\mathbf{X_1 / r_1 = 17}$$

CONCLUSION

Both above methods provide an X/R value.

The ‘Method 1’ steady state value of **22** is in line with the ‘Method 2’ value of **17**.

Method 2’s use of positive sequence parameters and therefore, associated with steady state rated load conditions, offers a value for steady state operational conditions throughout a connected distribution system.

Method 1’s steady state short circuit current conditions, not unsurprisingly, produces a value associated with a forced steady state level of excitation supporting a sustained very low impedance fault located close to the terminals of the alternator.

However, when considering the fault discrimination study within a total electrical system, with ‘real world’ considerations, there is a need to take into account the time zero and just after region, where fault current level contribution from the alternator is dynamic.

Including the alternator’s behaviour in the Method 1 Sub-Transient and Transient described time regions is imperative, as the resulting high fault current levels enable system discrimination to take place.