ELECTROWAVE
Power Solutions Ltd.
Specialised Electrical Engineering Services

Abbey Business Park,
Keats Lane, Earl Shilton,
Leicestershire,
LE9 7DQ, UK,
Tel; 01455-841141 Fax; 0871-661-6590
www.electrowaveps.co.uk

TECHNICAL NOTE No2 FOR ELECTROWAVE CLIENTS

Protection of circuits supplied by an Alternator

Tech Note Date 26/04/06

Study researched and compiled by Cliff Forbes

Protection of circuits supplied by an Alternator

Overview

A major difficulty encountered when an installation may be supplied from alternative **sources** (e.g. a HV/LV Transformer or a LV Generator) is the provision of electrical protection which operates satisfactorily on either source. The crux of the problem is the great difference in the source impedances; that of the Alternator being much higher than that of the Transformer, resulting in a corresponding difference in the magnitudes of fault currents.

Most water sites have large electrical installations that includes certain important loads for which a power supply must be maintained, in the event that the public electricity supply fails:

- Either, because safety systems are involved (emergency lighting, storm pumps, automatic fire-protection equipment, telemetry alarms and signalization, and so on)

or:

- Because it concerns priority circuits, such as certain equipment, the stoppage of which would entail a fine by the EA etc. One of the current means of maintaining *a* supply to the so-called "essential" loads, in the event that other sources fail, is to install a diesel-Alternator set connected, via a changeover switch, to an emergency-power standby switchboard, from which the essential services are fed.

An alternator on short circuit

The establishment of short-circuit current

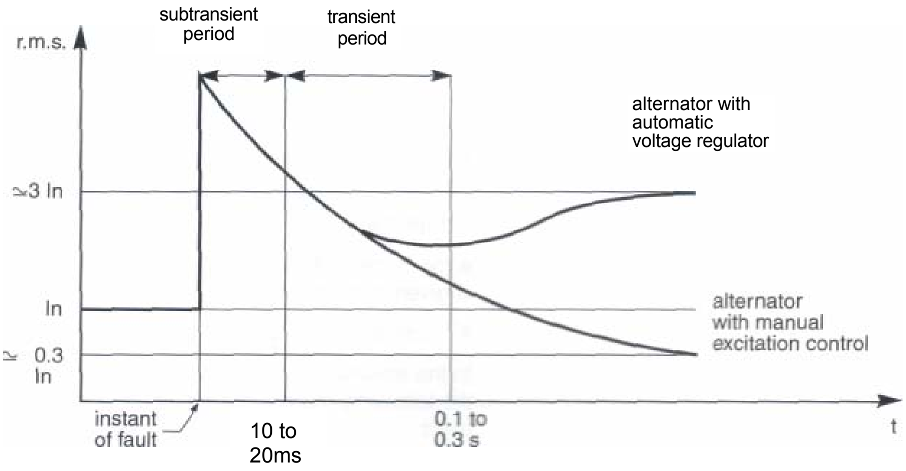
Apart from the limited magnitude of fault current from a standby alternator, a further difficulty (from the electrical-protection point of view) is that during the period in which LV circuit breakers are normally intended to operate, the value of short-circuit current changes drastically. For example, on the occurrence of a short-circuit at the three phase terminals of an alternator, the r.m.s. value of current will immediately rise to a value of 3 In to 5 In (depending on machine). An interval of 10 ms to 20 ms following the instant of short-circuit is referred to as the "sub-transient" period, in which the current decreases rapidly from its initial value. The current continues to decrease during the ensuing "transient" interval which may last for 80 ms to 280 ms depending on the machine type, size, etc. The overall phenomenon is referred to as the "a.c. decrement". The current will finally stabilize in about *0.5* seconds, or more, at a value which depends mainly on the type of excitation system, viz:

Manual or Automatic

Almost all modern generator sets have automatic voltage regulators, compounded to maintain the terminal voltage sensibly constant, by overcoming the synchronous impedance of the machine as reactive current demand changes.

This results in an increase in the level of fault current during the transient period to give a steady fault current in the order of 2.5 In to 4 In* .(see figure below).

In the (rare) case of manual control of the excitation, the synchronous impedance of the machine will reduce the short-circuit current to a value which can be as low as *0.3* In, but is often close to In*.



The figure above shows the r.m.s. values of current, on the assumption that no d.c. transient components exist. In practice, d.c. components of current are always present to some degree in at least two phases, being maximum when the short-circuit occurs at the alternator terminals.

This feature would appear to complicate still further the matter of electrical protection, but, in fact, the d.c. component in each phase simply increases the r.m.s. values already mentioned, so that calculations and tripping-current settings for protective devices based only on the a.c. components, as indicated below, will be conservative, i.e. the actual currents will always be either equal to or higher than those calculated. The further the point of short-circuit from the generator the lower the fault current, and the more rapidly the transient d.c. components disappear.

Furthermore, the a.c. decrement also becomes negligible when the network impedance to the fault position attains ohmic values which are high compared with the reactance values of the alternator (since the overall change in impedance is then relatively small)

Alternator impedance data

Manufacturers furnish values of the several impedances mentioned below. Resistances are negligibly small compared to the reactances.

It can be seen from the constantly-changing value of r.m.s. current that the effective reactance changes constantly from a low value (sub-transient reactance) to a high value (synchronous reactance) in a smooth progression.

The values discussed below are derived from test curves and correspond with current values measured at the instant of short-circuit.

- The sub-transient reactance x"d is expressed in % by the manufacturer (analogous to the short-circuit impedance voltage of a transformer). The ohmic value X"d is therefore calculated as follows;

$X''d\ (\text{ohms}) = x''d\ UN^2\ 10^{-5} / Pn$

Where:
x”d is in %
Un is in volts (phase/phase)
Pn is in kVA

The % transient reactance x’d is given in ohms by:

$X'd\ (\text{ohms}) = x'd\ UN^2\ 10^{-5} / Pn$

The % zero-phase-sequence reactance x”o is given in ohms by:

$X'o\ (\text{ohms}) = X'o\ (\text{ohms}) = x'o\ UN^2\ 10^{-5} / Pn$

For this exercise, and in the absence of more precise information, the following representative values could be used:

x"d = 20% ; x'd = 30 % ; x'o = 6%
Pn and Un being, respectively, the rated 3-phase power (kVA) and the rated phase/phase voltage of the alternator (volts).

The sub-transient reactance is used when calculating the short-circuit current-breaking rating for LV circuit breakers which have opening times of 20 ms or less, and also for the electrodynamic stresses to be withstood by ACB/MCCBs and other components (such as Busbars, single-core cables, etc.)

The transient reactance is used when considering the breaking capacity of LV circuit breakers with an opening time that exceeds 20 ms, and also for the thermal withstand capabilities of switchgear and other system components.

Note: From the instant at which the short-circuit is established, the alternator reactance will rapidly increase. This means that the currents calculated from the defined fixed values x"d and x'd (for breaking capacity) will always exceed those that will actually occur at the instant of circuit breaker contact separation, i.e. there is an inherent safety factor incorporated in the current-level calculation.

These calculations for the circuit breaker short-circuit **breaking** capacity are based on the symmetrical a.c. components of current only, i.e. no account is taken of the d.c. unidirectional components. For the circuit breaker short-circuit **making** capacity, the d.c. components are crucial, as IDC x 100/IAC.

Short-circuit current magnitude at the terminals of an Alternator

The transient 3-phase short-circuit current at the terminals of an alternator is given by:
Isc = Ig/x'd 100* where:

* (for CBs with opening time exceeding 20 ms)

Ig: rated full-load current of the alternator x'd = transient reactance per phase of the alternator in %;

- When these values are compared with those for a short-circuit at the LV terminals of a transformer of equal kVA rating, the current from the alternator will be found to be of the order of 5 or 6 times less than that from the transformer. The difference will be even greater where (as is generally the case) the alternator rating is lower than that of the transformer.

Example;
What is the value of 3-phase short-circuit current at point A according to the origin of supply?

Circuit impedances are negligible compared with those of the sources.

a) 630kVA Transformer supply 3-phase Isc = 12.6 kA

b) 250kVA Calculate Alternator supply 3-phase Isc =

Ig/x'd*100= Pn/√3 Un*100/x'd

where: Pn is expressed in kVA
Un is expressed in volts
x'd is expressed in %
Isc is expressed in kA.

3-phase Isc = 250*100/(√3*400*30) = Answer 1.2 kA