Criticalities in Section B.4 of ENA EREC G99

Connection of a synchro generator directly to the 11kV distribution network

B.4.4 Fault Ride Through and Fast Fault Current Injection

B.4.4.1 This section applies to **Power Generating Module**s to demonstrate the modules **Fault Ride Through** and **Fast Fault Current** injection capability.

B.4.4.2 The **Generator** shall supply time series simulation study results to demonstrate the capability of **Synchronous Power Generating Module**s and **Power Park Module**s to meet paragraphs 12.3 and paragraph 12.6 as applicable by submission of a report containing:

(i) a time series simulation study of a 140 ms three phase short circuit fault with a retained voltage as detailed in Table B.4.1 applied at the **Connection Point** of the **Power Generating Module**.

(ii) a time series simulation study of 140 ms unbalanced short circuit faults with a retained voltage as detailed in Table B.4.1 on the faulted phase(s) applied at the **Connection Point** of the **Power Generating Module**. The unbalanced faults to be simulated are:

1. a phase to phase fault
2. a two phase to earth fault
3. a single phase to earth fault.

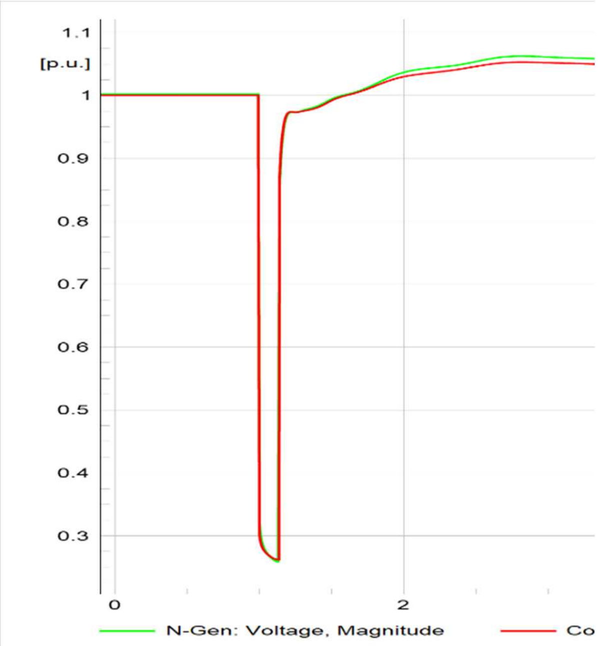
Table B.4.1

Power Generating Module	Retained Voltage
Synchronous Power Generating Module	30%
Power Park Module	10%

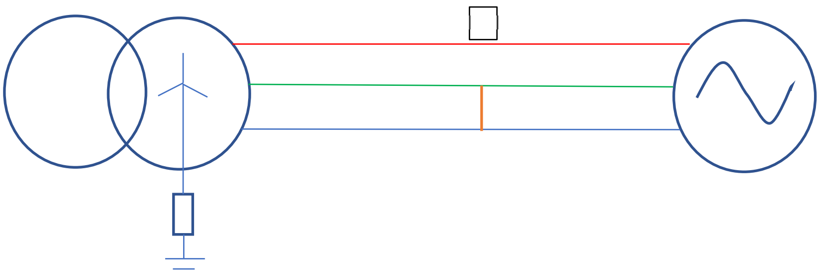
Does the retained voltage refer to the phase to phase or the phase to earth voltage?

12.3.1.2 The voltage against time curves defined in Table 12.1 and Table 12.2 express the lower limit (expressed as the ratio of its actual value and its reference 1pu) of the actual course of the **<u>phase to phase voltages (or phase to earth voltage in the case of asymmetrical/unbalanced faults</u>**) on the network voltage level at the Connection Point during a symmetrical or asymmetrical/unbalanced fault, as a function of time before, during and after the fault.

*For a **single phase to earth fault** and **a three phase fault**, the required retained voltage can be obtained if a fault impedance is considered. It is interesting to consider that the presence of a synchronous generator makes the retained voltage variable, as shown here below. We could consider the average value or the initial value or the final value as the retained voltage. Can you please clarify?*

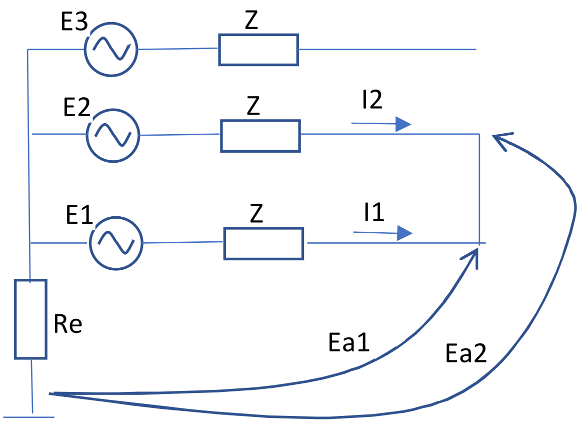


*For a **phase to phase fault**, considering the simplified system shown in the following figure, a ph-to-ph fault is applied between phase blue (1) and phase green (2).*



Due to the kind of fault and the neutral status, no earth fault current can flow.

Mathematical demonstration for a simplified system. Phase to earth voltages Ea1 and Ea2 are identical: Ea1 = Ea2. The fault current flowing in phase 1 is the same current flowing in phase 2 but with the opposite sign.



Fault at section A → Ea1=Ea2, I1 = -I2, I3=0, no current flowing in the neutral.

There is only one mesh.

$$\bar{E}_1 - \bar{z}\bar{I}_1 = \bar{E}_2 - \bar{z}\bar{I}_2 \qquad \bar{E}_1 - \bar{z}\bar{I} - \bar{z}\bar{I} - \bar{E}_2 = 0 \qquad -2\bar{z}\bar{I} = \bar{E}_2 - \bar{E}_1$$

$$\bar{I} = \frac{\bar{E}_2 - \bar{E}_1}{-2\bar{z}} = \frac{\bar{E}_1 - \bar{E}_2}{2\bar{z}} = \frac{E}{2z}\left(\frac{1 - e^{-j\frac{2\pi}{3}}}{e^{j\varphi}}\right) = \frac{\sqrt{3}}{2}\frac{E}{z}e^{\left(\frac{\pi}{6} - j\varphi\right)}$$

The phase to earth voltage at the faulted point is given by

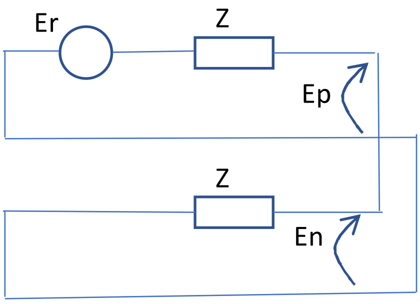
$$\bar{E}_{a1} = R_e\bar{I}\bar{e} + \bar{E}_1 - \bar{z}\bar{I}$$

Since Ie=0, then

$$\bar{E}_{a1} = \bar{E}_1 - \bar{z}\bar{I} \quad = E - ze^{j\varphi}\frac{\sqrt{3}}{2}\frac{E}{z}e^{\left(\frac{\pi}{6} - j\varphi\right)} = \cdots = \frac{E}{2}e^{-j\frac{\pi}{3}}$$

This demonstrates that the module of the phase to earth voltage at the faulted point is 50% of Er and <u>cannot be lower</u>. The triangle of voltages is completely distorted and phase to phase voltages are V12 = 0, V23 = -V31 = 1.5 Er.

*Representing the system with the **Symmetrical Components**, the circuit becomes:*



Positive sequence

Negative sequence

The zero sequence circuit is not involved. Ep=En=Er/2. E_0=0.

Recalculating the phase voltages at the faulted point, we can find that

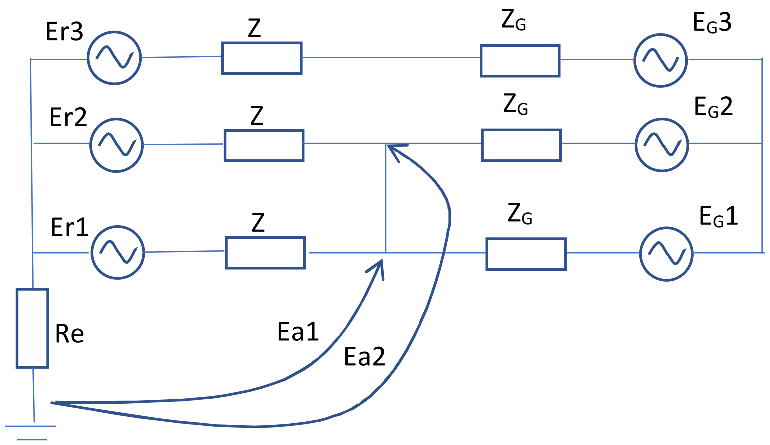
$$\begin{bmatrix} E_{a1} \\ E_{a2} \\ E_{a3} \end{bmatrix} = \begin{bmatrix} \alpha^2 & \alpha & 1 \\ \alpha & \alpha^2 & 1 \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} E_p \\ E_n \\ E_0 \end{bmatrix} = \begin{bmatrix} E_p(\alpha^2 + \alpha) \\ E_p(\alpha + \alpha^2) \\ E_p(1+1) \end{bmatrix} = \begin{bmatrix} -E_p \\ -E_p \\ 2E_p \end{bmatrix} = \begin{bmatrix} -\frac{E_r}{2} \\ -\frac{E_r}{2} \\ E_r \end{bmatrix}$$

The retained voltage is equal to 50% of Er and cannot be less.

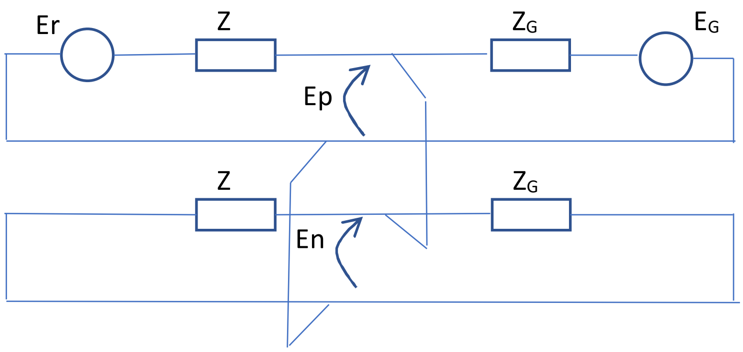
<u>The retained voltage equal to 30% (10%) of Er cannot be achieved!</u>

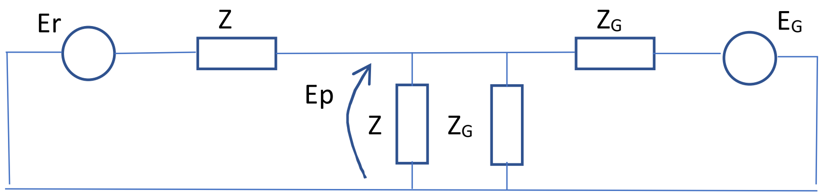
If a fault impedance is to be considered, it must be connected between phase 1 and 2 and makes Ea1 different from Ea2, the triangle of voltages is distorted yet and the request about the retained voltage must be better clarified.

Representing the synchronous alternator with its Thevenin equivalent, the scheme becomes this one:



This is converted in the following scheme when applying the symmetrical components. The negative sequence impedance of the synchro gen has been assumed identical to the positive sequence. This hypothesis is not far from reality because the negative seq reactance is very similar to the subtransient reactance.





Solving the circuit with the "loop current" method, the set of equations is:

$$\begin{bmatrix} 2Z & -Z & 0 \\ -Z & Z+Z_G & -Z_G \\ 0 & -Z_G & 2Z_G \end{bmatrix}\begin{bmatrix} J_1 \\ J_2 \\ 3 \end{bmatrix} = \begin{bmatrix} E_r \\ 0 \\ -E_G \end{bmatrix}$$

$$det = 2ZZ_G(Z+Z_G)$$

$$J_1 = \frac{1}{det}\begin{bmatrix} E_r & -Z & 0 \\ 0 & Z+Z_G & -Z_G \\ -E_G & -Z_G & 2Z_G \end{bmatrix} = \frac{Z_G}{det}[E_r(Z+Z_G) + Z(E_r - E_G)]$$

$$J_2 = \frac{1}{det}\begin{bmatrix} 2Z & E_r & 0 \\ -Z & 0 & -Z_G \\ 0 & -E_G & 2Z_G \end{bmatrix} = \frac{2ZZ_G}{det}[E_r - E_G]$$

$$E_p = Z(J_1 - J_2) = \cdots = \frac{Z_G E_r + Z E_G}{2(Z_G + Z)}$$

$$if\ E_G \cong E_r \rightarrow\ E_p \cong \frac{E_r}{2}$$

The hypothesis that E_G is almost equal to E_r is realistic. This solution is identical to the one of the simplified scheme. The other results are the same. Hence the retained voltage of 50% of Er is the minimum one.

We know that many simulations showed that a lower retained voltage is possible. This can be done by substituting the Thevenin equivalent of the network with three controlled voltage sources. This is a mathematical trick used to satisfy the Grid Code requirement, but the final system does not represent a three-phase system anymore.

*Similar demonstration can be done for a **two phases to earth fault**. Without a fault impedance, the phase to earth voltages = 0. With a fault impedance, a clarification about how phases and earth are connected and about which fault impedances must be considered is necessary: impedance between phases or between earth and phases.*