ORIGINAL DATA FROM BOOK



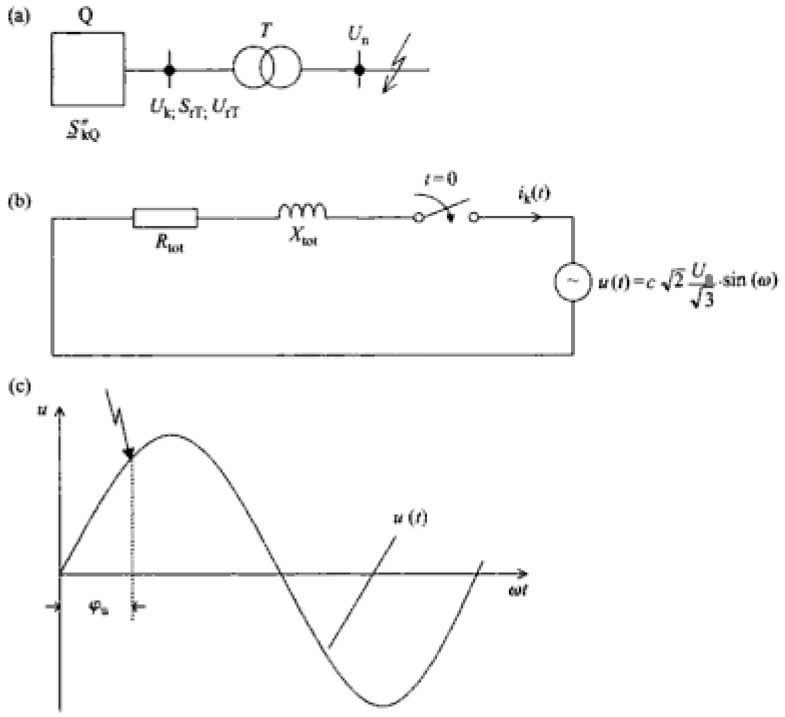


*Figure 8.5 Equivalent circuit diagram of a power system with three-phase short-circuit. (a) Circuit diagram, (b) simplified diagram of a single-fed three-phase short-circuit and (c) time course of voltage with voltage angle $\varphi_U$*

The time course of the short-circuit current $i_k(t)$ is calculated from the differential equation

$$L * \frac{di_k(t)}{dt} + R * i_k(t) = \sqrt{2} * \frac{c * U_n}{\sqrt{3}} * \sin(\omega t + \varphi_U) \tag{8.10}$$

The solution of the differential equation is given by

$$i_k(t) = \sqrt{2} * \frac{c * U_n}{\sqrt{3}} * \frac{1}{\sqrt{R^2 + X^2}} * (\sin(\omega t + \varphi_U - \gamma) - e^{-t/T} * \sin(\varphi_U - \gamma)) \tag{8.11}$$

where $U_n$ is the nominal system voltage, $\varphi_U$ is the angle of voltage related to zero crossing as per Figure 8.5, $c$ is the voltage factor according to Table 4.1, $T$ is the time constant: $T = L/R$, $X$ is the reactance of the short-circuit impedance: $X = \omega L$, $R$ is the resistance of the short-circuit impedance, $\omega$ is the angular velocity and $\gamma$ the angle of the short-circuit impedance: $\gamma = \arctan(X/R)$.

The initial short-circuit current $I_k''$ is equal to the first part (periodic term) of Equation (8.11), the second term is the aperiodic and decaying d.c.-component of the current. If the time course of the short-circuit current as per Equation (8.11) is related to the peak value of the initial short-circuit current

$$I_k'' = \sqrt{2} * \frac{c * U_n}{\sqrt{3}} * \frac{1}{\sqrt{R^2 + X^2}} \tag{8.12}$$

the peak factor $\kappa$ is obtained

$$\kappa(t) = \sin(\omega t + \varphi_U - \gamma) - e^{-t/T} * \sin(\varphi_U - \gamma) \tag{8.13a}$$

The maximum of the peak factor $\kappa$ determines the maximum of the short-circuit current (peak short-circuit current $i_p$) to be calculated by partial differentiation of Equation (8.13a) with respect to $\varphi_U$ and $t$. The maximum of the peak factor always occurs for short-circuits at $\varphi_U = 0$ and $t \leq 10$ ms (50 Hz), respectively $t \leq 8.33$ ms (60 Hz), whatever the ratio $R/X$ might be

$$\kappa(t) = \sin(\omega t - \gamma) + e^{-(R/X) * \omega t} * \sin\gamma \tag{8.13b}$$

A sufficient approximation of the peak factor $\kappa$ is given by

$$\kappa = 1.02 + 0.98 * e^{-3(R/X)} \tag{8.14}$$

Special attention for the calculation of peak short-circuit current must be given in the case of short-circuits in meshed systems or in systems having parallel lines with $R/X$-ratios different from each other [34]. A detailed analysis of these conditions is given in IEC 60909-1 and is mentioned in Chapter 4. The peak factor $\kappa$ according to Equation (8.14) is outlined in Figure 4.7.

## 8.5 Factor $\mu$ for symmetrical short-circuit breaking current

The short-circuit current in the case of a near-to-generator short-circuit decays significantly during the first periods after initiation of the short-circuit due to the change of the rotor flux in the generator. This behaviour cannot be calculated exactly as eddy currents in the forged rotor of turbine generators, non-linearities of the iron and saturation effects especially in the stator tooth are difficult to be calculated. Furthermore, the decay of the short-circuit current and by this the breaking current depend on different generator and system parameters such as time constants of the generator itself, location of short-circuit in the system, operational condition prior to the fault, operation of excitation and voltage control device, tap-changer position of transformers, etc. which cause unpredictable deviations of the calculated results from those obtained from measurements. Detailed calculations with digital programmes are therefore only applicable in special cases if high safety requirements are to be met.

The above is correct as it is widely used in our industry but it is just assumed and I struggle to find anyone being able to explain to me.

I have demonstrated back equation 8.11 but I wrote it in a different way as follow:

$$i(t) = \frac{U\sqrt{2}}{Z}\left[\sin(\omega t + \varphi - \psi) - \sin(\varphi - \psi)e^{-(\frac{R}{L})t}\right]$$

It is equivalent.
However I am struggling to understand how k factor (equation 8.14) is obtained. This factor is the same as used in IEC60909.
In the standard I am working everyday, we are talking of the following table here attached:

**Table 7 – Values for the factor $n$ [a] (9.3.3)**

| r.m.s. value of short-circuit current kA | cos $\varphi$ | $n$ |
|---|---|---|
| $I \leq 5$ | 0,7 | 1,5 |
| $5 < I \leq 10$ | 0,5 | 1,7 |
| $10 < I \leq 20$ | 0,3 | 2 |
| $20 < I \leq 50$ | 0,25 | 2,1 |
| $50 < I$ | 0,2 | 2,2 |

[a] Values of this table represent the majority of applications. In special locations, for example in the vicinity of transformers or generators, lower values of power factor may be found, whereby the maximum prospective peak current may become the limiting value instead of the r.m.s. value of the short-circuit current.

This time n is used to calculate the minimum peak that the equipment shall be tested to, which a function of the declared RMS current we have designed the equipment for.

**I am trying overall to establish the link between k and n**. Could anyone help me?

Thank you.