Busbar Protection 7SSx

Current transformer requirements

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Contents

Abstract

One of the important efforts for engineering a differential protection scheme is the layout respectively the check of the primary current transformers (CTs).
Compared to high-impedance busbar protection schemes, the primary CT requirements are much less for low-impedance protection devices. A few conditions have to be fulfilled nevertheless.

The required data are

- maximum symmetrical short-circuit current
- rated CT ratio
- rated CT symmetrical short-circuit current factor
- rated restive CT burden
- secondary CT winding resistance
- resistance of leads
- relay burden

Usually the appearance of displaced short-circuit currents or CT remanence causes a higher stress to a closed iron-core transformer and fortifies its non-linear transformation behavior. In turn this challenges the protection performance. These conditions (full displacement, high remanence) are already mastered by the 7SSx[1] protection algorithm itself and the CT checks can be carried out favorably with static current conditions only.
Thus the suitability of a given CT -which is very often the case- can be checked easily by applying a few formulas -based on the default settings of the stabilization factor k- as per chapter 1. In case of compliance the CT check is already finished.
If this simple check fails the proper setting of the k-factor has to be calculated according to chapter 2.1 or 2.2.
Two reasons may call for a detailled calculation of the k-factor:

- CT saturation between 3ms and 5ms (50Hz) resp. 2.5ms and 4ms (60Hz)
- Current clipping when the protection input range of 100 I_N is exceeded

The k-factor has to be set accordingly. If both conditions apply, the higher k-factor of the both has to be selected.

The following calculations are valid for iron-core transformers (e.g. type P or TPX) and remanence up to ±70% with a transient dimensioning factor k_{td}=0.5. Remanence of up to ±80% can be mastered with considering a k_{td}=1. Furthermore they are applicable for antiremanence CTs such as type TPY or 5PR.

[1] 7SSx represents 7SS60, 7SS52, and 7SS85

<u>Symbols:</u>

c	= short-circuit current ratio ($I_{scc\ max}$ / I_{pn})
$I_{scc\ max}$	= maximum symmetrical short-circuit current
I_{pn}	= rated CT ratio
I^*_{stab}	= modified stabilizatrion current in 7SSx
K_{ssc}	= rated symmetrical short-circuit current factor
K'_{ssc}	= effective symmetrical short-circuit current factor
k_b	= burdening factor
k	= stabilizing factor (7SSx: k=0.1 … 0.8)
k_{td}	= transient dimensioning factor
R_b	= rated restive burden
R'_b	= R_l + R_{relay} (connected burden)
R_{ct}	= secondary winding resistance
R_l	= resistance of leads
R_{relay}	= relay burden

1 Check with default settings

1.1 *Calculation of the effective symmetrical short-circuit current factor K´_{ssc}*

The *effective* symmetrical short-circuit current factor K'_{ssc} can be calculated from the nominal and effective CT data.

$$K'_{ssc} = K_{ssc} \times \frac{R_b + R_{ct}}{R'_b + R_{ct}} \qquad (1)$$

1.2 *Required symmetrical short-circuit current factor K´_{ssc}*

The *required* symmetrical short-circuit current factor K'_{ssc} can be expressed by the following condition

$$K'_{ssc} \geq k_{td} \times \frac{I_{scc\,max}}{I_{pn}}$$ with k_{td} = 0.5 (for 7SSx) we get $$K'_{ssc} \geq 0.5 \times \frac{I_{scc\,max}}{I_{pn}} \qquad (1.2)$$

The CT requirement is: **K'_{ssc} (effective) > K'_{ssc} (required)** (1.3)

The formula (1.2) describes a CT which can transform at least half of the maximum static short-circuit current without saturation. The equivalent current/time area is found for the full short-circuit current with a point of saturation at 90°el (quarter period). At 90° saturation the stabilisation current will reach its peak value.
A stabilisation factor of k=0.5 is assumed in the following calculation.
For an external fault the effective stabilisation current is

$I^*_{stab} = k\cdot(|\Sigma I_{in}|+|\Sigma I_{out}|) = 0.5\cdot 2\cdot I_{thru} = I_{thru}$

The maximum differential current under this condition (CT of outgoing feeder fully saturated) is $I_{diff} = |\Sigma I_{in}+0| = I_{thru}$. Hence $I_{diff} = I^*_{stab}$ and the stability limit is reached. Details see also chapter 2.1.
Saturation after 90° will cause a smaller differential current whereas the stabilization current is equally high as at 90° due to the special algorithmic treatment. Thus saturation at 90° will be the worst case.
Keeping the default setting of the stabilisation factor k=0.65 ensures the recommended safety margin of 10-15%.

1.3 *Measuring range*

$$\frac{I_{scc\,max}}{I_{pn}} \leq 100 \qquad (1.4)$$

This formula reflects the measuring range of 100·In of the current inputs.

> ☞ ***If both formulas (1.3) and (1.4) are fulfilled the CT is suitable for the 7SSx without further calculation!***

These checks have to be carried out for each CT. Therefore no relation between the smallest and biggest CT ratio has to be considered!

2 Specific calculation of k-factor

2.1 *Violation of inequation (1.2)*

If inequation (1.2) is violated a closer inspection of the CT is necessary to determine its saturation-free time. The minimum saturation-free time of 3ms(50Hz)/2.5 ms(60Hz) results from the needs of the differential protection algorithm. Stability can be achieved by increasing the k-factor for saturation-free times between 3ms and 5ms (50Hz) /2.5ms and 4.2ms (60Hz).

First, the relation between the point in time at which saturation occurs and the stabilization factor shall be derived.

The following condition must be fulfilled to maintain stability for external faults:

$$I^*_{stab} > I_{diff}$$

with conditions according to figure 1 we get

$$2 \cdot k \cdot I_{stab\ max} > I_{scc\ max}$$
$$2 \cdot k \cdot I_{scc\ max} \sin \omega T_S > I_{scc\ max}$$
$$\sin \omega T_S > 1 / 2 \cdot k \qquad (2.1)$$

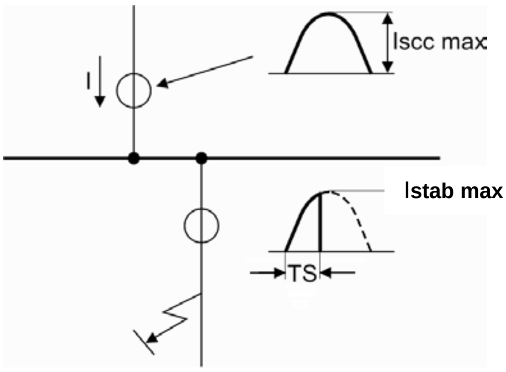
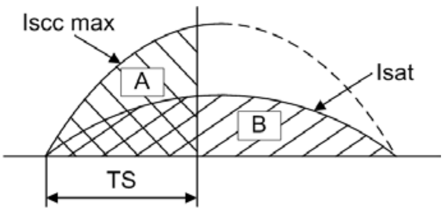


Figure 1: Short-circuit on a feeder with CT saturation

Second, to determine the point in time T_S at which saturation occurs, the burdening factor K_b must be considered.



$I_{sat} = I_{pn} \cdot K'_{ssc}$ max. non-saturated current

$k_b = I_{scc\ max} / I_{sat}$

Figure 2: Current/time characteristic

If the CT is burdened with $I_{scc\ max} = k_b \cdot I_{sat}$, it will saturate after time T_S, with area [A] \\\\ being equal to area [B] //// . This can be expressed by the equation:

$$\int_0^{\omega T_s} I_{scc\,max} \bullet \sin \omega t = \int_0^{\pi} I_{sat} \bullet \sin \omega t \qquad (2.2)$$

⇨ $k_b\,(1 - \cos \omega T_S) = 2$

$\cos \omega T_S = 1 - 2 / k_b$ (2.3)

If inequation (2.1) and equation (2.3) are combined, the result is the minimum admissible stabilisation factor k:
With use of the trigonometric relation $\sin^2 \alpha + \cos^2 \alpha = 1$ we get

$(1 / 2 \cdot k)^2 + (1 - 2 / k_b)^2 < 1$ or

$$k > \frac{k_b}{4\sqrt{k_b - 1}} \qquad \text{for } k_b > 2 \qquad (2.4)$$

The practical setting of the k-factor should consider a safety margin 10-15% onto this calculated k-factor.

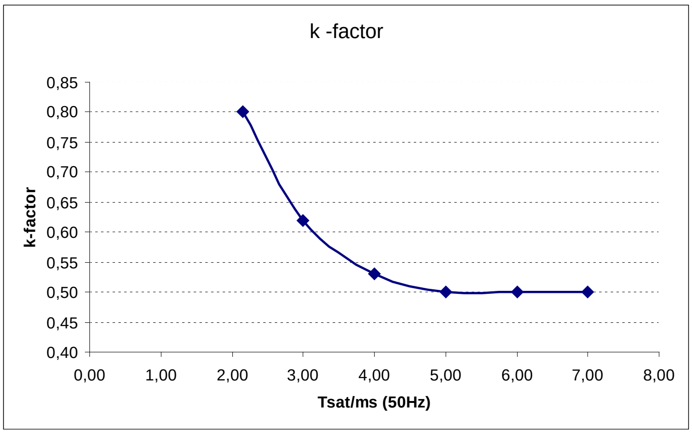
The relation between time to saturation T_{sat} and burdening factor k_b can be derived from formula (2.3)

$$T_{sat} = \frac{T * \arccos(1 - 2 / k_b)}{360°} \qquad (2.5)$$

The following table and diagram show the relation between T_{sat} and required k-factor.

ωT_{sat} (°el)	T_{sat}/ms (60Hz)	T_{sat}/ms (50Hz)	k [1]
90	4.2	5	0.50
72	3.3	4	0.53
54	2.5	3	0.62
39	1.8	2.15	0.80

[1]) the practical k-setting should include a 10-15% safety margin



2.2 *Violation of inequation (1.4)*

From inequation (1.4)

$$\frac{I_{scc\max}}{I_{pn}} \leq 100$$ and with the current ratio $c := \frac{I_{scc\max}}{I_{pn}}$ we get $c \leq 100$

Short-circuit currents beyond 100·In will be cut off by the device-internal A/D-converter and will lead to a differential current. The short-circuit current ratio c has to be considered as one parameter.
Furthermore the CT behaviour has to be taken into account as saturation may cause an additional differential current.
The proper setting of the k-factor is decisive for the stability of the protection for external faults.

2.2.1 Case1: No CT saturation (K'_{ssc} > c)

- the maximum differential current will be I_{diff}= |(c–100)·In|
- the effective stabilisation current will be I^*_{stab}= k·($|i_1(t)|+|i_2(t)|$) = k·(c·|In|+100|In|)= |k·(c+100)·In|

☞ With the condition for stability $I^*_{stab} > I_{diff}$ we get

k > (c-100)/(c+100) or (5.1)

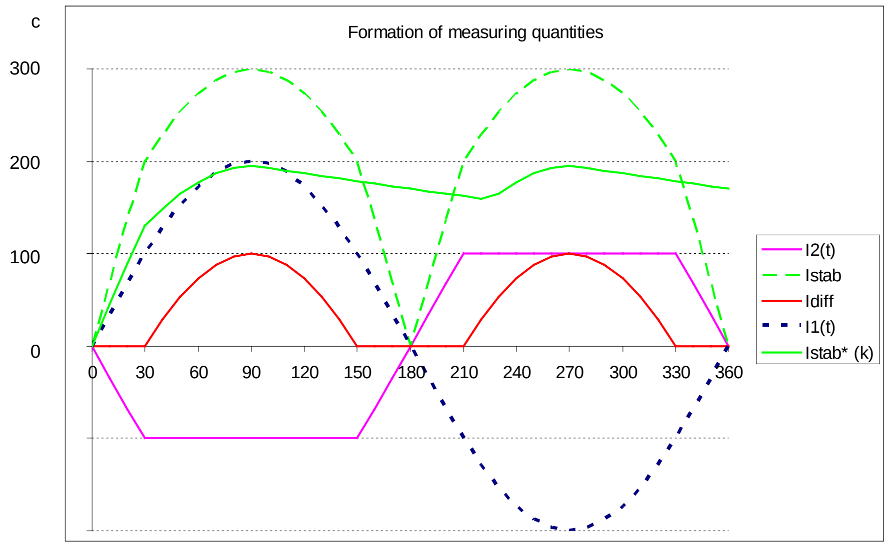
c < 100·(1+k)/(1-k)

For c<400: k=0.6 is sufficient (default setting k=0.65 guarantees safety margin);

Limit: c=640 requires k=0.73 (max. setting of k=0.8 guarantees safety margin)

The following example depicts the measuring quantities with:

c=200; k=0.65; i1(t)= sum of non-limited currents except i2(t)



2.2.2 Case2: Saturation after T_{sat}= 90°el (5ms@50Hz/4ms@60Hz)

- the maximum differential current will be I_{diff}= |c@T_{sat}·In|
- the effective stabilisation current will be I^*_{stab}= |k·(c+100)·In|

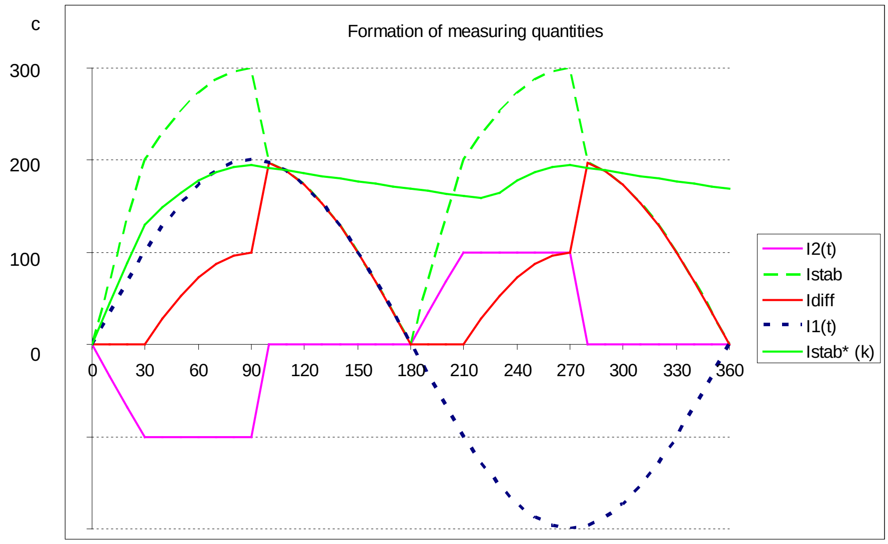
☞ With the condition for stability $I^*_{stab} > I_{diff}$ we get ***k > c@T_{sat}/(c+100)*** (5.2)

☞ worst case for $I_{diff}(t)$ is at T_{sat}= 90°. Here I_{diff} = c·In, and as condition for stability $I^*_{stab} > I_{diff}$ we get ***k > c /(c+100)*** or

c ≤ 100 / (k/1-k)

For c<150: k=0.6 is sufficient (default setting k=0.65 guarantees safety margin);
Limit: c=250 requires k=0.72 (max. setting k=0.8 guarantees safety margin)

The following example depicts the measuring quantities with:
c=200; k=0.65; i1(t)= sum of non-limited currents except i2(t)
T_{sat}= 90°el (t=5ms@50Hz/ t=4ms@60Hz)



2.2.3 Case3: Saturation before T_{sat}= 90°el (5ms@50Hz/4ms@60Hz)

- the maximum differential current will be $I_{diff}= |c \cdot In|$
- the effective stabilisation current will be $I^*_{stab}= |k \cdot (c@T_{sat}+100) \cdot In|$

☞ With the condition for stability $I^*_{stab} > I_{diff}$ we get

$$k > c/(c@T_{sat}+100) \quad (5.3)$$

with T_{sat} = 3ms@50Hz/ 2.5ms@60Hz as worst case we get

$c@T_{sat} = c \sin \omega T_{sat} = c \sin 54° \approx 0.8c$ and

$$c \leq 100 / (1/k - 0.8)$$

For c<115: k=0.6 is sufficient (setting k=0.65 guarantees safety margin);

Limit: c=175 requires k=0.73 (setting k=0.8 guarantees safety margin)

The following example depicts the measuring quantities with:

c=200; k=0.65; i1(t)= sum of non-limited currents except i2(t)

T_{sat}= 60°el (t=3.3ms (50Hz)/ t=2.8ms (60Hz))