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7SJ80 High Impedance Tests

7SJ80 High Impedance Tests– Report

Siemens AG
Infrastructure & Cities Sector
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Power Technologies International

Project reference	it 200 025
Date	2012-07-13
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1 Introduction

This report presents the simulation environment of the high impedance restricted earth fault protection (REF) scheme. This simulation environment makes the high impedance testing of numerical relays (like 7SJ80) possible. In order to validate the performance of the relay the tests case scenarios were prepared and described. Also some application notes are provided.

1.1 References

[1] SIEMENS SIPROTEC CATALOGUE- Catalog SIP 2010, Ordering No. E50417-G1100-C343-A4, or visit www.siprotec.com,

[2] Data Questionnaire: “2012-05-23-Response_NETOMAC data for REF calculation.doc” and “2012-06-13-Response_it200025_Datenanfrage.doc”

1.2 Status of the document

Status of the document:

	Date	Note
R.0	2012-07-13	released

2 General test set up

2.1 Test set up

The concept of simulations and tests was developed in the way that on the one hand it has provided a good consistency with real situations and on the other hand it has offered the flexibility needed to carry out comprehensive simulations of a high impedance protection scheme (Figure 2.1). Thereby, power system and high impedance circuit were modeled in Power System Simulator PSS®NETOMAC. Then, the current flowing through the stabilizing resistance branch was saved at each studied case as a Comtrade-file.

Consequently, the simulated data can be then exported via Omicron Test Universe Software to the amplifier that generates the test signals to the relay. Finally, the fault record of the relay can be read and can be evaluated using DIGSI/SIGRA.

Such a construction of the simulation environment allows studying the protection system’s behavior by wide range of settings and different values of external components, like stabilizing resistor and MOV (MetallOxid Varistor).

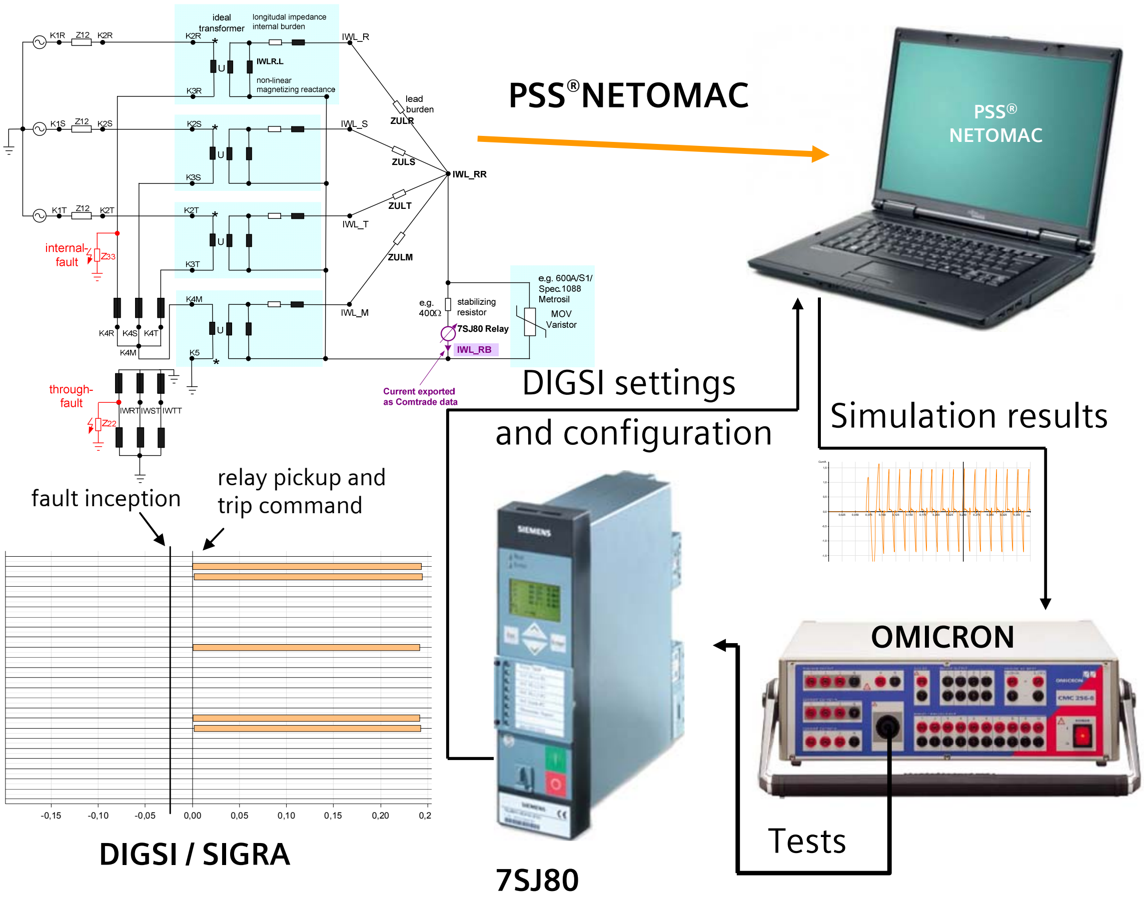

Figure 2.1 Full test set-up for testing of protection relays using PSS®NETOMAC simulations

2.1.1 CT and MOV models

Dedicated models were developed within the PSS®NETOMAC suite to simulate the non-linear characteristic of CT (Current Transformer)-core and that one of the non-linear resistor MOV (MetallOxid Varistor). The MOV characteristic of type Metrosil 600A/S1/Spec.1088 used in tests is shown in Figure 2.2.

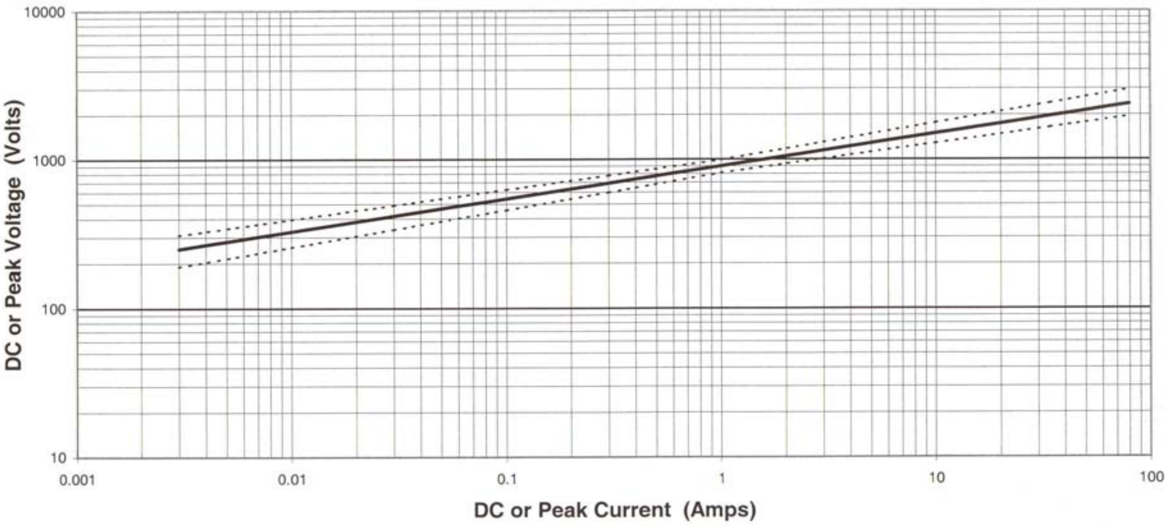

Figure 2.2 Voltage vs. Current characteristic of the MOV type Metrosil 600A/S1/Spec.1088 used in simulations

2.1.2 REF protection scheme set up

Figure 2.3 shows the simplified connection diagram of the circuit together with the concept of the PSS®NETOMAC model structure. The simulated circuit encloses four CTs connected to the network in which different types of faults can be simulated. Thereby, the amplitude of the fault current, the fault inception angle and the network time constant can be changed, as well.

Due to changing of the fault location both the internal and through-faults can be simulated, as three-pole and single-pole faults.

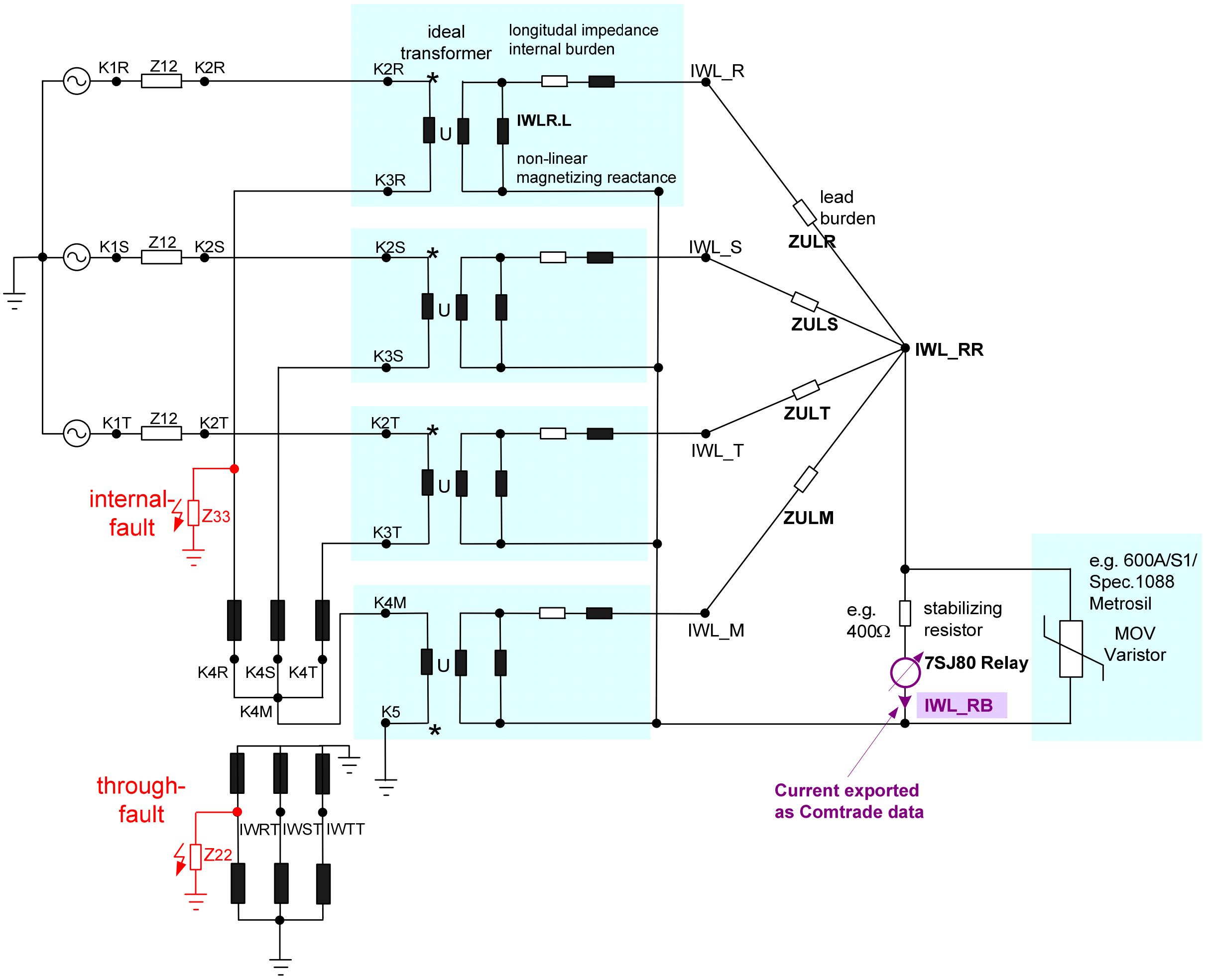

Figure 2.3 Structure of PSS®NETOMAC simulation model for REF protection scheme tests

3 REF protection scheme

3.1 Summarized test set up and simulation parameters

For the simulations following assumptions have been made:

1. faults duration of 900 ms with the inception angle (0^0 for L1, i.e. at voltage zero-crossing) were simulated in a network with time-constant of 125 ms,
2. four 300/1 IEC Class PX CTs were chosen and dimensioned with U_{knee} = 350 V and I_{knee} = 60 mA, internal burden of 3 Ω each
3. MOV of type: Metrosil 600A/S1/Spec.1088 was used.

The current transformer dimensioning report for the corresponding restricted earth fault protection scheme was carried out using software tool CTDim[1]. This document is presented in item 3.2.

Below, the summarized data are presented in concise form:

General system/ protected object data:	
Frequency	60 Hz
Rated voltage	132 kV
Network time-constant or X/R of the primary system:	125 ms
Rated steady state symmetrical short-circuit current I_k"of the equipment:	40 kA
Protected object:	Star connected 132kV winding of a power transformer
Data of the protected object: S_r U_r, $z_\%$ to calculate the rated current I_r of the protected object and through fault	S = 60 MVA U = 132kV I_r = 262A z = 12.4 %
Maximum through fault current for stability of the scheme (primary value)	calculated as 16 x I_r=4.192kA , set to =4.5kA
Fault setting for the sensitivity of the scheme (primary value)	striven as of 15% of I_r, set to 15.6% of I_r = 40.8A,
Adopted relay setting to reach the fault sensitivity (secondary value)	set to 0.075A

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[1] for more information please visit www.siemens.com/ctdim

CT / protection scheme data:	
Number of CTs connected in parallel	4 (three in a switchgear, one in transformer neutral)
Type:	IEC Class PX
CT Ratio:	300 / 1 A
Knee point voltage U_{knee}:	350 V @ 300 A tap
Magnetizing current I_{knee} at knee point voltage:	60 mA
Internal burden R_{CT} at 75^0C:	3 Ohm @ 300 A tap
Length /cross section of the secondary lead from the CT to the paralleling point e.g. within protection cubicle:	50 m /4mm^2
Stabilizing resistor used:	yes, Rstab=1175 Ohm
Shunt resistor used:	not necessary
Non-linear resistor MOV:	Metrosil 600A/S1/Spec.1088
Relay to be used (on-site):	7SJ8032-5EB96-1FC3+L0R
Simulation framework:	
Fault duration simulated	900 ms
Fault inception angle:	0° referred to the phase L1
Short circuit type (external&internal)	three-pole and single-pole
Short circuit current value	simulated as internal and external with variable range

According to the dimensioning report (item 3.2) a voltage stability setting of **88.12 V** is used to ensure stability with external faults. Considering the striven fault setting for REF a current setting of **0.075A** was used. This leads to the stabilizing resistance of **1175 Ω**.

Therefore, the following was set to the tested relay **7SJ80:**

2703	**high-set inst. pickup IEE>>**	**= 0.075A**
2704	**high-set inst. time delay t>>**	**= 0s**

3.2 Dimensioning of the Restricted Earth Fault Protection Scheme

A. System Information:

The protected object is 132-kV winding of a 60MVA transformer (rated current I_r=262A). Type of protection: Restricted Earth Fault.

- Maximum through fault current for external faults $I_{k,max,thr}$
  (typically considered as I_r/uk or calculated as per ESI standard as 16 times rated current I_r of the protected winding)
  = here taken as 16 x 262A ~ 4.5kA
- Maximum internal fault current $I_{k,max,int}$ (according to the rated short circuit current level of the S/S)
  = here taken as 40kA,
- Minimum internal fault current to be detected $I_{k,min,int}$ = here striven for 15% of the rated current of the protected winding, i.e. ~40 A

B. Current Transformer Information

All CTs used in this type of scheme must have the same turns ratio ($K_n=I_{pn}/I_{sn}$). They should be of high accuracy and low leakage reactance type, as well (IEC Class 5P or IEC Class PX). Here IEC standard Class PX is considered.

- Turns Ratio K_n = 300/1
- Secondary resistance R_{ct} = 3 Ohm
- Knee-point voltage U_{knee} = 350V
- Magnetizing current at knee-point voltage I_{knee} = 60mA
- CT lead loop resistance R_{wire} ~ 0.55 Ohm (resistance of 2x50m=100m with 4mm^2 copper wire)

C. Protection Relay Information

- **7SJ80 (MLFB- 7SJ8032-5EB96-1FC3+L0R)** digital overcurrent relay with Single Phase Overcurrent 50 1ph(I >>) and input F7 and F8 should be used.
- Operating current or current setting range I_{set} = 0.001 A to 1.6 A in steps of 0.001 A.
- Relay burden R_{relay} = 50mΩ

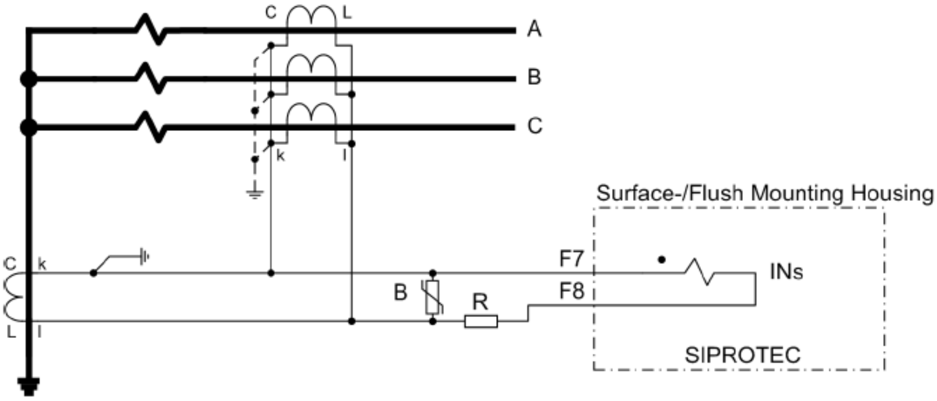

Figure A-18 High-impedance differential protection for a grounded transformer winding (the illustration shows the partial connection for high-impedance differential protection)

D. Scheme calculation protocol

GENERAL SYSTEM AND SUBSTATION DATA:

Nominal voltage:	132 kV
Nominal frequency:	60 Hz
Rated short-circuit current of station:	40 kA
Remark:	

DATA OF CT 1 (wHI) ACCORDING TO IEC-PX:

CT type:	IEC Class PX
Transformation ratio:	300 A / 1 A
Kneepoint voltage U_{knee}:	350 V
Mag. current I_{knee} at U_{knee}:	0.06 A
Internal resistance R_{ct}:	3 Ω
Remark:	

RELAY DATA:

Manufacturer:	SIEMENS	
Type:	7SJ80 ANSI 87N(HI)	
Internal burden:	0.05	VA
Remark:		

CT REQUIREMENTS FOR 7SJ80 ANSI 87N(HI):

All CTs must have the same transformation ratio. To prevent maloperation of the relay during saturation of the CTs on an external fault, the actual stability voltage U_S must be at least the voltage $U_{s,min}$ produced by the maximum secondary through fault current, flowing through the cable resistance and the CTs' internal resistance:

$$U_s \geq U_{s,\min}$$

where

$$U_{s,\min} = I_{k,\,max,\,thr} \frac{I_{sn}}{I_{pn}} \left(R_{ct} + R_{wire}\right)$$

In addition to this, the kneepoint voltage must be higher than twice the actual stability voltage:

$$U_{knee} \geq 2 \cdot U_s \qquad \text{(Requirement)}$$

The kneepoint voltage of the CT should not be higher than four times the relay setting voltage.

$$U_{knie} \leq 4 \cdot Us \qquad \text{(Recommendation)}$$

where :

U_S :	actual stability voltage
$U_{s,min}$:	minimum stability voltage
U_{knee} :	kneepoint voltage of CT
$I_{k,max,thr}$:	max. symmetrical short-circuit current for external faults
I_{pn} :	CT primary nominal current
I_{sn} :	CT secondary nominal current
R_{ct} :	internal burden of CT
R_{wire} :	cable burden

CALCULATION OF CABLE BURDEN:

The cable burden is calculated by the single length, the cross section, the specific resistivity for copper and an effective factor for the wire length. This factor k_{wire} is 2 if the return wire is to be considered.

Length:	l_{wire} = 50 m
Cross section:	α_{wire} = 4 mm^2
Spec. resistivity (Cu):	ρ_{cu} = 0.02171 Ω mm^2/m at 75 °C
Eff. wire length in p.u.:	k_{wire} = 2

$$R_{wire} = \frac{k_{wire} \cdot \rho_{Cu} \cdot l_{wire}}{\alpha_{wire}} \qquad = 0.5428\ \Omega$$

CHECK OF CT REQUIREMENT:

Calculation of stability voltage:

The minimum stability voltage of 7SJ80 ANSI 87N(HI) to ensure stability on external faults:

$$U_{s,\min} = I_{k,\,max,\,thr} \frac{I_{sn}}{I_{pn}} \left(R_{ct} + R_{wire}\right) \qquad = 53.141 \text{ V}$$

where:

$U_{s,min}$:	minimum stability voltage	53.141 V
$I_{k,max,thr}$:	max. symmetrical short-circuit current for external faults	4.5 kA
I_{pn} :	CT primary nominal current	300 A
I_{sn} :	CT secondary nominal current	1 A
R_{ct} :	internal burden of CT	3 Ω
R_{wire} :	cable burden	0.5428 Ω

The actual stability voltage U_S should be set to at least $U_{s,min}$.

The actual stability voltage for the scheme can be then chosen: **U_S = 88.12 V**

Calculation of maximum sensitivity:

The higher is the sensitivity, the lower the value of the fault current that is detected by the relay. According to the actual stability voltage and considering that the relay has a variable a.c. current setting on the 1 A tap of 0.001 A to 1.6 A in 0.001 A steps, the maximum primary current sensitivity I_p can be obtained:

$$I_p = \frac{I_{pn}}{I_{sn}} \left(I_{s,\min} + N \cdot I_{knee} \cdot \frac{U_s}{U_{knee}} + I_{\text{var}} \right) \qquad = 18.186 \text{ A}$$

where:

Ip :	maximum primary current sensitivity	18.186 A
$I_{s,min}$:	minimum relay current setting	0.001 A
N :	number of CTs in parallel with relay	4
I_{knee} :	mag. current I_{knee} at U_{knee}	0.06 A
U_S :	actual stability voltage	88.12 V
U_{knee} :	kneepoint voltage of CT	350 V
Ivar :	current in non-linear resistor at the relay circuit setting voltage, calculated as follows: $I_{var} = 0.52 \cdot \left(\frac{\sqrt{2} \cdot U_S}{C} \right)^{1/\beta}$ for the chosen varistor (600A/S1/Spec 1088 Metrosil) are C = 900 and β = 0.25	0.19mA

The calculated current Ip corresponds to a sensitivity of 6% of nominal primary current Ipn of the CT. This corresponds to a sensitivity of 6.9% of nominal current of the object In_obj= 262 A.

Desired sensitivity calculation:

For a desired decreased sensitivity of 15 % of In_obj a corresponding relay current setting can be calculated:

$$I_s = I_{p,des} \cdot \frac{I_{sn}}{I_{pn}} - N \cdot I_{knee} \cdot \frac{U_s}{U_{knee}} - I_{\text{var}} \qquad = 0.07041\text{ A}$$

where:

I_S :	secondary relay current setting to reach the desired sensitivity	0.07041 A
N :	number of CTs in parallel with relay	4
I_{knee} :	mag. Current I_{knee} at U_{knee}	0.06 A
Ip,des :	desired current sensitivity of object	39.3 A
Us :	actual stability voltage	88.12 V
U_{knee} :	kneepoint voltage of CT	350 V
Ivar :	current in non-linear resistor (see above)	0.19mA

Considering the setting range of the relay on the 1 A tap of 0.001 A to 1.6 A in 0.001 A steps the pickup current can be chosen: **$I_{s,set}$ = 0.075 A**

Effective sensitivity calculation:

The effective primary fault sensitivity can be then calculated as follows:

$$I_{eff\_sens,prim} = \frac{I_{pn}}{I_{sn}} \left(I_{s,set} + N \cdot I_{knee} \cdot \frac{U_s}{U_{knee}} + I_{\text{var}} \right) \qquad = 40.8\text{A}$$

where:

$I_{eff\_sens,prim}$:	effective fault sensitivity (primary)	
$I_{s,set}$:	relay current setting to reach the sensitivity	0.075 A
N:	number of CTs in parallel with relay	4
I_{knee}:	mag. current I_{knee} at U_{knee}	0.06 A
U_S :	actual stability voltage	88.12 V
U_{knee} :	kneepoint voltage of CT	350 V

This corresponds to a sensitivity of 13.6% of Ipn of the CT and to a sensitivity of 15.6 % of the rated current of the protected object In_obj= 262 A.

Therefore:

2703	**high-set inst. pickup IEE>>**	**= 0.075A**
2704	**high-set inst. time delay t>>**	**= 0s**

Calculation of stabilizing resistor:

The proper value of stabilizing resistor Rstab is required to ensure stability during through-faults and is calculated by using the actual stability voltage = 88.12 V and the pickup current setting of the relay

Is,set = 0.075 A (please refer to above).

$$R_{stab} = \frac{U_s}{I_{s,set}} - R_{relay}$$ = **1175 Ω**

where the relay burden Rrelay = 0.05 Ω is neglected.

The stabilizing resistor Rstab can be chosen with a necessary minimum continuous power rating Pstab,cont of :

$$P_{stab,cont} \geq \frac{U_s^{\ 2}}{R_{stab}}$$ = 6.6 W

Please note that in order to keep the resistor healthy during commissioning tests the fault current from the testing equipment should be immediately withdrawn after the device gives a protection trip.

Moreover, Rstab must have a short time rating large enough to withstand the fault current levels before the fault is cleared. The time duration of 0.5 seconds can be typically considered (Pstab,0.5s) to take into account longer fault clearance times of back-up protection.

The rms voltage developed across the stabilizing resistor is decisive for the thermal stress of the stabilizing resistor. It is calculated according to formula:

$$U_{rms,f} = 1.3 \cdot \sqrt[4]{U_{knee}^{\ 3} \cdot R_{stab} \cdot I_{k,\max,\mathrm{int}} \cdot \frac{I_{sn}}{I_{pn}}}$$ = 2092.85 V

where

U_{knee} :	kneepoint voltage of CT	350 V
R_{stab} :	resistance of the stabilizing resistor	1175 Ω
$I_{k,max,int}$:	max. symmetrical short-circuit current for internal faults	= 40 kA
I_{pn}:	CT primary nominal current	300 A
I_{sn} :	CT secondary nominal current	1 A

The resulting short-time rating Pstab,0.5s equals to:

$$P_{stab,0.5s} \geq \frac{U_{rms,f}^{\ 2}}{R_{stab}}$$ = 3728 W

Calculation of max. voltage at relay terminal:

The relay should normally be applied with an external varistor which should be connected across the relay and stabilizing resistor input terminals. The varistor limits the voltage across the terminals under maximum internal fault conditions. The theoretical rms voltage which may occur across the panel terminals (i.e. tie with relay and R_{stab} connected in series) can be determined according to the following equation:

$$U_{k,\max,\text{int}} = I_{k,\max,\text{int}} \cdot \frac{I_{sn}}{I_{pn}} \cdot \left(R_{relay} + R_{stab}\right)$$ = 156673 V

The resulting maximum peak voltage across the panel terminals (i.e. tie with relay and R_{stab} connected in series):

$$U_{max,relay} = 2\sqrt{2U_{knee}(U_{k,max,int} - U_{knee})}$$ = 20921 V

where:

$I_{k,\ max,\ int}$: max. symmetrical short-circuit current of internal faults = 40 kA

CT dimensioning check:

Requirement:

The minimum kneepoint voltage of the CTs must be twice the relay setting voltage

$$U_{knee} \geq 2 \cdot Us$$

U_{knee}	= 350 V	
2 U_s	= 176.25 V	Meets requirement

Recommendation:

Furthermore, it is recommended that the kneepoint voltage of the CT should not be higher than four times the relay setting voltage.

$$U_{knie} \leq 4 \cdot Us$$

U_{knee}	= 350 V	
4 U_s	= 352.5 V	Meets the recommendation

CTs correctly dimensioned

Varistor check:

A varistor is required if:

$$U_{\max,relay} \geq 1500V$$

In this case:

$U_{max,relay}$ = 20921 V

Varistor required

3.3 REF protection tests cases scenarios

In the scope of the project the simulation scenarios for testing were developed. These are shown in the following tables. In order to validate the protection scheme the tripping time of the relay should be tested using attached COMTRADE-files.

The following cases are considered:

A. RELAY SENSITIVITY with **internal single-pole faults**
B. RELAY STABILITY with following fault types:
   a. **through-faults** (single- and three-pole),
   b. **three-pole internal faults**.

For each of the following cases the relay reaction/tripping time shall be tested.

3.3.1 RELAY SENSITIVITY with internal single-pole fault

In Table 3.1 the cases for internal primary currents flowing through the fault branch are showed.

Table 3.1 Sensitivity with internal single-pole faults

Trip time for internal fault scenario with **Uk = 350 V, Us = 88,12 V, Im = 0,075 mA,** Rstab=1175 Ohm, Metrosil 1088 Relay setting Is,set: IEE>> = 0.075A giving a FAULT SETTING primary of the whole scheme of 40.8 A primary = FAULT SETTING													
Ifault,set, primary	*Ifault,set,prim [A]*	*40.8*											
Multiple Fault set:	Ikint /Ifault,set,prim	0.7	0.8	0.9	1	1.1	1.5	2	5	10	20	50	981
Fault current:	Ikint [A]	28.56	32.64	36.72	40.8	44.88	61.2	81.6	204	408	816	2040	40024.8
Simulation case	No.:	1	2	3	4	5	6	7	8	9	10	11	12
Tripping time	[ms], ▪ - to be tested	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪

3.3.2 RELAY STABILITY with through-faults

In Table 3.2 and Table 3.3 the simulation cases for external 1 pole and 3 pole faults are showed correspondingly.

Table 3.2 Stability with single pole through-faults

Trip time for external fault scenario with **Uk = 350 V, Us = 88,12 V, Im = 0,075 mA,** Rstab=1175 Ohm, Metrosil 1088
Relay setting Is,set: IEE>> = 0.075A giving a FAULT SETTING primary of the whole scheme of 40.8 A primary = FAULT SETTING

CT primary current	*Ict,prim [A]*	*300*								
Multiple Ifault/CTratio:	Ik,ext/Ict,prim	8	16	24	32	40	50	80	100	134
Fault current:	Ik,ext [kA]	2.4	4.8	7.2	9.6	12	15	24	30	40.2
Simulation	No.:	1	2	3	4	5	6	7	8	9
Tripping time	[ms], ▪ - to be tested	▪	▪	▪	▪	▪	▪	▪	▪	▪

Table 3.3 Stability with three pole through-faults

Trip time for external fault scenario with **Uk = 350 V, Us = 88,12 V, Im = 0,075 mA,** Rstab=1175 Ohm, Metrosil 1088
Relay setting Is,set: IEE>> = 0.075A giving a FAULT SETTING primary of the whole scheme of 40.8 A primary = FAULT SETTING

CT primary current	*Ict,prim [A]*	*300*								
Multiple Ifault/CTratio	Ik,ext/Ict,prim	8	16	24	32	40	50	80	100	134
Fault current:	Ik,ext [kA]	2.4	4.8	7.2	9.6	12	15	24	30	40.2
Simulation	No.:	1	2	3	4	5	6	7	8	9
Tripping time	[ms], ▪ - to be tested	▪	▪	▪	▪	▪	▪	▪	▪	▪

3.3.3 RELAY STABILITY with three pole internal faults

Moreover, the stability of the relay shall be checked by the simulation of three pole internal faults. In Table 3.4 the simulation cases for internal 3 pole faults are showed.

Table 3.4 Stability with three pole internal faults

Trip time for internal fault scenario with **Uk = 350 V, Us = 88,12 V, Im = 0,075 mA,** Rstab=1175 Ohm, Metrosil 1088
Relay setting Is,set: IEE>> = 0.075A giving a FAULT SETTING primary of the whole scheme of 40.8 A primary = FAULT SETTING

CT primary current	*Ict,prim [A]*	*300*								
Multiple Ifault/CTratio	Ik,int/Ict,prim	8	16	24	32	40	50	80	100	134
Fault current:	Ik,int [A]	2400	4800	7200	9600	12000	15000	24000	30000	40200
Simulation	No.:	1	2	3	4	5	6	7	8	9
Tripping time	[ms], ▪ - to be tested	▪	▪	▪	▪	▪	▪	▪	▪	▪

3.4 Conclusions

The tests results shall verify the correct operation of the 7SJ80 relay applied as high impedance relay. Relay earth current input (F7 and F8) is suitable for restricted earth fault protection.

The current flowing through the stabilizing resistance branch (saved as COMTRADE-file) can be used then for testing of SENSITIVITY and STABILITY of 7SJ80 relay. The full test set-up was showed in Figure 2.1.

The test results as COMTRADE-files have been attached to the report. The data package contains four compressed .zip files:

1. ExternalFaults_1pole.zip
2. ExternalFaults_3pole.zip
3. InternalFaults_1pole.zip
4. InternalFaults_3pole.zip

The corresponding COMTRADE-file can be found regarding the Simulation No. from the tables: Table 3.1, Table 3.2, Table 3.3, and Table 3.4.

Important: Please note that due to pre defined internal PSS®NETOMAC processing procedure the ending of the name of the COMTRADE-file equals to: **Simulation No. minus (-) 1**, e.g.

Simulation **No. = 1** ---> COMTRADE-file = WSTST_REF.cfg

Simulation **No. = 2** ---> COMTRADE-file = WSTST_REF_**0001**.cfg