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The Bible of Generator Protection Engineering

The Commissioning Manual for Professionals

ALEXANDER MUTH

COMPLEX ELECTRICAL ENGINEERING IN YOUR POCKET

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Preface

Think of this manual as the plug'n'play bible for everyone who makes a living by commissioning complex generator protection systems. It will also be of interest to those who only occasionally have to concern themselves with such affairs, perhaps as plant operators or specialists in similar trades.

Generator protection is and remains the undisputed king amongst the disciplines associated with electrical protection engineering systems. The secrets of how they are commissioned — the Holy Grail — are about to be unveiled, as this concise manual contains all the crucial facts that we need to know about this process.

The book is designed as a handy on-site pocket-sized reference tome, a readily available reference work for professionals, and also a How-To-Do-Guide for plant operators, who, due to ever-shrinking project and maintenance budgets, are increasingly finding themselves having to turn their hand to these matters. Not only that, it will also give students and first-time employees an illuminating insight into the “secret world” of generator protection engineering.

We explain the tests that need to be carried out on current and voltage transformers, the linking and isolation elements between the primary measured values and the secondary measuring signals processed in the protection system. What do we have to do to get stator and rotor ground fault protection systems up and running? How are primary and secondary checks carried out? What do we need to be aware of when commissioning synchronizing equipment? All the tests and checks that need to be carried out when commissioning a generator protection system are described in detail in this small book. We generally begin with the preliminary checks of all the existing current transformer circuits (Chapter 1).

In protection engineering, the skill often lies in paring a very complex subject down to its bare essentials.

As my former university professor Alfred Tempel used to say:

Every solution must fit on a beer mat!

We hope that this “slightly unusual” text book will inspire you to pluck up the courage and give you the confidence to take matters into your own hands and discover for yourself the fun that is always to be had when commissioning a protection system.

PS: As every individual is only as good as his, or her, team, I've decided to use the first person plural form (“we”) throughout this manual.

Alexander Muth

Safety Notice

Failure to observe the following points can result in death, serious injury or material damage!

Hazardous voltages may be present when carrying out the tests and checks described in this manual. The safety rules and regulations regarding electrical systems must be strictly observed at all times. The generator must always be shut down when working on the primary system; appropriate grounding and short-circuiting facilities are to be provided at the respective workplaces. When carrying out a primary check on a turbine set, take care to ensure that no overheating of the turbine occurs.

The work described in this manual may only be carried out by qualified personnel, who must be conversant with the relevant safety regulations and safety measures as well as the warnings in the manuals provided by the suppliers of the various components. The contents of this manual must not construed as work instructions. All statements in this manual must be carefully considered in light of the safety rules and regulations. The information presented in this manual does not claim to be complete.

"I've never made a mistake.
I've only learned from experience."

Thomas A. Edison

Chapter 1 - Current Transformer Test

Here we go!

Normally, two things have to be tested when commissioning a current transformer:

- **the secondary circuit wiring** including the connected equipment
- **the transformer** itself

The sequence described here is important, as we have to demonstrate that the secondary circuits are closed and correctly burdened before measuring the ratio of the transformer.

As everywhere else in the world of protection engineering, no compromises can be tolerated, especially in the testing of current transformers. This is where we have to get serious and proceed with the utmost care and attention.

The secondary circuit of a live transformer must always be short circuited or closed. Any transformer circuits that are open during operation may damage the transformer itself or, more critically, result in potentially lethal secondary voltages of several kV. A current transformer circuit may only be opened when the primary system has been put out of operation and secured to prevent it being accidentally switched on again (see Safety Notice).

Testing the Secondary Circuit Wiring

Testing of the secondary circuit wiring involves 3 steps:

✯ Insulation test

✯ Wiring check

✯ Measurement of rated burden

Firstly, we decide which terminal block to use for our tests in the direction of the protection devices or transducers. The obvious candidates in this case are the terminal blocks in the transformer terminal box or on-site control cubicle. It's always good to use an accessible transformer terminal board, as the closer we are to the transformer the better. These terminals are then slid open and short-circuited on the transformer side.

Insulation Test

To protect the device and prevent the measuring circuit influencing our results, we disconnect the wires of the current transformer circuit on the corresponding field device and screen them with insulating sleeves up to 1 kV.

For the test, we use an insulation tester to apply approx. 1 kV DC to the phase-to-ground and phase-to-phase loops of the first accessible terminal block in the terminal box or on-site control cubicle and determine and assess the measured insulation resistance. Both DIN VDE and ÖNORM expect a value ≥ 1 MΩ. On completing the test, we reconnect the wires of the protection device and consign the insulation test to history.

Wiring Check

With the help of a suitable secondary testing device, we inject a symmetrical three-phase system with differing amplitudes in the direction of the field device. This enables us to make a phase-selective assignment. Choosing the test values shown below permits "metrological labeling" of the phases:

IP1 = 0.1 A / 0°   IP2 = 0.2 A / -120°   IP3 = 0.3 A / 120°

The test values do not need to be any higher, as we need to keep an eye on the pickup thresholds of connected protection devices. Ideally, a current of 0.1 A*√3 / 150° (173 mA) will be measured in the outgoing conductor.

If intermediate transformers are present, we increase the amplitude of each test current by the ratio factor. The test currents can now be either read off directly or checked using a clamp meter in the protection or metering cabinet. It's always good practice to carry out the test from the protection or metering cabinet as well, particularly when we come across faulty wiring, as this enables us to filter out any phase turners between these terminal points.

Another good tip is to inject the test values using a modern testing device from Omicron©. Using CPol-Tools© enables the current direction from the first terminal block to be “checked in advance”, before the current test.

If only a single phase tester is available, there is of course nothing to stop us checking each phase in turn. The diagram below shows the classical test arrangement for the wiring check:

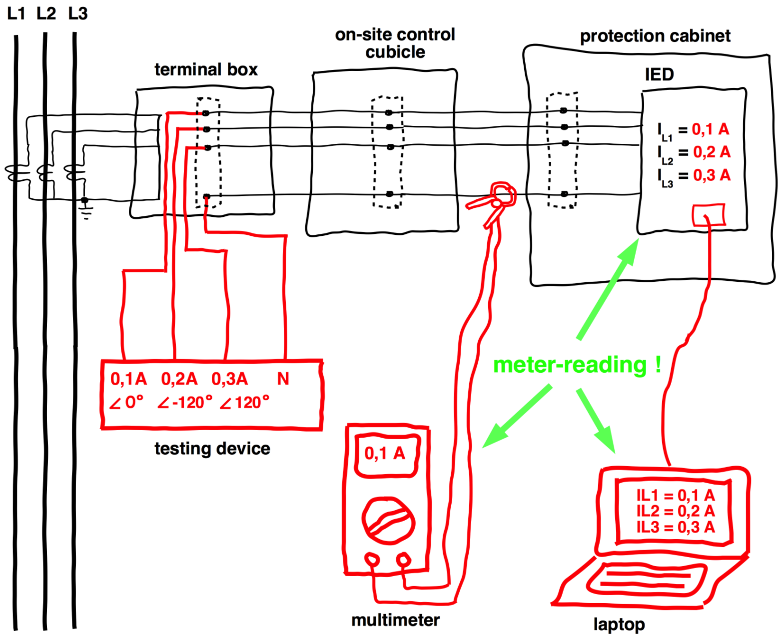

Figure 1: Test arrangement for the wiring check

Measurement of Rated Burden

The purpose behind the measurement of the rated burden is to demonstrate that the burden of the connected secondary circuit does not exceed the rated burden of the current transformer. In other words, we want to exclude the possibility of “overburdening” the current transformer, as only then is it safe to assume that the transformer can handle what its rating plate would have us believe.

This is done by injecting the secondary nominal current of the current transformer, usually 1 A or 5 A, into the phase-to-ground loops of the terminal block in the transformer's terminal box and measuring the voltage drop on the terminals with a multimeter. If it proves impossible to carry out the measurement directly on the terminal board, we'll simply move to the next terminal block, e.g., the one in the on-site control cubicle. We can make an intelligent guess for the section we've had to skip over and add this figure to the result of the measurement. The table below provides a quick guide to the values for the section we haven't been able to measure and also helps us carry out a plausibility check on the measured values and the overall results. The “protection boxes" themselves don't add much to the result, as digital relays usually have internal burdens of less than 100 mΩ.

Table 1: Secondary burden P / VA (function of nominal current, cross section of a single conductor)

	Secondary nominal CT current = 1 A						Secondary nominal CT current = 5 A					
	1,5 mm²	2,5 mm²	4 mm²	6 mm²	10 mm²	16 mm²	1,5 mm²	2,5 mm²	4 mm²	6 mm²	10 mm²	16 mm²
5 m	0,2	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1	3,7	2,2	1,4	0,9	0,6	0,3
10 m	0,3	0,2	0,1	< 0,1	< 0,1	< 0,1	7,4	4,4	2,8	1,8	1,1	0,7
20 m	0,6	0,4	0,2	0,2	< 0,1	< 0,1	14,7	8,8	5,5	3,7	2,2	1,4
30 m	0,9	0,5	0,3	0,2	0,1	< 0,1	22,1	13,2	8,3	5,5	3,3	2,1
40 m	1,2	0,7	0,4	0,3	0,2	0,1	29,4	17,7	11,0	7,4	4,4	2,8
50 m	1,5	0,9	0,6	0,4	0,2	0,1	36,8	22,1	13,8	9,2	5,5	3,4
60 m	1,8	1,1	0,7	0,4	0,3	0,2	44,1	26,5	16,6	11,0	6,6	4,1
70 m	2,1	1,2	0,8	0,5	0,3	0,2	51,5	30,9	19,3	12,9	7,7	4,8
80 m	2,4	1,4	0,9	0,6	0,4	0,2	58,9	35,3	22,1	14,7	8,8	5,5
90 m	2,6	1,6	1,0	0,7	0,4	0,2	66,2	39,7	24,8	16,6	9,9	6,2
100 m	2,9	1,8	1,1	0,7	0,4	0,3	73,6	44,1	27,6	18,4	11,0	6,9
150 m	4,4	2,6	1,7	1,1	0,7	0,4	110,4	66,2	41,4	27,6	16,6	10,3
200 m	5,9	3,5	2,2	1,5	0,9	0,6	147,1	88,3	55,2	36,8	22,1	13,8
250 m	7,4	4,4	2,8	1,8	1,1	0,7	183,9	110,4	69,0	46,0	27,6	17,2
300 m	8,8	5,3	3,3	2,2	1,3	0,8	220,7	132,4	82,8	55,2	33,1	20,7
350 m	10,3	6,2	3,9	2,6	1,5	1,0	257,5	154,5	96,6	64,4	38,6	24,1
400 m	11,8	7,1	4,4	2,9	1,8	1,1	294,3	176,6	110,4	73,6	44,1	27,6
450 m	13,2	7,9	5,0	3,3	2,0	1,2	331,1	198,6	124,2	82,8	49,7	31,0
500 m	14,7	8,8	5,5	3,7	2,2	1,4	367,9	220,7	137,9	92,0	55,2	34,5
	These values apply to copper cable at an operating temperature of 80 °C											

For all those out-of-the-ordinary system configurations that are not to be found in the table, and for circuits between Earth and the planet Zog, the following equation will provide a rough estimate:

$$P = I_n^2 \cdot \frac{l}{A} \cdot 0{,}044 \left[\frac{\Omega \cdot mm^2}{m} \right]$$

(1-1)

P - secondary burden (80°) $[\mathrm{VA}]$

I_n - secondary nominal CT current $[\mathrm{A}]$

l - ne-way wire length $[\mathrm{m}]$

A - cross section $[\mathrm{mm}^2]$

The one-way wire length is used for the length l. The computed result naturally corresponds to the secondary burden of the entire line loop, including the incoming and outgoing conductors.

Once the wiring check has been completed, the terminals opened at the start of the process are slid closed and the short circuit to the transformer removed.

Now that we've checked the secondary loop wiring, we can move onto the testing of the transformer.

Testing the Current Transformer

Testing of the current transformer comprises the following steps:

✯ Visual check

✯ Measurement of winding resistance

✯ Insulation test

✯ Checking the nominal transformer power and rated accuracy limit factor

✯ Checking the winding direction (polarity)

✯ Checking the grounding

✯ Checking the assignment of the cores

✯ Measuring the ratio

Before starting, we need to disconnect the secondary-side grounding of the transformer.

Visual Check

Suggesting that a visual check be carried out sounds trivial. However, it's difficult to believe just how many of the possible faults can be detected simply by looking. Most of them are indeed “blindingly obvious”. So it's always worth starting by having a look at the transformer and the rating plate. Take a moment to check and make a note of the following transformer parameters, as they're important:

- Transformer type
- Rated ratio
- Accuracy class
- Nominal accuracy limit factor
- Nominal power
- Load rating

- Mounting direction
- Grounding
- Serial number

In addition, the transformer and the primary terminals must not display any visible damage, dirtiness or corrosion.

As it's important to know what the labels on the current transformer mean, we've used a couple of examples here to explain them.

Example 1: TPS or TPX with 2000 A / 1 A; 40 VA; 5 P 10

- TP stands for “transient performance”.
- TPS means “closed-core transformer” with low stray flux.
- TPX means “closed-core transformer” with no remanence limit.
- 2000 A / 1 A is the “rated ratio”.

- 40 VA corresponds to the "nominal power" of the core for cos phi = 0.8 when terminated with the rated burden.
- "Accuracy class" 5 means: Variance from nominal current < 1%, total variance at n times nominal current < 5% (in this case, 10 * In = 20 kA). If the accuracy class is 10, the following applies: Variance from nominal current < 3% and total variance at n times nominal current < 10%.
- P stands for "protection", what is being referred to here is a "protection core".
- Nominal accuracy limit factor n = 10: This is a multiple of the nominal current and can, if the error is less than the total variance, be transmitted. Prerequisite: A non-displaced short circuit has occurred and the transformer is terminated with the rated burden.

Example 2: TPY or TPZ with 2000 A / 1 A; 30 W

- TP stands for "transient performance".

- TPY means “anti-remanence core” or a core with air gaps (with a remanence < 10%).
- TPZ means “linear core” with hardly any remanence.
- 2000 A / 1 A is the “rated ratio”.
- 30 W is the “nominal power” of the core.

Figure 2: Current transformer rating plate

Measurement of winding resistance

The measurement is carried out and recorded using a multimeter from the transformer terminal board for the secondary windings of all the cores that are present. The result of the measurement helps us, amongst other things, when checking the nominal power and nominal accuracy limit factor of the transformer. It also helps us to differentiate between measuring cores and protection cores.

Insulation Test

Before starting the test, we need to ensure that the terminals in the direction of the protection are slid open or that the wires are disconnected. We then measure all the phase-to-phase and phase-to-ground loops from the first accessible terminal block in the direction of the transformer. A test voltage of 2.5 kV DC is used. To comply with DIN VDE and the Austrian ÖNORM standard, the measured insulation resistance should be ≥ 1 MΩ. When the test is finished we can re-establish the connection to the field device.

Checking the nominal transformer power and rated accuracy limit factor

The best way of checking the nominal transformer power and rated accuracy limit factor in practice is to measure the knee point voltage according to British Standard 3938. The knee point voltage is roughly the secondary voltage above which a 10% increase in voltage causes a 50% increase in current. To determine this saturation point, we use the famed magnetization characteristic.

We apply an alternating voltage to the core we want to measure at the first accessible terminal block and measure the resulting current. It's a good idea to enter the results in an Excel spreadsheet and take the knee point voltage directly from the characteristic curve according to the above definition.

The diagram below shows a magnetization characteristic measured in the field:

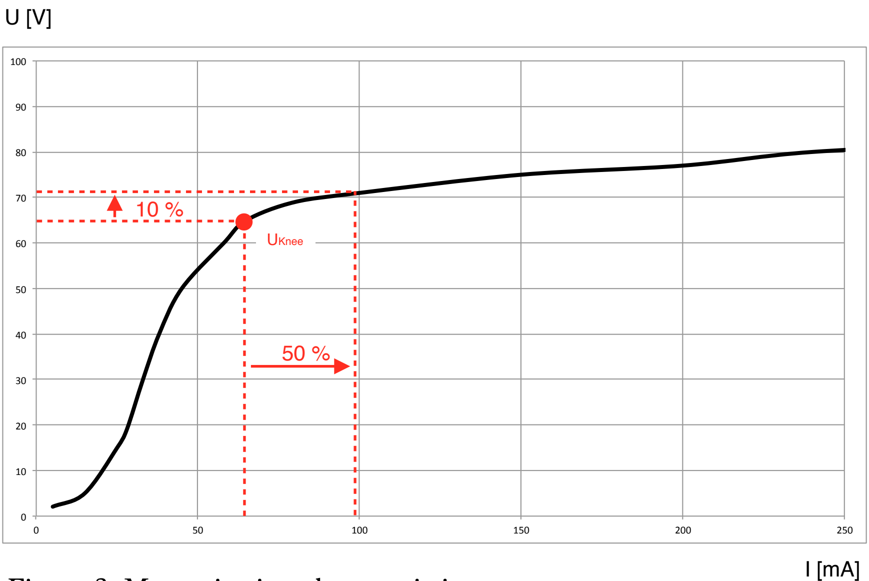

Figure 3: Magnetization characteristic

Computations are carried out to check that the following conditions relating to the transformer nominal power and overcurrent factor are satisfied:

Transformer nominal power

$$P \geq P_n \qquad (1\text{-}2)$$

$$P = I_n \left(\frac{1{,}25 \cdot U_{Knee}}{n_n} - R_i \cdot I_n \right) \qquad (1\text{-}3)$$

P - calculated transformer power (measurement based) $[\mathrm{VA}]$

P_n - transformer nominal power $[\mathrm{VA}]$

n - calculated accuracy limit factor (measurement based)

n_n - nominal accuracy limit factor

I_n - secondary nominal transformer current $[\mathrm{A}]$

R_i - measured winding resistance $[\Omega]$

U_{Knee} - identified knee point voltage $[V]$

Chapter 14 Test Checklists

We have gathered together below all the test points described in this manual in the form of test checklists, which we hope will act as a handy reference for you.

Checklist for current transformer test

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My family.

ELECTRICAL-ENGINEERING.ACADEMY

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(born 1978) is founder and owner of
ELECTRICAL-ENGINEERING.ACADEMY
After obtaining his degree in electrical engineering at the University of Lausitz in Senftenberg with a grade of "outstanding" and receiving an award for his doctorate from the VDE, he started work as an international commissioner of electrical protection systems and released several publications.

"He knows how to get to the heart of complex issues."
(Dr.-Ing. Udo Drechsler)

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