Testing self-powered relays
with SVERKER 900

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1. Introduction to this Technical Guide.

Self-powered relays will be an important component for the protection of the smart grid. While they allow reducing the cost of the protection system, they are definitely a challenge for relay test sets, that are required to provide the voltage and current signals to simulate the power system fault, but also the generated signals need to have necessary electric power to supply the protection relay.
SVERKER 900 is designed to manage this task and this Technical Guide describes how two self-powered relays can be tested.
This document guides through the testing of two self-powered overcurrent relays from SEG GmbH (formerly Woodward), WIC-1 and WIP-1, with the relay test set SVERKER 900, for commissioning/maintenance purposes. The Technical Guide details on the principles adopted in the testing with reference to relevant IEC standards and to the relay manuals. In addition, basic instructions on the correct usage of the testing possibilities offered by SVERKER 900 are described.

2. About self-powered relays: past and future.

Traditionally the self-powered relays have been used in secondary distribution network, in MV/LV substations for the last 40 years. Normally if the MV/LV power transformer is greater than 800 kVA the transformer is protected with a self-powered relay, and if the transformer has lower rated power, it is normally protected with a MV- Fuse.

In order to be operational, self-powered relays drain the necessary energy from the current signal delivered by the main CTs (some other applications may drain this energy from voltage transformers instead). Therefore, the load currents, and eventually the fault currents, deliver the energy to the relay for its operation.

The need to have an external power supply (typically a battery system with all the related DC network structure) for the relay functionality and for the tripping of the circuit breaker is then minimized, if not completely removed, bringing to a clear cost reduction and more simple protection system.

Looking at the near future, it can be said that the concept of smart grid[1] is penetrating our society more and more: solar panels are installed on the roofs of common people houses, electrical vehicles are charged at our homes and hopefully one day will be able to deliver energy to the grid (V2G [2])[2]. More technically, smart grids penetrates all the “voltage levels”.
One of the important factors that will affect the speed of this penetration is the “cost” to do it. Also for the protection of the smart grid power system, the cost is important. Technically the solutions to protect the smart grid are in principle available from the competence in protecting the high voltage power system networks (transmission networks), but the smart grid cannot tolerate the costs of the high voltage system protection, in terms of complexity and price of the equipment.

Self-powered relays provide an important contribution to reduce the cost of the protection of the smart grid [3], and it is then foreseen that their usage will grow in the near future, the more the smart grid is implemented.

3. General topics related to testing self-powered relays.

3.1. Direct secondary injection or injection through test circuits

There is in principle no practical difference between these two types of injection.
The “direct secondary injection” is the usual secondary injection for a usual protection relay. The test set applies the current waveforms to the analog inputs of the protection relay. The self-powered relay will draw the energy for its functionality from the injected currents [4].

The injection through test terminals on board of the relay is foreseen for some self-powered relays (Figure 1, [5] and [6]). This simplifies the practical maintenance operations in the field because there is no need to short circuit the secondary side of the main CTs and to create a connection from the relay test set to the relay analog inputs, as usually done for the conventional direct secondary injection.

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1 The definition of smart grid is not easy. According to the International Electrotechnical Vocabulary (IEV, IEC 60050) [1], smart grid is one electric power system that utilizes information exchange and control technologies, distributed computing and associated sensors and actuators, for purposes such as:
– To integrate the behaviour and actions of the network users and other stakeholders,
– To efficiently deliver sustainable, economic and secure electricity supplies
While this definition is very generic, in practice smart grid is in these years associated to distributed power generation (photovoltaic, wind), to energy storage, to standardised communication protocols and methods (IEC 61850).
2 V2G means Vehicle to Grid. Many tests are done already today in 2020 for achieving this goal.

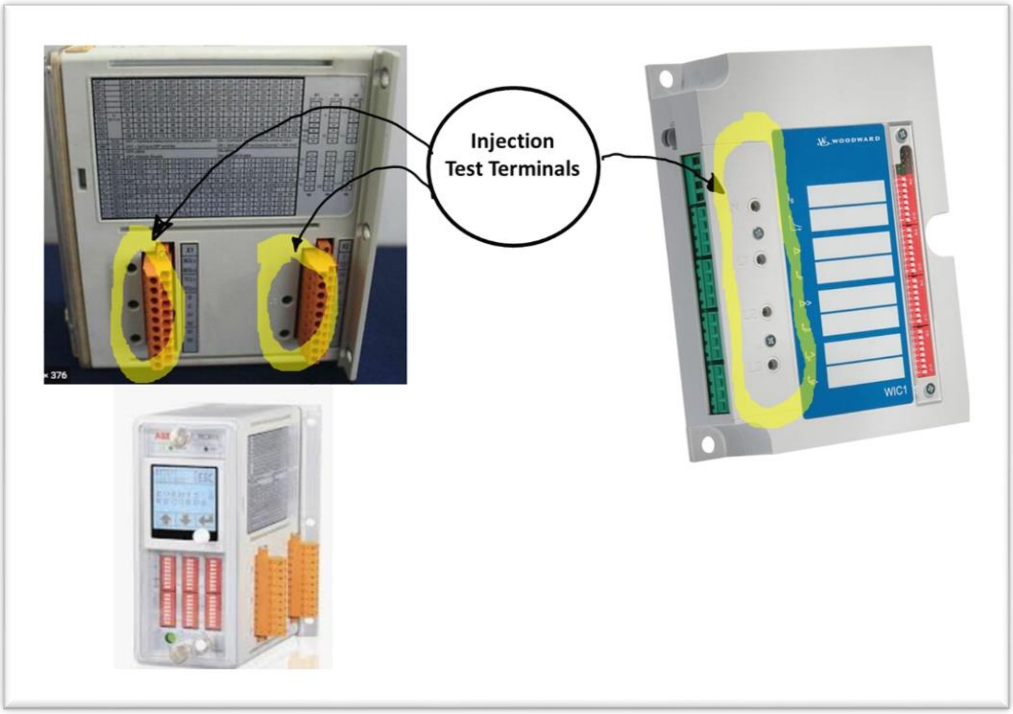


Figure 1. The test terminals provided by WIC-1 relay (from the WIC-1 user's manual [5], Copyright SEG GmbH) and by the ABB REJ603 (from the REJ603 user's manual [6], Copyright ABB)

The currents are injected through the test points easily accessible from the relay. The current flows through the special multi-winding main CTs, and it is induced back to the analog inputs of the relay. From that current, the relay draws the energy to power itself (Figure 2).

The line/feeder must be de-energized; no primary current shall flow into the primary circuit (see par. 6.1.1 of relay manual [5].

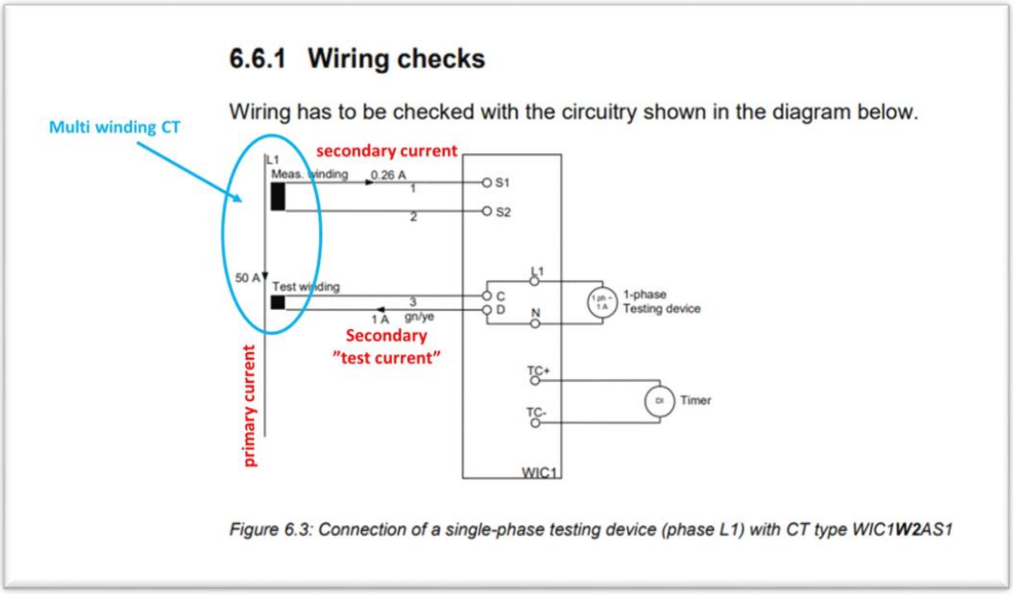


Figure 2. The injection in the test points L1 and N (1A in the figure) turns out to be an injection in the relay analog inputs (S1 and S2) through the multi-winding current transformer (from the WIC-1 user's manual [5], Copyright SEG GmbH). Note that the figure shows the relations for a particular CT type, which is the same used in this document.

So this is also a “secondary injection”, but through a current transformer. The test through the secondary test current is comfortably done by converting the relay characteristics/settings into the values of the secondary test current.

3.2. Pre-fault quantities

For overcurrent relays, the necessary energy for the relay operation is delivered by the current transformers. This mean that in general, if there is no load current in the protected feeder, there is no energy to power the relay and the relay is not active[3]. If the power system fault occurs, the fault current delivers energy to the relay, the relay starts-up, it detects the fault and issues the operate (trip) command. In this case. The operate time (trip time) of the relay is the normal relay operate time plus the time that the relay needs to start-up (to “wake-up”).

This situation is associated to a “switch onto fault condition” [7]: if the circuit breaker is closed on a permanent fault, there cannot be any pre-load into the protection relay before the circuit breaker is closed.
A similar situation can also happen if the circuit breaker is closed and the load level is below the necessary level to provide enough energy to the relay to be in operation, before the fault occurs.

Typically, we can suppose that the load current is available so that the relay is powered and ready to do its job when the power system fault occurs. To test this condition it is necessary to inject with the relay test set a certain level of pre-fault current for a certain period, before the fault current is really injected.
In SVERKER 900 this means that the “pre-fault and fault” instrument shall be used, where the pre-fault currents are set at a certain current level for a reasonable time which is long enough to let the protection relay be “ready” when the fault is simulated. One second is long enough to reach this status[4].

If the pre-fault current is set to zero, or the pre-fault time is set to zero, the switch onto fault (or low load) condition is tested.

3.3. SVERKER 900 and self-powered relays

SVERKER 900 is designed to manage the current generation into self-powered relays. The major technical challenges for succeeding in this are:

1) Harmonics generated from the self-powered relay that can disturb the control circuits in SVERKER 900;
2) Non-linear load presented by the self-power relay, that requires high real time control loops to make sure the correct waveforms are generated by the SVERKER 900;
3) The power associated to the injected currents is relatively high, as the relays draw the energy from the current signal for their functionality. This power must be delivered by the current generators of SVERKER 900.

Figure 3. The SVERKER 900 with indication “Current generator MkII” in the serial number is able to generate current signals for testing self-powered relays.

3 Unless the eventual presence of some small batteries, that can keep the relay alive in absence of the load, and that are recharged as soon as the load appears; this is not a representative situation.
4 Self-powered relays have usually a very fast start-up time, less than 100 milliseconds. It has not been observed a self-powered relay that needs more than 200 ms to start-up. One second of pre-fault is a reasonable time.

SVERKER 900 with indication “Current generator MkII” is designed to test self-powered relays.
It is important to be aware that the technology behind self-powered relays is in continuous and fast development (see par. 2), so it cannot be promised that all self-powered relays are managed. Please contact Megger if you need support.

4. General information about overcurrent relays.

4.1. IEC standard for overcurrent protection: IEC 60255-151:2009

The IEC standard for overcurrent protection function is IEC 60255-151:2009: Measuring relays and protection equipment - Part 151: Functional requirements for over/under current protection [8].

The information, definitions and testing methodologies described in the IEC relay protection functional standards, IEC 60255-1xx are of interest for [9]:

- protection relay manufacturer, where the standards describe the minimum requirements for type-testing,
- test equipment manufacturer –to apply the standardized test methodologies
- end-users, for procurement specification, acceptance tests
- the entire relay protection community in general (as well as for commissioning / testing engineers), for using the same terminology and definitions

If all the parties have a competence of IEC 60255-1xx standards, there will be less misunderstandings during the purchase but also at commissioning/maintenance of the protection relays, with less discussions, shorter testing times and a more reliable protection system [10],[7].

The following paragraphs summarize the most important details available in the standard that are useful for the work of a relay testing engineers.

4.1.1. Standardized IEC inverse time curves

One of the most important successes of IEC 60255-151:2009 was to reach an international consensus on the harmonisation of the so-called “IEC and IEEE time curves”. The recent IEEE standard C37.112: 2018 [11] has in principle adopted the same IEC curves.

The standardized IEC curves are A, B, C, D, E and F. The common names used for the curves are associated to the letters (Figure 4). SVERKER 900 has implemented the standardized curves, as the next paragraphs will show.

Annex A
(normative)

Constants for dependent time operating and reset characteristics

'able A.1 shows the constant for dependent time operating and reset characteristics.

Table A.1 – Constants for dependent time operating and reset characteristics

Curve type	Operating time $t(G) = TMS\left[\dfrac{k}{\left(\dfrac{G}{G_S}\right)^{\alpha} - 1} + c\right]$			Reset time $t_r(G) = TMS\left[\dfrac{t_r}{1 - \left(\dfrac{G}{G_S}\right)^{\alpha}}\right]$		Commonly used name
	k s	c s	α	t_r s	α	
A	0,14	0	0,02	*	*	Inverse
B	13,5	0	1	*	*	Very inverse
C	80	0	2	*	*	Extremely inverse
D	0,0515	0,1140	0,02	4,85	2	IEEE Moderately inverse
E	19,61	0,491	2	21,6	2	IEEE Very inverse
F	28,2	0,1217	2	29,1	2	IEEE Extremely inverse
* For curves A, B and C, the manufacturer shall declare if dependent time reset characteristic is implemented and provide the appropriate information.						

Figure 4. The 6 standardized IEC curves in IEC 60255-151:2009. From IEC 60255-151:2009 ed.1.0 - "Copyright © 201x IEC Geneva, Switzerland. www.iec.ch"

4.1.2. The "Time Multiplier", TMS.

Many names have always been given to the so-called time multiplier, known as "k factor", "alpha factor", "a factor" etc.
The standardized name according to IEC 60255-151 is TMS: Time Multiplier Setting, or simply Time Multiplier.

4.1.3. Testing the start value and the operate time.

In the IEC 60255-1xx series of standards for protection functions there is always the difference between two basic test methods:

1) Test of the "border" of the characteristics
2) Test of the operate time of the characteristic

For the test of the border, it is intended to verify the accuracy of the border of the relay characteristic. For overcurrent relays the characteristic is defined by the "start value" ("pick-up" value[5]): the current threshold above which the protection relay starts the timer for the trip command, according to a defined formula where the operate time is function of the current level. Below this start value (often denoted as "I>" or "I>>"), the protection relay does not react. In IEC 60255-151 this "start value" is called Gs.

[5] *Note that in IEC world it is usually used the name "start" (start time, start contact etc.), while in the ANSI/IEEE world it is often used the name "pick-up" (pick-up time, pick-up contact etc). At the same time, for tripping, the IEC world should use the name "operate" (operate time, operate contact) while the ANSI/IEEE world uses the name "trip" (trip time, trip contact). In this document we will use indifferently the terms "start" and "pick-up" and/or "operate" and "trip".*

When the operate time shown in the characteristic is tested, the inverse curve (or definite time curve) is tested. This means to verify the "operate time" of the overcurrent relay in different fault (current) conditions.
It is recommended to verify the operate time at least at current levels higher than 1,3 times the start value (1,3 x Gs)[6].

In this Technical Guide, the two test methods are combined in one test only. It is anyhow important to have in mind these two fundamental concepts, related to the above 1) and 2):

a) Verify "no trip" before the threshold. If overcurrent threshold I> is for example 1A, inject a current 10% below, at 0,9 A and verify that the relay does not operate (trip).
If the threshold I>> is 5A, remember to inject a current 10% below it (or less), where you will observe operation of I> but NOT the operation of I>>.

b) Verify the operate time at 1,3 times the threshold. If the overcurrent threshold I> is 1A, inject currents to measure the operate time from 1,3 A. If the threshold I>> is 5 A, inject currents from 6,5 A.

The start value of 90% of the threshold is not "written in the stones", so feel free to use other margins to verify the start values of the curves. Margins of 80% and 90% are reasonable.
Feel also free to test the operate times at values smaller than 1,3 times the threshold, but remember that in case of discussions, the IEC 60255-151 requires to test the operate time at least at 1,3 times the start value, if no other values are defined by relay manufacturer.

Figure 5 schematically represents the presented concepts.

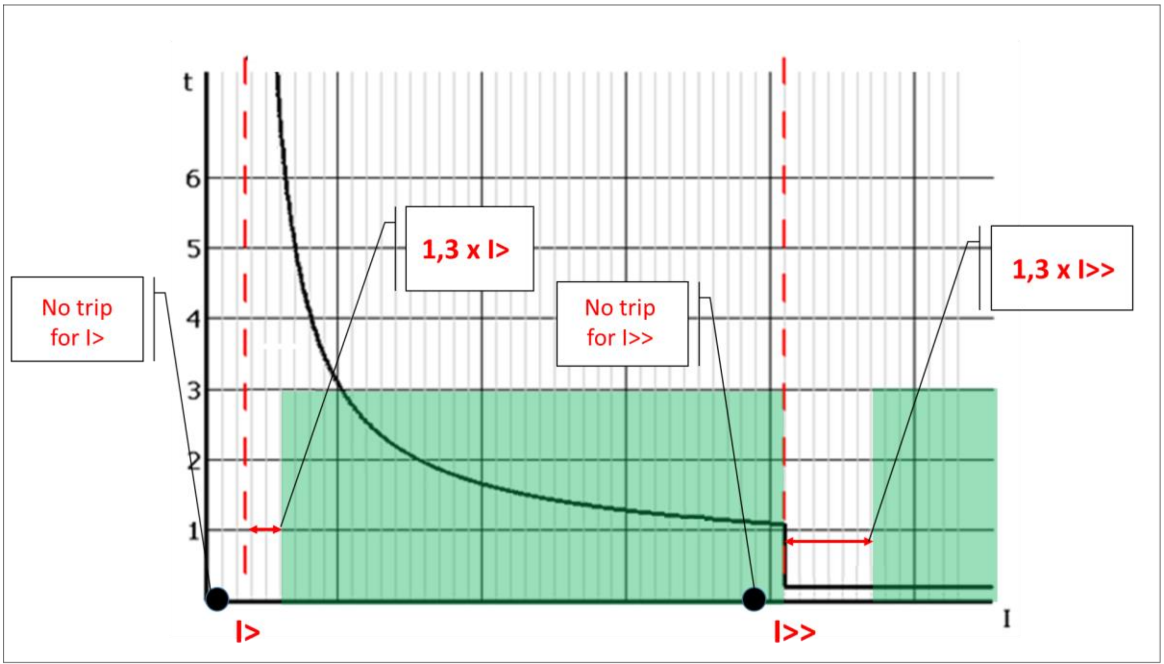


Figure 5. Representations of the suitable zones for testing the operate time (in green), with fault current values higher than the thresholds. Important is to test the "no-trip" for the thresholds, represented by the black fault points 90% (or less) below the thresholds.

Finally, this document presents a good practical and rapid method for graphically verifying the tested time characteristic for commissioning/maintenance purposes (par. 5.2.5).
The method is based on the idea that an error of the relay on the measurement of the current appear as an error in the operate time. Without considering additional errors on the timers of the relay itself, it is possible to graphically evaluate if the measured operate times are compatible with errors in current measurements of 10% or maybe also 15%. If this method does not give clear indications, it is necessary to perform tests that are more accurate before disqualifying the relay.

6 According to IEC 60255-151, the relay manufacturers have the right to declare the value of that coefficient. Some relays may have different values than 1,3. This means that the relay user's manual should be read. In general the value 1,3 (or 1,2) is a good value for a reasonable simplification.

5. Testing WIC-1 overcurrent relay with SVERKER 900.

5.1. Introduction

The WIC-1 relay is connected to the protected feeder via a special multi winding CT.
The one winding of the CT is the test winding. The test secondary current is injected from dedicated test terminals (see par. 3.1).

There are different standard CT types available for the WIC-1. The current transformer used in this document is W1C1-W2AS1 (Figure 6 and Figure 7).

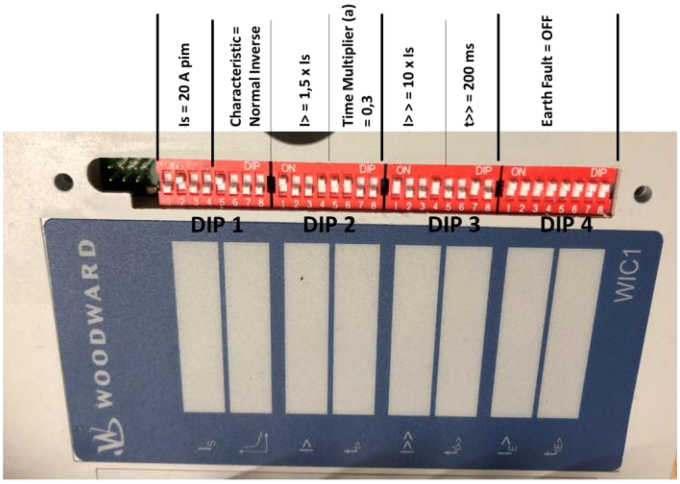
The selected nominal primary current “Is” will be chosen to be 20 A.

Figure 6. The multi winding CT of type W1C1-W2AS1

The relay settings are made with dipswitches on the front, see manual [5] for details about how to set the relay.

The overcurrent setting for primary start value are set by the position of dipswitches 1-1 to 1-4 The secondary set value is then decided from this setting and has the same value for all standard CTs. The settings for I> and I>> are then related to this value.

Figure 7 shows the meaning of the dipswitches, together with the position of the dipswitches for the tested WIC-1 relay.



DIP 1-1	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON
DIP 1-2	OFF	OFF	ON	ON	OFF	OFF	ON	ON	OFF	OFF	ON	ON	OFF	OFF	ON	ON
DIP 1-3	OFF	OFF	OFF	OFF	ON	ON	ON	ON	OFF	OFF	OFF	OFF	ON	ON	ON	ON
DIP 1-4	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON	ON	ON	ON	ON	ON	ON	ON
HEX 1	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
WIC1-W1	8	9	10	11	12	13	14	15	16	17	18	20	22	24	26	28
WIC1-W2	16	18	20	22	24	26	28	30	32	34	36	40	44	48	52	56
WIC1-W3	32	36	40	44	48	52	56	60	64	68	72	80	88	96	104	112
WIC1-W4	64	72	80	88	96	104	112	120	128	136	144	160	176	192	208	224
WIC1-W5	128	144	160	176	192	208	224	240	256	272	288	320	352	384	416	448
WIC1-W6	256	288	320	352	384	416	448	480	512	544	576	640	704	768	832	896

Figure 7. Meaning of the dipswitches (table from the WIC-1 user's manual pages 20, 21 and 22 [5] , Copyright SEG GmbH), their position in the tested relay and list of different CTs

The Normal Inverse characteristic for WIC-1 relay is the standardized curve "A" (Inverse) in IEC 60255-151 (Figure 8).

Technical Manual WIC1 — SEG Electronics GmbH

5.8.2 Calculation formula for IMT characteristics

Normal Inverse:

$$t = \frac{0.14}{\left(\frac{I}{I_S \times I_>}\right)^{0.02} - 1} \cdot a[s]$$

FROM WIC-1 Manual

Table A.1 – Constants for dependent time operating and reset characteristics

Curve type	Operating time $t(G) = TMS\left[\frac{k}{\left(\frac{G}{G_S}\right)^{\alpha} - 1} + c\right]$			Commonly used name
	k s	c s	α	
A	0,14	0	0,02	Inverse

FROM IEC-60255-151

For WIC this is valid: TMS = a; k = 0,14, a = 0,02 and c = 0 → "A" Curve, "Inverse"

Figure 8. The formulae for the "A" curve in IEC and for the Normal Inverse curve in WIC-1 are identical

5.2. Testing the phase overcurrent relay.

5.2.1. Relay settings.

The phase overcurrent protection relay has the following settings in primary values[7]:

I>= 30 A
Characteristic Normal Inverse (IEC “A”: Inverse, par. 4.1.1)
Time Multiplier (a) = 0,3

I>>= 200 A
Characteristic Definite Time
Time Delay t = 200 ms

The relay settings have been entered by using the dipswitches as shown in par. 5.1.

According to the relay manual, a current of 1A injected from the test terminals (connectors C-D) corresponds to a primay current of 50 A (Figure 9 and Figure 2).

CT Type	Induced Current	Primary Current	Transformation Ratio
WIC1-WE1	1A	25A	25:1
WIC1-W1	1A	25A	25:1
WIC1-WE2	1A	50A	50:1
WIC1-W2	1A	50A	50:1
WIC1-W3	1A	100A	100:1
WIC1-W4	1A	200A	200:1
WIC1-W5	1A	400A	400:1
WIC1-W6	1A	800A	800:1

Figure 9. Relationship between the “secondary test current and the primary current depending on the used current transformer (from the WIC-1 user’s manual [5], Copyright SEG GmbH)

As the relay will be tested with current injections from the test terminals, it is simple to get the relay characteristics as function of the test current (terminals C-D), because 1 A “secondary test current” is equivalent to 50 A “primary current”.

I>_test= 30 A x (1/50) = 0,6 A
Characteristic Normal Inverse
Time Multiplier (a) = 0,3

I>>_test = 200 A x (1/50) = 4,0 A
Characteristic Definite Time
Time Delay t = 200 ms

The table below represents an overview of the values. The secondary values (S2-S1) are shown only for reference, but they are not used for the testing procedure:

7 The secondary settings (in the relay analog inputs, connectors S2-S1) are derived from the CT ratio, which is 14,4 A / 0,075 A = 192.
I>= 30 A / 192 = 0,156 A, Characteristic Normal Inverse, Time Multiplier (a) = 0,3
I>>= 200 A / 192 = 1,042 A, Characteristic Definite Time, Time Delay t = 200 ms
These values are not fully relevant as the test will be done by using the “secondary test current method”, but they are good to know.
The secondary values from the test terminals (connectors C-D) are 1/0,26 = 3,846 times the secondary values (see Figure 2 and the relay manual [5]): 1 A in the test terminals gives 0,26 A in the relay analog inputs:
I>_test= 0,156 A x 3,846 = 0,6 A, Characteristic Normal Inverse, Time Multiplier (a) = 0,3
>>_test = 1,042 A x 3,846 = 4,0 A, Characteristic Definite Time, Time Delay t = 200 ms
All of this is correct but it is not the process we will follow in this document.

Settings	Primary Settings	Secondary Test Current Settings from the test circuits (C-D)	Secondary Settings (S2-S1)
I>	I> = 30 A Normal Inverse (IEC “A”: Inverse) Time Multiplier = 0,3	I>_test = 0,6 A Normal Inverse (IEC “A”: Inverse) Time Multiplier = 0,3	I> = 0,156 A Normal Inverse (IEC “A”: Inverse) Time Multiplier = 0,3
I>>	I>> = 200 A Definite Time Time Delay = 200 ms	I>>_test = 4,0 A Definite Time Time Delay = 200 ms	I>> = 1,042 A Definite Time Time Delay = 200 ms

Another practical method to follow, described in the relay manual, is that once the primary “base current” Is = 20 is selected with the dipswitches 1-1 to 1-4 (Figure 7), this table in par. 6.7.1 of the manual [5] informs that no matter which current transformer is used, the base value of the “secondary test current” is 0,4 A (Figure 10).

DIP 1-1	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON
DIP 1-2	OFF	OFF	ON	ON	OFF	OFF	ON	ON	OFF	OFF	ON	ON	OFF	OFF	ON	ON
DIP 1-3	OFF	OFF	OFF	OFF	ON	ON	ON	ON	OFF	OFF	OFF	OFF	ON	ON	ON	ON
DIP 1-4	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON	ON	ON	ON	ON	ON	ON	ON
HEX switch I_S	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
WIC1-W1	8	9	10	11	12	13	14	15	16	17	18	20	22	24	26	28
Test current CD	0.32	0.36	0.40	0.44	0.48	0.52	0.56	0.60	0.64	0.68	0.72	0.80	0.88	0.96	1.04	1.12
WIC1-W2	16	18	20	22	24	26	28	30	32	34	36	40	44	48	52	56
Test current CD	0.32	0.36	0.40	0.44	0.48	0.52	0.56	0.60	0.64	0.68	0.72	0.80	0.88	0.96	1.04	1.12
WIC1-W3	32	36	40	44	48	52	56	60	64	68	72	80	88	96	104	112
Test current CD	0.32	0.36	0.40	0.44	0.48	0.52	0.56	0.60	0.64	0.68	0.72	0.80	0.88	0.96	1.04	1.12
WIC1-W4	64	72	80	88	96	104	112	120	128	136	144	160	176	192	208	224
Test current CD	0.32	0.36	0.40	0.44	0.48	0.52	0.56	0.60	0.64	0.68	0.72	0.80	0.88	0.96	1.04	1.12
WIC1-W5	128	144	160	176	192	208	224	240	256	272	288	320	352	384	416	448
Test current CD	0.32	0.36	0.40	0.44	0.48	0.52	0.56	0.60	0.64	0.68	0.72	0.80	0.88	0.96	1.04	1.12
WIC1-W6	256	288	320	352	384	416	448	480	512	544	576	640	704	768	832	896
Test current CD	0.32	0.36	0.40	0.44	0.48	0.52	0.56	0.60	0.64	0.68	0.72	0.80	0.88	0.96	1.04	1.12

Figure 10. No matter which current transformer is used, the windings are arranged in such a way that the “base current” (Is) has always the same “secondary test current” value (from the WIC-1 user’s manual [5], Copyright SEG GmbH). The calculation of the relay thresholds in secondary test values is very much facilitated.

At this point all the other settings (chosen with other dipswitches, see Figure 7) are easy as they are proportional to the value of the base current expressed from the test terminals:

I> = 1,5 x Is → I> = 1,5 x 0,4 A = 0,6 A (secondary test currents)
I>> = 10 x Is → I>> = 10 x 0,4 A = 4 A (secondary test currents)

5.2.2. Connecting SVERKER 900 to WIC-1 relay.

SVERKER 900 is connected to the protection relay according to Figure 11, where the three phase currents and the operate (trip) contact are shown.

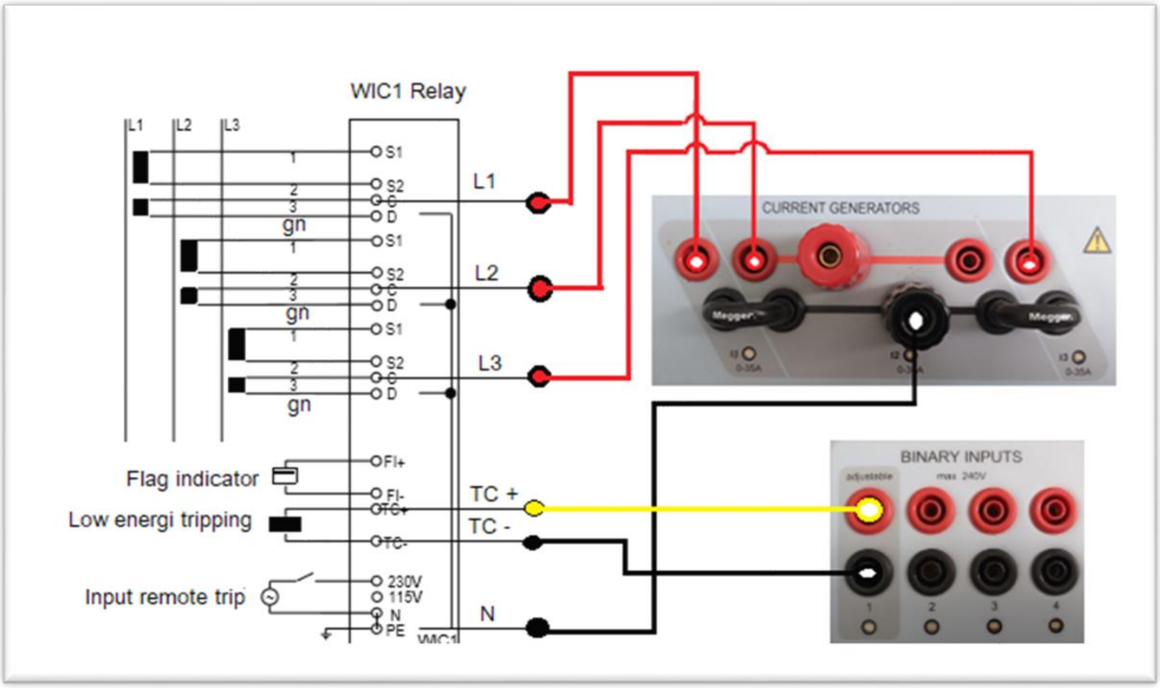


Figure 11. Schematic diagram representing the connections of the 3 current generators of SVERKER 900 to WIC-1 and the operate contact. Also the connection diagram of WIC-1 is shown (from the WIC-1 user's manual [5], Copyright SEG GmbH).

The operate (trip) signal is a DC polarized signal that sends a sequence of pulses, each pulse 50 ms long.

5.2.3. SVERKER 900 settings.

The binary input nr. 1[8] of SVERKER 900 needs to be configured in such a way to be able to manage the voltage trip signal from WIC-1:

Voltage sensing, trigger on voltage presence (from "0" to "1")
DC voltage threshold 20 V
Debounce time 30 ms.

Some small adjustments may be needed in case the measured operate time is noticed to be wrong (Figure 12), by both adjusting the voltage threshold of the binary input 1 and/or the length of the debounce time.

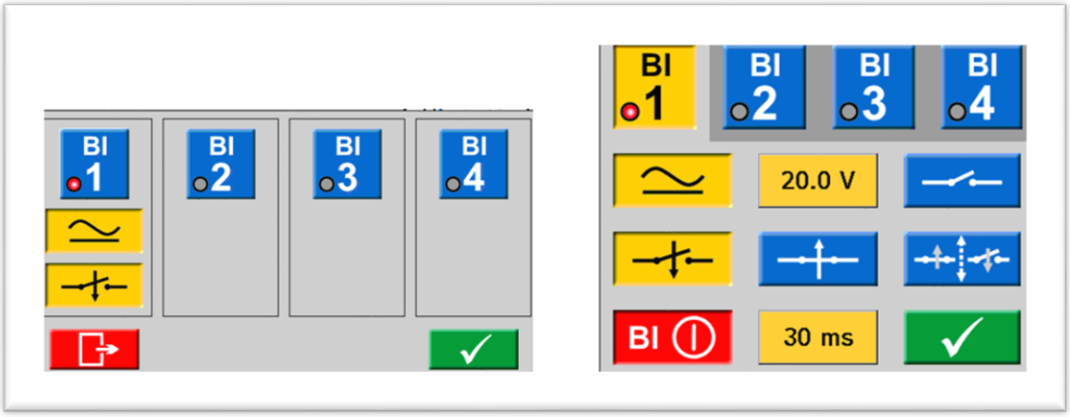


Figure 12. Settings for Binary Input 1 of SVERKER 900 connected to the trip signal from WIC-1,

8 Note that only binary input 1 in SVERKER 900 has the flexibility to adjust both debounce filter and voltage threshold!

For testing the phase overcurrent protection function the instrument MTT [12] of pre-fault and fault and the possibility to draw graphs of time curves is used[9] [13].

Figure 29 shows an extract of the SVERKER 900 user's manual where the functionality of MTT in pre-fault and fault instrument is described.

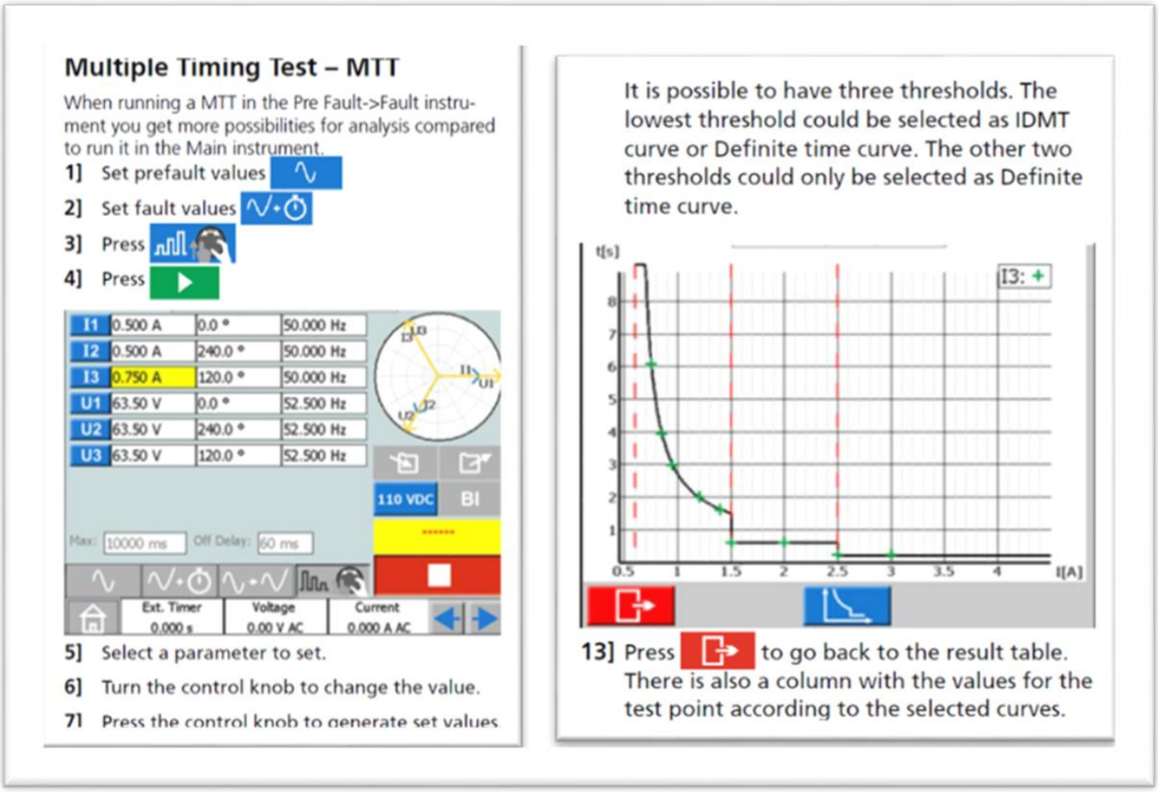


Figure 13. Short description of the functionality of MTT in pre-fault and fault instrument (from the SVERKER 900 user's manual [13], Copyright Megger).

In MTT the following major settings are necessary:

Pre-fault level:	0,25 A duration t = 1000 ms
First fault level:	0,8 A max duration t = 10 s (this timer could be increased if higher operate times may be measured, especially if the no-trip condition needs to be considered)
Binary Input (BI):	use BI1 and set is as shown in Figure 12

5.2.4. Testing the overcurrent protection function.

Considering the information in par. 5.2.3, set up the necessary conditions in SVERKER 900 and run the sequence of tests[10].

Before the sequence of the tests is run, consider a no-trip test at a current level of approximately 0,55 A (roughly 90% of the threshold, 0,6 A, see par. 4.1.3). Consider to increase the time-out to some 30 seconds ("Max" in fault state) to avoid the risk of declaring no-trip only because a very short time-out was set.

Set in MTT pre-fault and fault the pre-fault values (Figure 14):

9 Note that not all SVERKER 900 are equipped with this functionality, please contact Megger for details.
10 As no earth fault relay is activated, it is indifferent from the protection functionality point of view, if single-phase injections or three phase injections are executed. This document shows tests executed with single-phase injection, but it is possible of course to execute three-phase faults in order to avoid the activation of the earth fault.

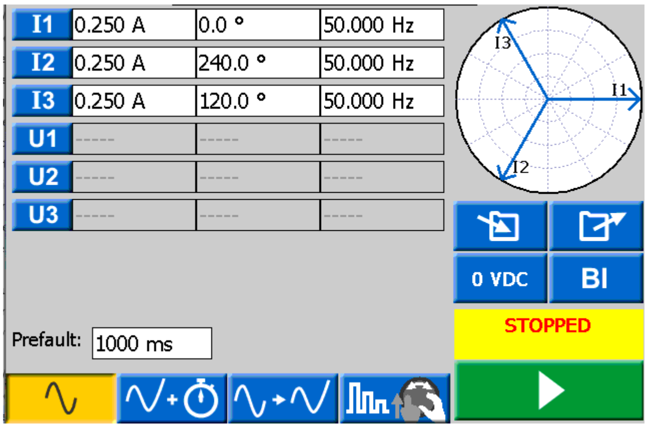


Figure 14. Pre-fault of 0,25 A for 1 second in MTT pre-fault and fault.

Set then the "first fault" values (Figure 15):

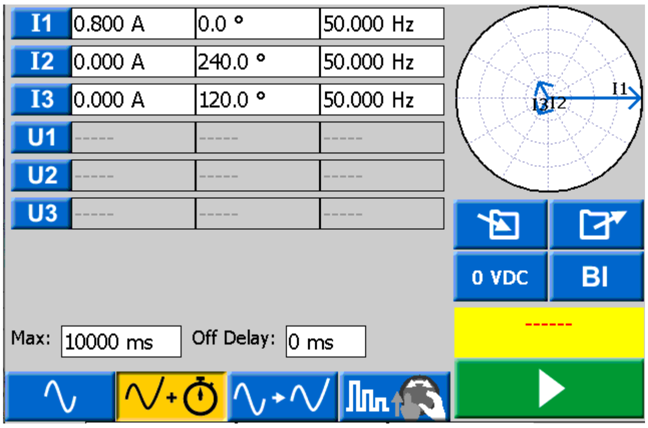


Figure 15. "First fault" of 0,8 A (timeout after 10 seconds) in MTT pre-fault and fault.

Select MTT by tapping on its button. MTT is now armed (Figure 16):

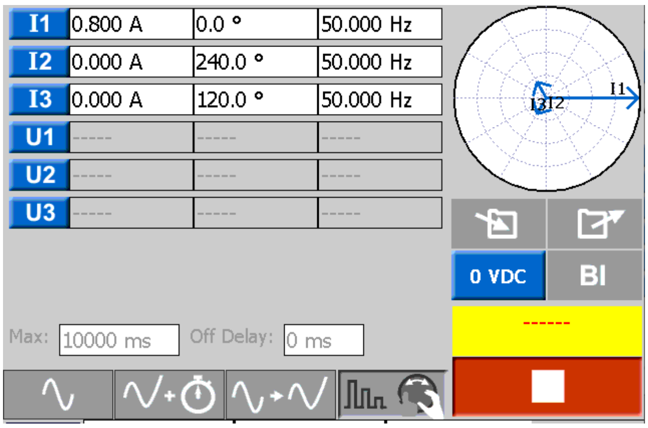


Figure 16. Activation (arming) of the MTT mode in pre-fault and fault. Press the knob to start the injection

By pressing the knob, the pre-fault and fault sequence will start and the operate (trip) time will be recorded (Figure 17):

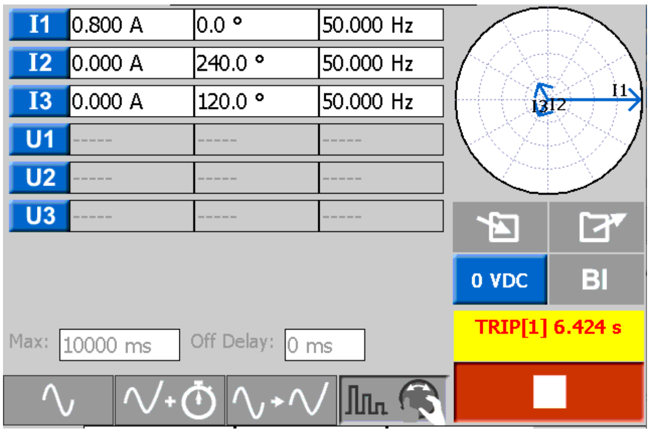


Figure 17. First operate time measurement for 0,8 A.

Select the quantity that you want to change (I1 in this case), rotate the knob to change its value and press the knob to inject that current level after the pre-fault (Figure 18):

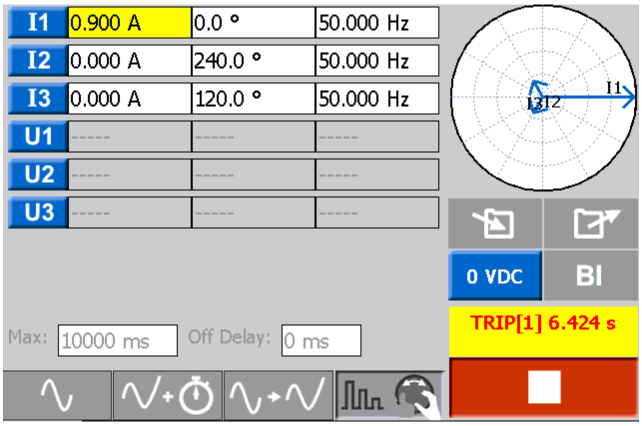


Figure 18. Select the quantity you want to change by tapping on it, change it with the knob. Press the knob to inject it.

To stop the sequence of tests, tap (Figure 19); the list of the tests will be shown.

Notice the test values below 4A (threshold for I>>) for testing the non-trip of the I>> threshold (par. 4.1.3). In this case, tests slightly above 4A have been done, but the test results were well in line with the expected values, so there was no need to run tests with currents above 1,3 x 4 A = 5,2 A. Also it can be noticed that the I>> threshold was measured at roughly 3,9 A of injection. This represents a 10% error on current measurement and is reasonable (see par. 5.2.5) considering the analog circuitry between the SVERKER 900 and the analog inputs of the protection relay (S1-S2 terminals). See details in par. 5.2.5.

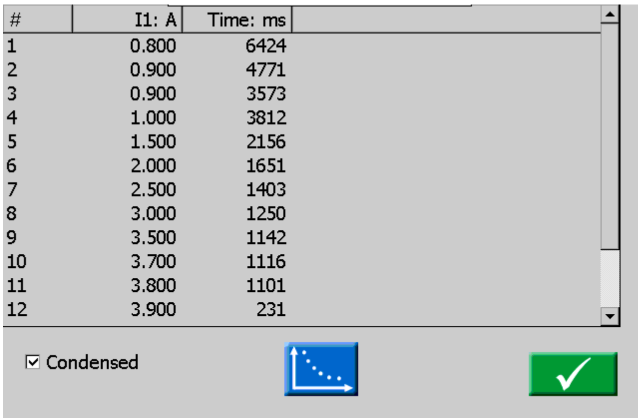


Figure 19. The sequence of tests is finished and the list of the tests is shown by SVERKER 900

To graphically view the test results, tap on (Figure 20):

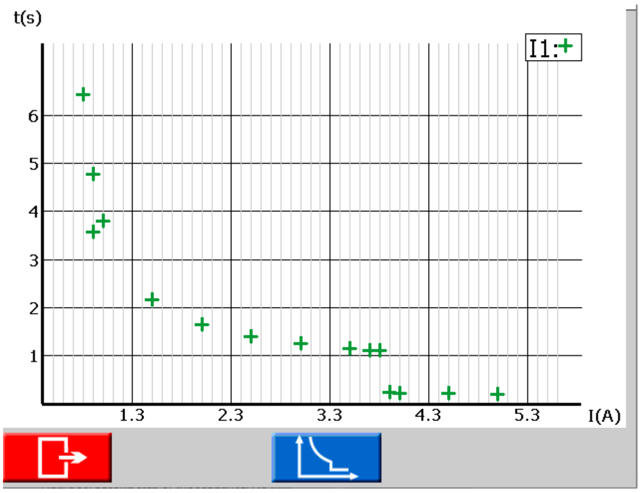


Figure 20. Viewing the test results graphically

Add the reference curve by tapping on  (Figure 21).

Remember that the reference curve must be entered as function of the "test current" (see par. 5.2.1). The procedure is very intuitive.

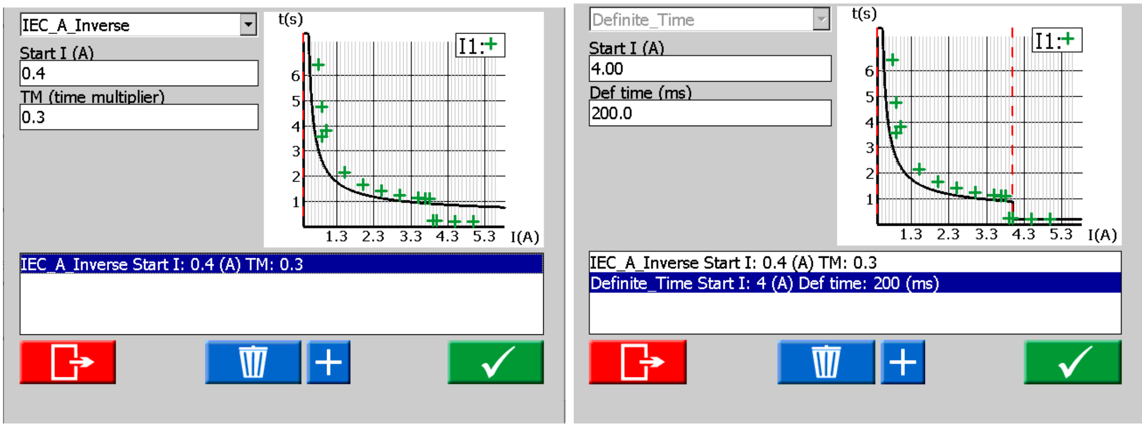


Figure 21. Adding the reference curve for I> and I>>

Tap on  to see the result on a larger graph (Figure 22):

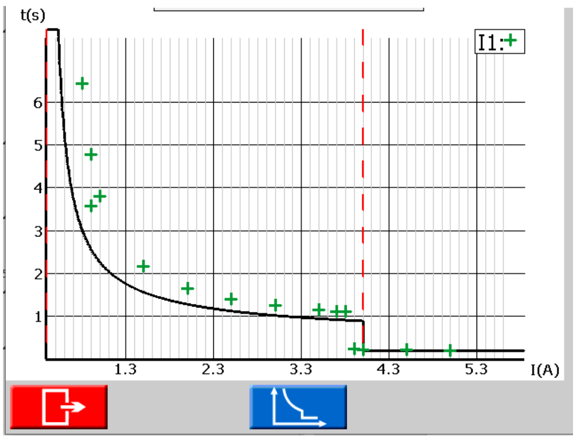


Figure 22. Viewing the test results graphically. The current shown is the "TEST CURRENT" (1A test current = 50 A primary current)

To save the file, and eventually view the report in the PC application SVERKER VIEWER, please follow the instructions given in SVERKER 900 manual [13].

5.2.5. Can we accept the test results?

SVERKER 900 is a relay test equipment that lets the engineer decide if the test result is Ok or not.

From the graph shown in Figure 22, the result is doubtful: a noticeable large deviation from the "theoretical curve" is noticed.

As a rule of thumb (due to the voltage level where these relays are requested to operate) if the measured points are within 10% (or 15%) of the theoretical characteristic, the test results can be accepted without need of deeper investigations. The combination of relay error and CT error[11] can justify this approach.
One error in the current measurement, is reflected as an error on the operate time. To easily verify this graphically with a reasonable approximation (valid for small percentages of errors: 10% is a small percentage), it is possible to draw the characteristic with new modified settings: 10% above and 10% below the real settings. In this case, we obtain two curves that reasonably show the error in the time characteristic.
When the error for the measured current is below the injected value, we obtain the characteristic with times above the theoretical times. When the error is above the injected value, we obtain the characteristic below the theoretical one.

The characteristics that will be drawn are then:

CURVE "BELOW" (Figure 23):

I>_test= 0,6 A * 0,9 = 0,54 A	Characteristic Normal Inverse (IEC "A": Inverse, par. 4.1.1) Time Multiplier (a) =0,3
I>>_test = 4,0 A * 0,9 = 3,6 A	Characteristic Definite Time Time Delay t = 200 ms

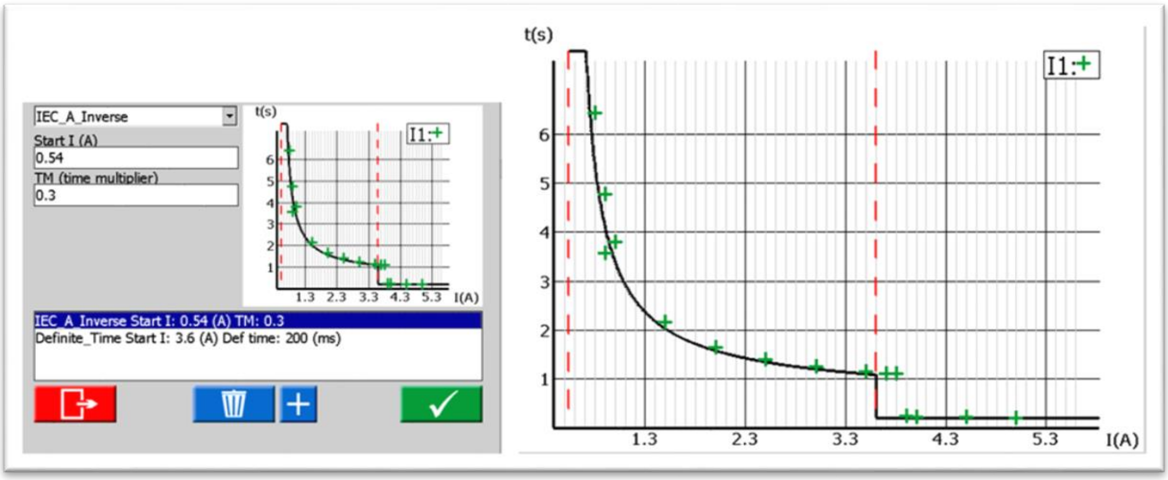


Figure 23. Graphical verification for the time curve for measurement errors 10% higher than the injected ones. These measured points are above the curve "BELOW".

CURVE "ABOVE" (Figure 24):

I>_test= 0,6 A * 1,1 = 0,66 A;	Characteristic Normal Inverse (IEC "A": Inverse, par. 4.1.1) Time Multiplier (a) =0,3
I>>_test = 4,0 A * 1,1 = 4,4 A	Characteristic Definite Time Time Delay t = 200 ms

11 consider that we are injecting the currents from a small winding, and through the real secondary winding it reaches the analog inputs of the relay

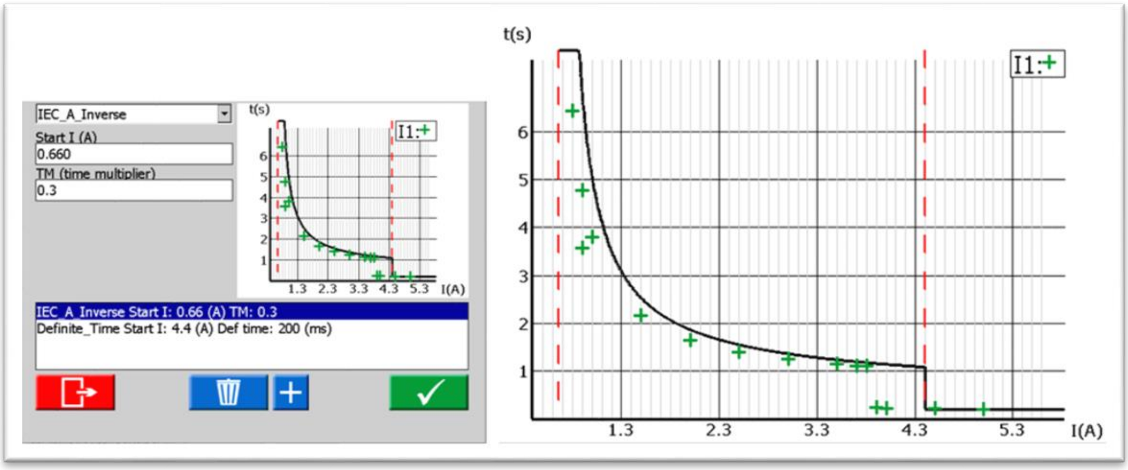


Figure 24. Graphical verification for the time curve for measurement errors 10% lower than the injected ones. These measured points are below the curve "ABOVE".

As conclusion, the test results can be accepted, as the measured points are reasonably between the high and low curves.

Obviously, the tests should be repeated for the other phases, or maybe they could be done just once by injecting three-phase faults.

5.3. Testing the protection function without pre-fault (switch onto fault).

As mentioned in par. 3.2, there can be a difference in the relay performance when the power system fault occurs after a situation with a certain pre-fault (load) level, or without it. As also mentioned, this condition can be connected to the "switch onto fault" situation, but it may happen when the circuit breaker is closed on an energized and unloaded feeder.
This test aims to compare the operate time of the relay in the two conditions:

1) Pre-fault of 250 mA present for 1 second, fault current of 7 A (above I>> threshold of 4 A)
2) No pre-fault, fault current of 7 A (above I>> threshold of 4 A)

Remember please that those current values are always referred to the "test" current. It is always good to have in mind the primary values associated to the secondary test currents.

One rule easy to remember is that 1 A in the test circuit, is equivalent to 50 A primary, no matter which "nominal current" (Is) has been chosen, or which CT has been used with the WIC-1 relay.

It is enough to run 5 tests[12] with the pre-fault current of 0,25 A (Figure 25) to get an idea of the operate time, then set the pre-fault current to 0 A and run 5 tests again (Figure 26).
For repeating the tests, MTT in pre-fault and fault instrument has been used. Different approaches are of course possible.

---

12 "One shot is not enough". Repeating the tests 5 times, gives an idea of the spread of the values, and helps to be comfortable with the test results. We are evaluating the operate time! Note that we have not repeated the tests for the inverse characteristics, as many shots are anyway generated. However, it could have been easily done, and we would have seen a sort of distribution of time measurements around the mean value, probably near the theoretical value. In case of doubts, use the statistical approach, especially if you need to report some doubtful performances.

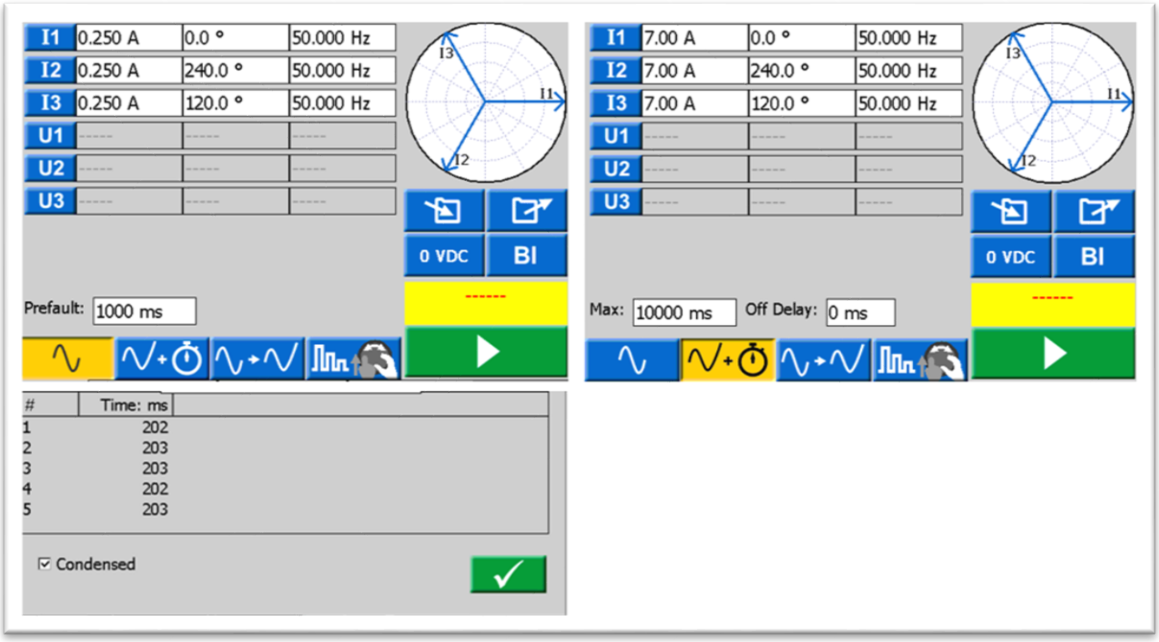


Figure 25. MTT Pre-fault and fault sequence for the presence of load before the fault and test results.

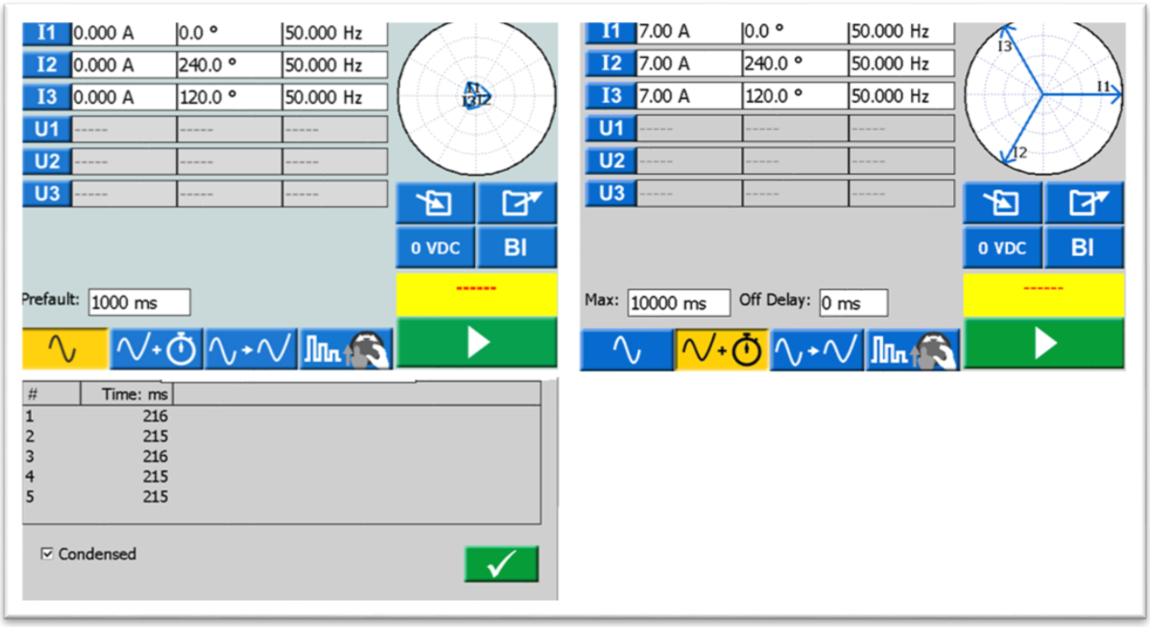


Figure 26. MTT Pre-fault and fault sequence for simulation of no presence of load before the fault and test results (switch onto fault).

Table below summarizes the test results:

Test Nr.	WIC-1 Operate Time pre-fault 250 mA / 1 s Fault 7 A	WIC-1 Operate Time NO pre-fault (switch onto fault) Fault 7 A
1	202 ms	216 ms
2	203 ms	215 ms
3	203 ms	216 ms
4	202 ms	215 ms
5	203 ms	215 ms
AVERAGE	**202,6 ms**	**215,4 ms**

We can conclude that the additional time required by WIC-1 to start-up (some 10 … 20 ms) is negligible compared to the operate time when the load current is available.

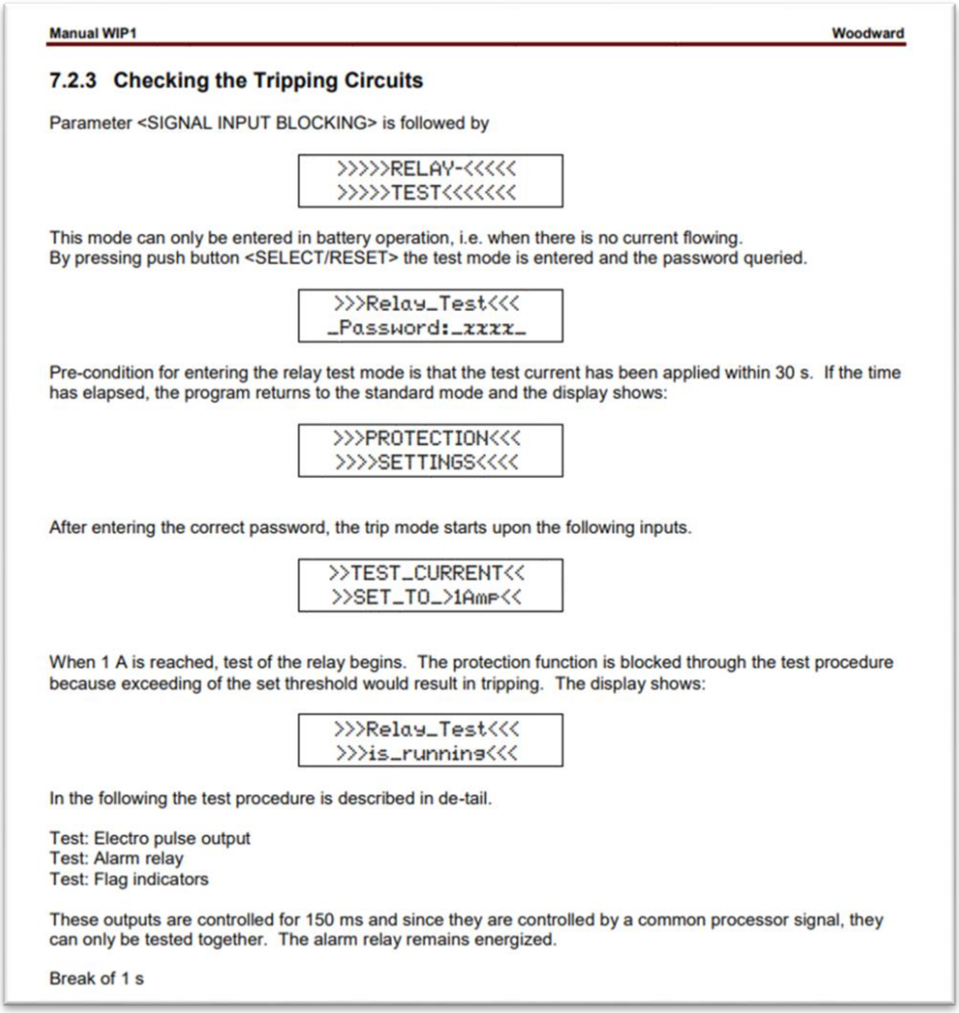
Switch onto fault condition (or fault in unloaded feeders) does not create any noticeable extra time delay in the relay operation.

6. Testing WIP-1 overcurrent relay with SVERKER 900.

6.1. Introduction

The WIP-1 relay is tested from direct secondary injection, as it would be done from any “conventional” relay connected to main CTs.

There is one additional test, characteristic to WIP-1 relay that is necessary to perform both in commissioning and in maintenance conditions; this test enables a self-testing (self-supervision) through a special procedure that tests the “tripping circuit” and other signals (Figure 27).


Manual WIP1 Woodward

7.2.3 Checking the Tripping Circuits

Parameter <SIGNAL INPUT BLOCKING> is followed by

```
>>>>>RELAY-<<<<<
>>>>>TEST<<<<<<<
```

This mode can only be entered in battery operation, i.e. when there is no current flowing.
By pressing push button <SELECT/RESET> the test mode is entered and the password queried.

```
>>>Relay_Test<<<
_Password:_xxxx_
```

Pre-condition for entering the relay test mode is that the test current has been applied within 30 s. If the time has elapsed, the program returns to the standard mode and the display shows:

```
>>>PROTECTION<<<
>>>>SETTINGS<<<<
```

After entering the correct password, the trip mode starts upon the following inputs.

```
>>TEST_CURRENT<<
>>SET_TO_>1Amp<<
```

When 1 A is reached, test of the relay begins. The protection function is blocked through the test procedure because exceeding of the set threshold would result in tripping. The display shows:

```
>>>Relay_Test<<<
>>>is_running<<<
```

In the following the test procedure is described in de-tail.

Test: Electro pulse output
Test: Alarm relay
Test: Flag indicators

These outputs are controlled for 150 ms and since they are controlled by a common processor signal, they can only be tested together. The alarm relay remains energized.

Break of 1 s

Figure 27. Procedure for testing the tripping circuit (from the WIP-1 user’s manual [4], Copyright SEG GmbH).

The above test is a complement to the relay secondary injection tests that are executed in the normal way

6.2. Testing the phase overcurrent relay.

6.2.1. Relay settings.

The phase overcurrent protection relay has the following settings in secondary values:

I>= 1,2 A
characteristic Normal Inverse (IEC “A”: Inverse, par. 4.1.1)
Time Multiplier (a) = 0,1

I>>= 5 A
characteristic Definite Time
Time Delay t = 100 ms

The relay settings are entered in secondary values. The associated primary values depend on the ratio of the main CTs connected to the relay.

The earth fault relay was not used in this application.

The relay settings have been entered manually from the local HMI into the relay with this procedure [4]:

Press 

push ones on plus, now you are in ”Protection Setting”

Press 

push plus or minus to change value then press 

.
Enter password if necessary (“++++” is the default password) then press “Enter” again until selected value comes up.

When I> value is set press 

again to to set “Characteristic” repeate above to select. If password is still valid only press “Enter” until selected choise comes up.

Repeate point 2 and 3 above to change the other parameters.

6.2.2. Connecting SVERKER 900 to WIP-1 relay.

SVERKER 900 is connected to the protection relay according to Figure 28, where the three phase currents and the operate (trip) contact are shown.

The operate contact is an auxiliary contact usually available in the terminal block of the protection cubicle, which “mirrors” the operate signal to the circuit breaker. The functionality of this last signal, connected instead to the trip coil of the circuit breaker, is tested with the self-check of the tripping circuit shown in Figure 27.

4.1 Connections

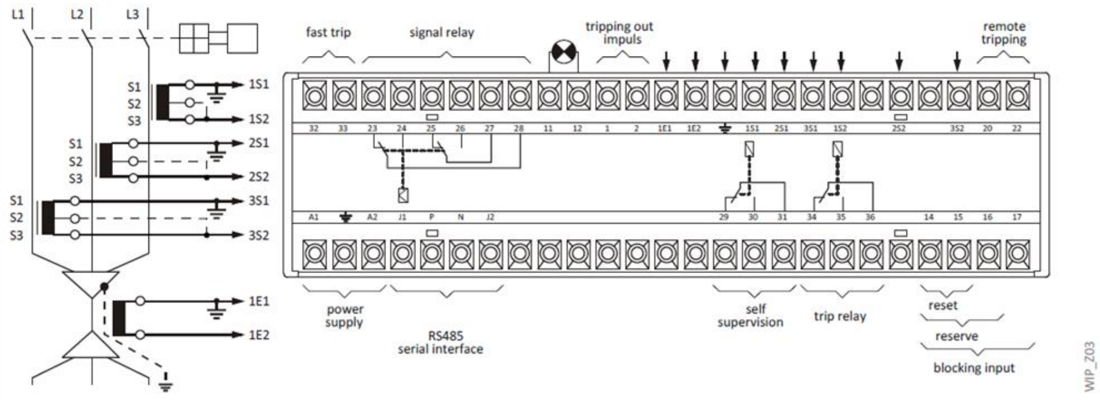


Figure 4.1: Connection example with relay tripping

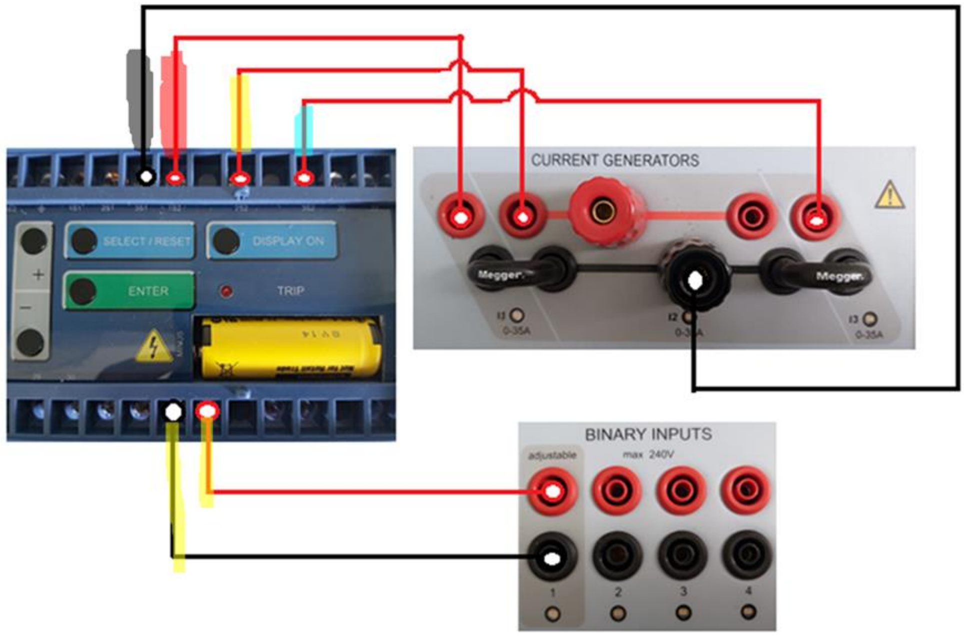


Figure 28. Schematic diagram representing the connections of the 3 current generators of SVERKER 900 to WIP-1 and the operate contact. Also the connection diagram of WIP-1 is shown (from the WIP-1 user's manual [4], Copyright SEG GmbH).

6.2.3. SVERKER 900 settings.

For testing the phase overcurrent protection function the instrument MTT [12] of pre-fault and fault and the possibility to draw graphs of time curves is used[13] [13].

Figure 29 shows an extract of the SVERKER 900 user's manual where the functionality of MTT in pre-fault and fault instrument is described.

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13 Note that not all SVERKER 900 are equipped with this functionality, please contact Megger for details.

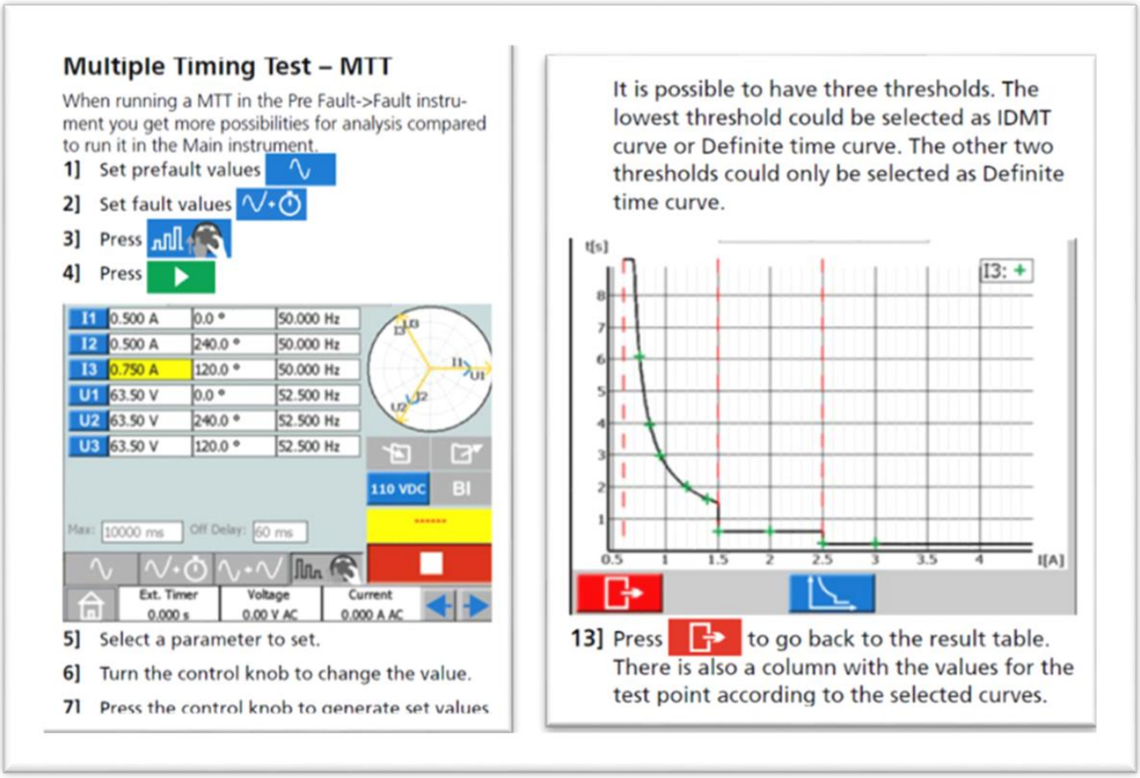


Figure 29. Short description of the functionality of MTT in pre-fault and fault instrument (from the SVERKER 900 user's manual [13], Copyright Megger).

In MTT the following major settings are necessary:

Pre-fault level:	0,5 A duration t = 1000 ms
First fault level:	1,5 A max duration t = 20 s (this timer could be increased if higher operate times may be measured, especially if the no-trip condition needs to be considered)
Binary Input (BI):	set to contact sensing no particular adjustments are necessary for the debounce time than can be kept as default. (in principle any of the 4 available BIs of SVERKER 900 could be used)

6.2.4. Testing the overcurrent protection function.

Considering the information in par. 6.2.3, set up the necessary conditions in SVERKER 900 and run the sequence of tests[14]. Each pre-fault and fault sequence is started by pressing the knob. Once the operate time is recorded by the SVERKER 900, just rotate the knob to change the fault level, and press it again to inject it. Until you have finished with the sequence of tests. Figure 30, Figure 31 and Figure 32 show the most important points. Also the tests for WIC-1 relay (par. 5.2.4) details about this procedure.

Also for WIP relay, please make sure you perform the non-trip test of the thresholds, i.e. foresee tests at 1 A for verifying the non-trip of I> and tests at 4,5 A to verify non-trip of (I>>). In this last case, of course there will be the trip from I>, reasonably higher than the time delay of I>>. See par. 4.1.3 for details.

Please keep in mind what said in par. 4.1.3 for the "no trip tests" and for the "distance" from the thresholds.

[14] *As no earth fault relay is activated, it is indifferent from the protection functionality point of view, if single-phase injections or three phase injections are executed. This document shows tests executed with single-phase injection, but it is possible of course to execute three-phase faults in order to avoid the activation of the earth fault.*

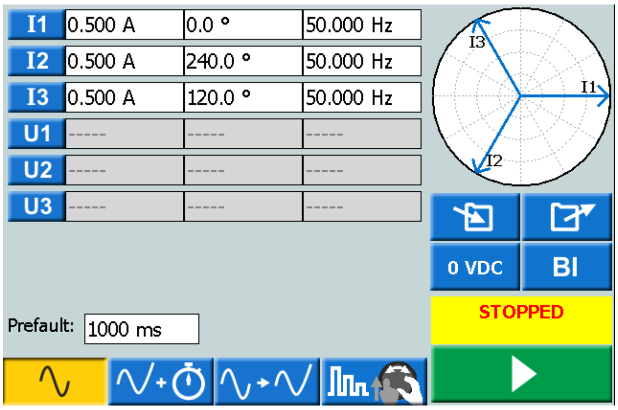


Figure 30. Pre-fault of 0,5 A for 1 second in MTT pre-fault and fault.

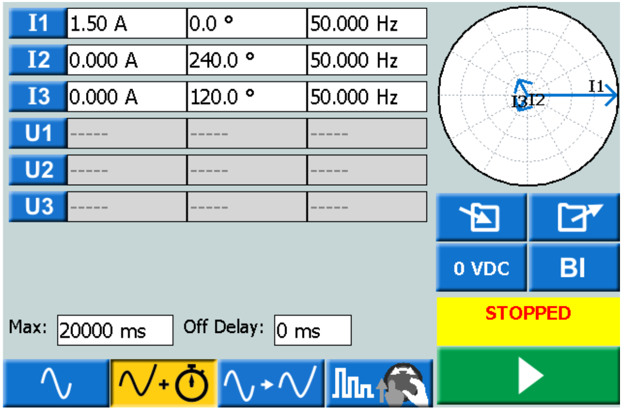


Figure 31. "First fault" of 1,5 A (timeout after 20 seconds) in MTT pre-fault and fault.

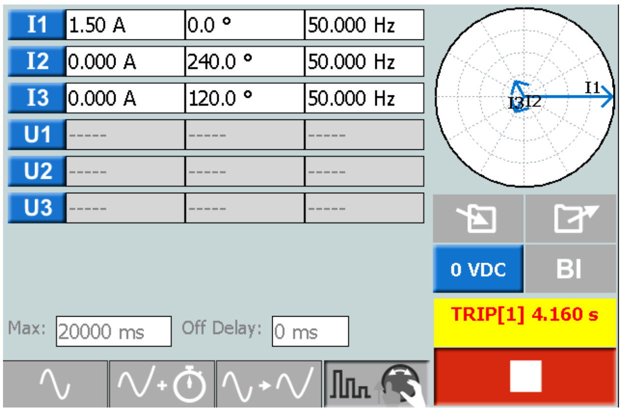
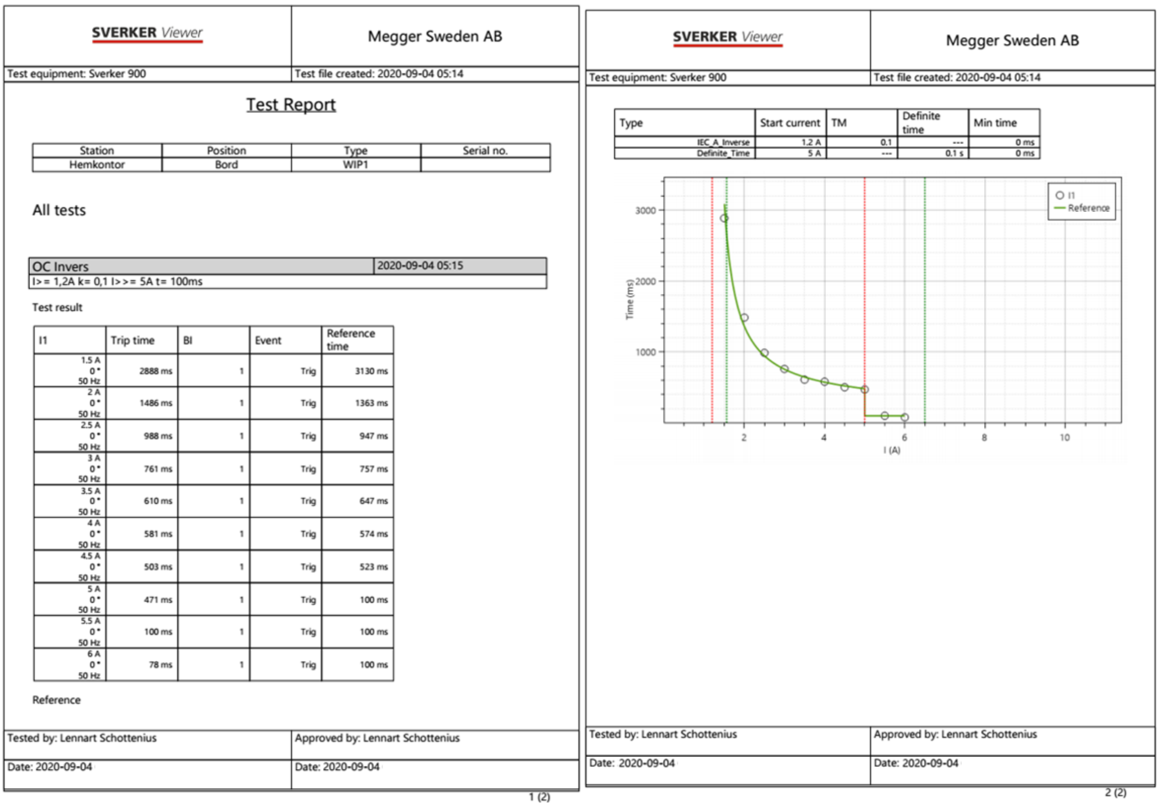


Figure 32. Activation (arming) of the MTT mode in pre-fault and fault. Press the knob to start the injection

To stop the sequence of tests, tap .

At this point follow the instructions in the SVERKER 900 manual to view the data, insert the time characteristic curves, save the file and view the report with SVERKER VIEWER.



SVERKER Viewer | Megger Sweden AB

Test equipment: Sverker 900 | Test file created: 2020-09-04 05:14

Test Report

Station	Position	Type	Serial no.
Hemkontor	Bord	WIP1	

All tests

OC Invers	2020-09-04 05:15
I>= 1,2A k= 0,1 I>>= 5A t= 100ms	

Test result

I1	Trip time	BI	Event	Reference time
1.5 A 0 ° 50 Hz	2888 ms	1	Trig	3130 ms
2 A 0 ° 50 Hz	1486 ms	1	Trig	1363 ms
2.5 A 0 ° 50 Hz	988 ms	1	Trig	947 ms
3 A 0 ° 50 Hz	761 ms	1	Trig	757 ms
3.5 A 0 ° 50 Hz	610 ms	1	Trig	647 ms
4 A 0 ° 50 Hz	581 ms	1	Trig	574 ms
4.5 A 0 ° 50 Hz	503 ms	1	Trig	523 ms
5 A 0 ° 50 Hz	471 ms	1	Trig	100 ms
5.5 A 0 ° 50 Hz	100 ms	1	Trig	100 ms
6 A 0 ° 50 Hz	78 ms	1	Trig	100 ms

Reference

Tested by: Lennart Schottenius | Approved by: Lennart Schottenius

Date: 2020-09-04 | Date: 2020-09-04

1 (2)

SVERKER Viewer | Megger Sweden AB

Test equipment: Sverker 900 | Test file created: 2020-09-04 05:14

Type	Start current	TM	Definite time	Min time
IEC_A_Inverse	1.2 A	0.1	---	0 ms
Definite_Time	5 A	---	0.1 s	0 ms

Tested by: Lennart Schottenius | Approved by: Lennart Schottenius

Date: 2020-09-04 | Date: 2020-09-04

2 (2)

Figure 33. Result for the time characteristic of the two-stage phase overcurrent protection, from SVERKER Viewer. The green lines represent values at 1,3 times the threshold, suitable for having the indication of representative values for the operate time (see par. 4.1.3). Clearly it was not necessary to run tests above the 1,3 values for I>> (definite time). For inverse time curves, it is a very good hint to follow this rule.

6.3. Testing the tripping circuits of WIP-1 (self-test).

The procedure of “testing the tripping circuits” for WIP-1 is described in the relay manual [4] and shortly shown in Figure 27.

First WIP-1 relay must be prepared for this, by the procedure indicated in Figure 27. Once the relay is prepared, the user has 30 seconds to manage a current injection of 1A in phase L1. If this time elapses without that the injection has occurred, the procedure must be started again from the relay HMI.

Before preparing the relay for this test, prepare the SVERKER 900 connections and the test sequence. For this test, the Sequencer instrument will be used in SVERKER 900.

SVERKER 900 current generators should be connected in **parallel mode**[15].

A particular 3-step test sequence is necessary to manage this test:

1) STEP 1: Injection of 1A in L1, for 190 ms (Figure 34)
2) STEP 2: No injection for 40 ms (Figure 35)
3) STEP 3: Injection of 1A in L1, for 30 s (Figure 36).

During the third step, the WIP-1 relay will start its own self-testing procedure. Several contacts will click several times and if everything is all right, the WIP-1 will inform that the test has been performed.

15 The activation of this test may also succeed when current generations are set in individual mode, but due to tolerances and high non-linearity of the load offered by WIP-1 relay when this mode is activated, we suggest to use the parallel mode connection

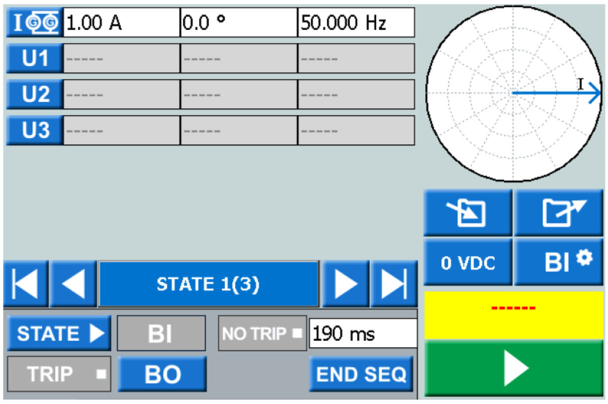


Figure 34. First step of the sequence. Injection of 1 A in phase L1 for 190 ms.

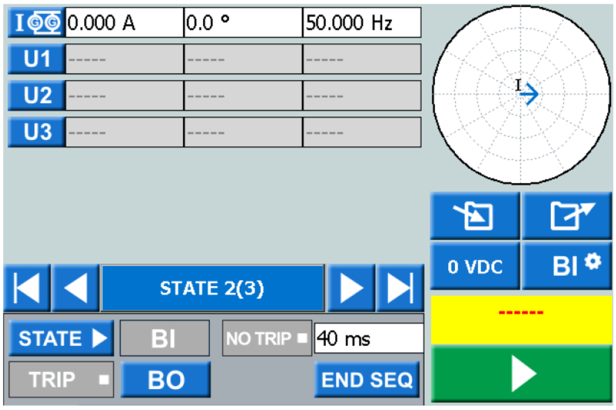


Figure 35. Second step of the sequence. No injection (injection of 0 A in phase L1) for 40 ms.

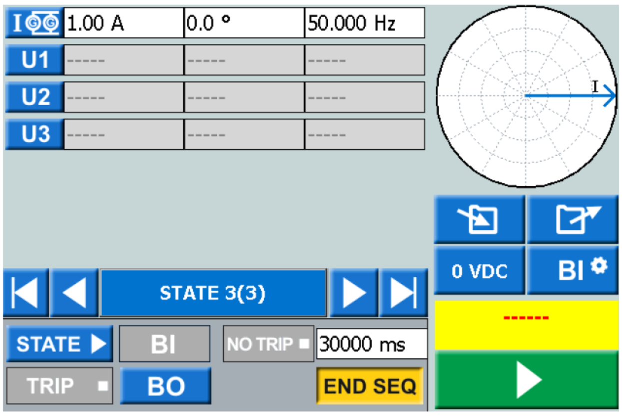


Figure 36. Third step of the sequence. Injection of 1 A in phase L1 for 30 seconds; period long enough to let WIP-1 relay perform the self-test procedure and press the button on its HMI as requested at the end of the test.

At the end you need to press the “SELECT” button on relay HMI to acknowledge that the test is terminated (just follow the instructions that the relay proposes through its screen).

A simple video clip [14] shows the self-testing procedure in WIP-1 relay activated when this sequence is run. In the video clip, the injection is done without current generators in parallel, but it is anyhow suggested to perform this with the parallel connection in SVERKER 900.

6.4. Testing the protection function without pre-fault (switch onto fault).

As mentioned in 3.2, there is a difference in the relay performance when the power system fault occurs after a situation with a certain pre-fault (load) level, or without it. As also mentioned, this condition can be connected to

the "switch onto fault" situation, but it may happen when the circuit breaker is closed on an energized but unloaded feeder.
This test aims to compare the operate time of the relay in two conditions:

1) Pre-fault of 500 mA present for 1 second, fault current of 8 A (above I>> threshold of 5A)

2) No pre-fault, fault current of 8 A (above I>> threshold of 5A)

It is enough to run 5 tests[16] with the pre-fault current of 0,5 A (Figure 37) to get an idea of the operate time, then set the pre-fault current to 0 A and run 5 tests again (Figure 38).
For repeating the tests, MTT in pre-fault and fault instrument has been used. Different approaches are of course possible.

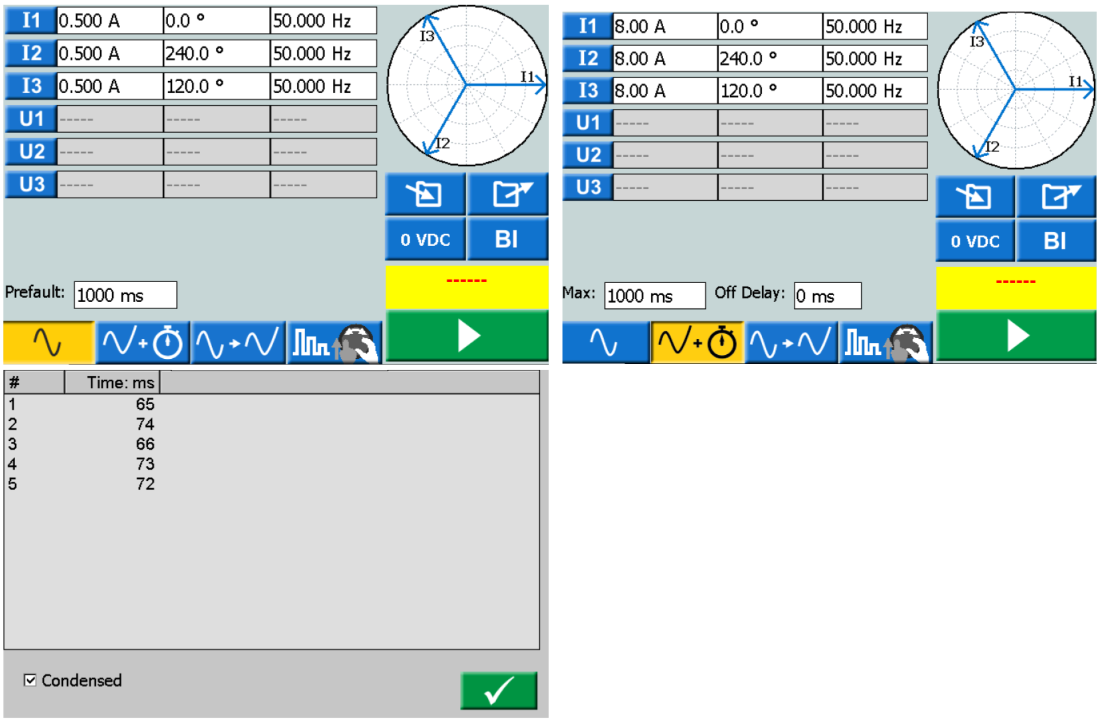


Figure 37. MTT Pre-fault and fault sequence for the presence of load before the fault and test results.

16 "One shot is not enough". Repeating the tests 5 times, gives an idea of the spread of the values, and helps to be comfortable with the test results. We are evaluating the operate time! Note that we have not repeated the tests for the inverse characteristics, as many shots are anyway generated. However, it could have been easily done, and we would have seen a sort of distribution of time measurements around the mean value, probably near the theoretical value. In case of doubts, use the statistical approach, especially if you need to report some doubtful performances.

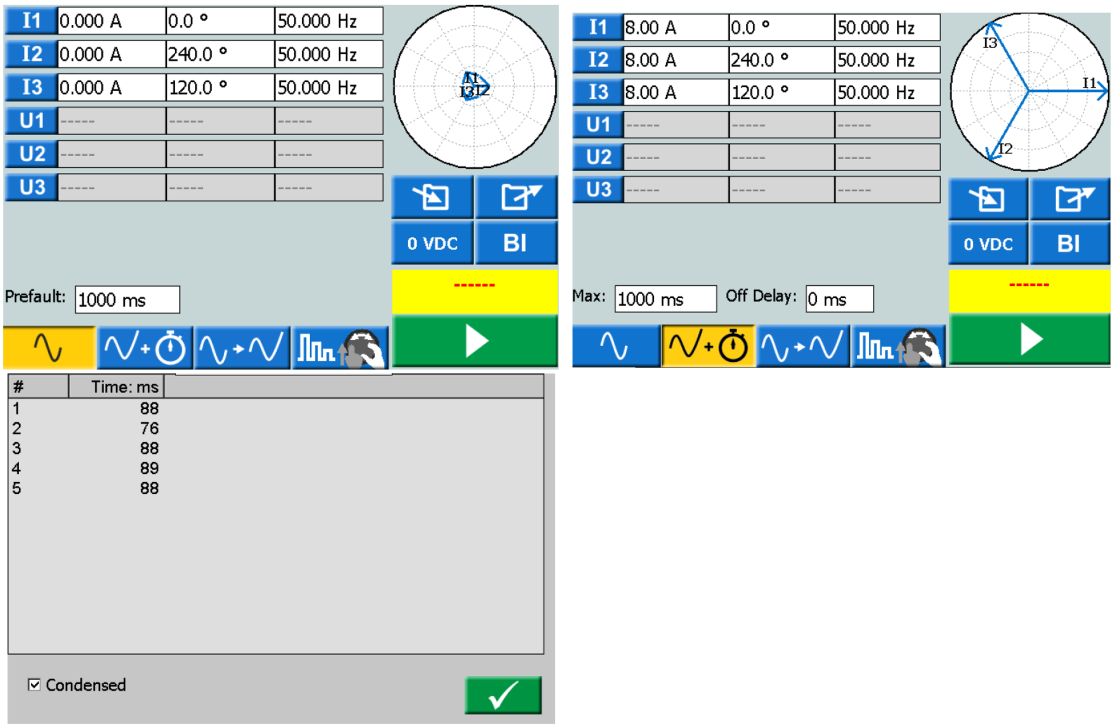


Figure 38.MTT Pre-fault and fault sequence for simulation of no presence of load before the fault (switch onto fault) and test results.

Table below summarizes the test results:

Test Nr.	WIP-1 Operate Time pre-fault 500 mA / 1 s Fault 8 A	WIP-1 Operate Time NO pre-fault Fault 8 A
1	65 ms	88 ms
2	74 ms	76 ms
3	66 ms	88 ms
4	73 ms	89 ms
5	72 ms	88 ms
AVERAGE	**70 ms**	**86 ms**

We can conclude that the additional time required by WIP-1 to start-up is (some 10 … 20 ms) is negligible compared to the operate time when the load current is available before the fault.

Switch onto fault condition (or fault in unloaded feeders) does not create any noticeable extra time delay in the relay operation.

7. Acknowledgment

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9. Revisions.

9.1. Revision 1.

This is the first revision of the Technical Guide.

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