APPLICATION NOTE

Testing ROCOF with SVERKER 900

applying the new

IEC 60255-181 standard

Megger Sweden AB, Danderyd, Sweden

T: +46 8 510 195 00 **E:** seinfo@megger.com

Technical support: support.sweden@megger.com

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Introduction

Rate Of Change Of Frequency (ROCOF) protection is used in distributed or embedded generation schemes, where a local generator is connected directly to the distribution network, as specified in national standards such as ANSI 81R or G59/3.

Since February 2019, there is a new relay protection standard from IEC: IEC 60255-181, specifying relay performances and test methodologies of Frequency and ROCOF relays (see figure below, from IEC website).

The IEC 60255-181 standard was created with special attention to new protection requirement for the smart grid.

Figure: The new IEC 60255-181 standard for frequency and ROCOF protections

IEC 60255-181

Edition 1.0 2019-02

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

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MEASURING RELAYS AND PROTECTION EQUIPMENT –

Part 181: Functional requirements for frequency protection

1 Scope

This part of IEC 60255 specifies the minimum requirements for functional and performance evaluation of frequency protection. This document also defines how to document and publish performance test results.

This document covers the functions based on frequency measurement or rate of change of frequency measurements. This document also covers frequency protection where additional blocking elements are used.

This document defines the influencing factors that affect the accuracy under steady state conditions and performance characteristics during dynamic conditions. The test methodologies for verifying performance characteristics and accuracy are also included in this document.

The frequency functions covered by this document are shown in Table 1:

Table 1 – Frequency protection designation

	IEEE/ANSI C37.2 function numbers	IEC 61850-7-4 logical nodes
Underfrequency protection	81U	PTUF
Overfrequency protection	81O	PTOF
Rate of change of frequency protection (ROCOF)	81R	PFRC

This functional document is applicable to frequency functions embedded in a protection relay but also to other physical devices which include frequency protection in their functionality (for example, trip units in a low-voltage circuit breaker or inverters associated with photovoltaic or storage systems).

The role of the ROCOF protection function is to detect power supply failures and to isolate the generator in the event of a loss of supply. If the power flow from the utility supply prior to an islanding generator is not zero, the frequency changes to the islanded systems natural resonance frequency islanding can be dangerous to utility workers, who may not realize that a circuit is still powered, and it may prevent automatic re-connection of devices. For that reason, distributed generators must detect islanding and immediately stop producing power.

ROCOF protection is quicker to detect frequency changes than conventional frequency protection functions.

SVERKER 900 and IEC 60255-181 standard

With SVERKER 900 it is possible to test the ROCOF protection according to IEC 60255-181 standard, interpreted for commissioning and maintenance tests, by using the Ramping Instrument (see section 4.5 in the SVERKER 900 User's manual).

IEC 60255-181 requires a special method (a special waveform) for the frequency ramp to be used for testing ROCOF protection. This ramp shall follow a special mathematical formula. No other method is allowed, as the definition of the mathematical formula is in a mandatory annex of the Standard (Annex A, normative, “Test signal equation with constant frequency variation (df/dt)”) see figure below, from IEC 60255-181.

Figure: The mandatory equation according to IEC 60255-181 for the formula generating the frequency changing signal (frequency ramp)

IEC 60255-181 © IEC 2018 – 71 –

Annex A
(normative)

Test signal equation with constant frequency variation (*df/dt*)

The equation for the signals used to perform the test of frequency and ROCOF functions with a constant variation of the frequency is specified below.

$$G(t) = \mathrm{Amp} \times \sin\left(2\pi\left(f_0 + \frac{f\_\mathrm{slope}}{2}(t - t_0)\right)(t - t_0) + \varphi_0\right)$$

where

Amp	is the peak amplitude of the input energizing quantity/quantities (for example, phase voltage);
f_0	is the initial frequency (for example, nominal frequency, before the frequency change);
*f*_slope	is the frequency slope in Hz/s used for the test;
φ_0	is the initial phase (used for the test with three-phase voltage injection);
t_0	is the beginning of the frequency variation.

The concept of using a standardized waveform for assessing ROCOF protection is of fundamental importance, because many unwanted operations of ROCOF relays in service, have been caused by misunderstandings and/or lack of common understanding on how the waveform for the frequency ramp was supposed to look like[1].

SVERKER 900 is designed to provide the standardized IEC waveform in real time. The standardized waveform has a frequency that changes at any instant. It is also called “smooth frequency changing curve”. Figures below should help in understanding this concept.

[1] *Testing with a frequency ramp where for example the frequency of the voltage signal changes of 0,04 Hz every 20 ms (which would means 0,04 Hz / 20 ms = 2 Hz/s) may not give the same results as testing the same ROCOF relay with the standardized ramp at 2 Hz/s, where the frequency changes* ***continuously*** *at any time instant and not discretely at predefined steps, no matter how shorts the steps can be.*

Figure: The standardized "smooth frequency ramp" is a waveform where the frequency changes at any instant

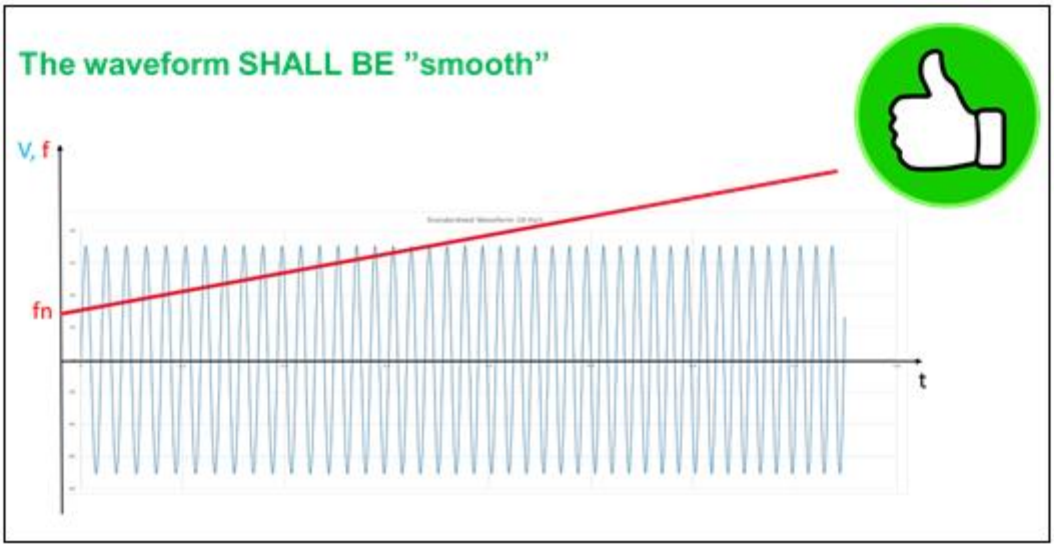
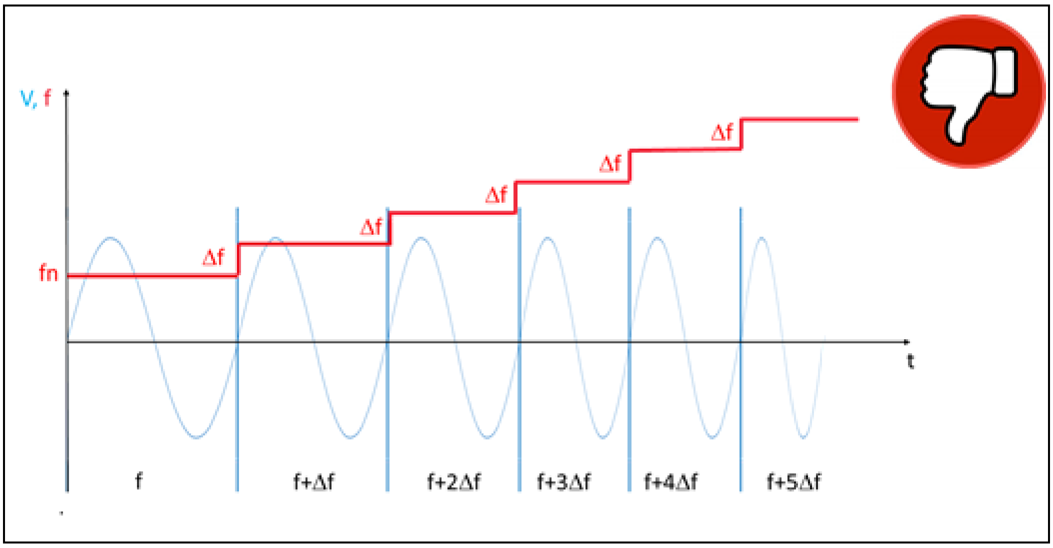


Figure: Creating the frequency ramp with "pieces" of waveforms at different frequencies is not allowed.



ROCOF Relay Settings

If no selective plan is made always use the settings recommended by the manufacturer. Settings are dependent on the power generator used and are very often calculated based on power system studies.

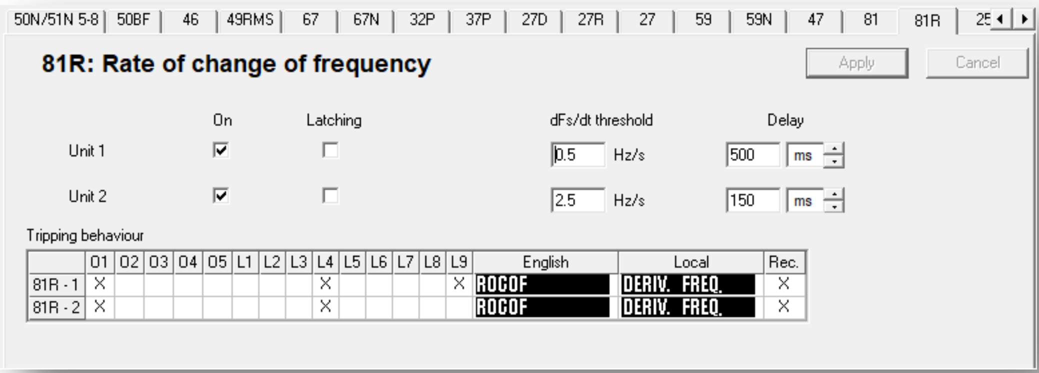
Below is one example of settings for power generators 2-10 MVA and over 10 MVA

Generator power	2 to 10 MVA	>10 MVA
ROCOF Settings, Low Stage		
df/dt threshold	+ 0,5 Hz/s	+ 0,2 Hz/s
Operate Time, Definite Time delay	500 ms	500 ms
ROCOF Settings, High Stage		
df/dt threshold	+ 2,5 Hz/s	+ 1,0 Hz/s
Operate Time, Definite Time delay	150 ms	150 ms

In this example the ROCOF protection (Sepam S84) is set for generators from 2 to 10 MVA.

As ROCOF activates at positive frequency derivative, this is called by IEC 60255-181, a positive ROCOF protection function.

Figure: ROCOF relay settings for high stage and low stage



The low stage (Unit 1) is set to 0.5 Hz/s with definite time delay of 500 ms

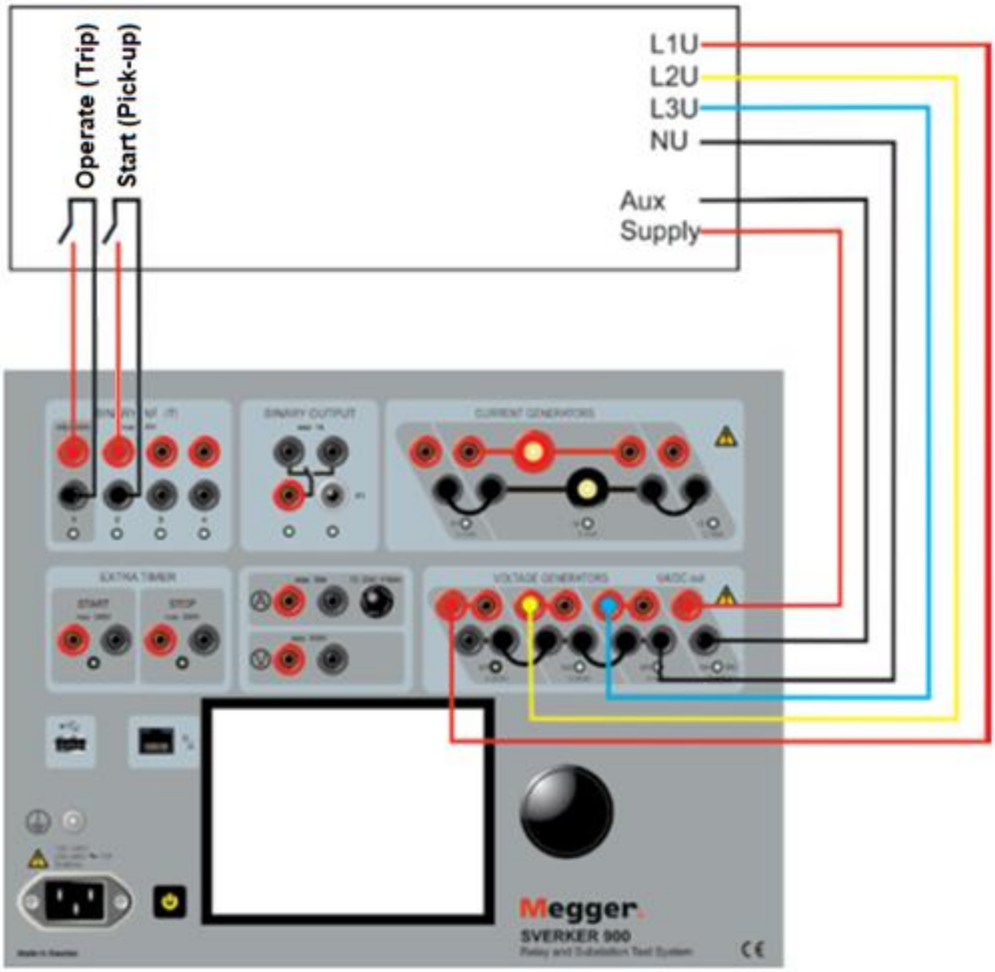
The high stage (Unit 2) is set to 2.5 Hz/s with definite time delay of 150 ms.

Test of low ROCOF stage with ramping instrument

Connecting SVERKER 900 to the ROCOF relay

Connect the SVERKER 900 according to the figure below, using the aux supply to power the relay, if needed.
Select the binary inputs for operate (trip)[2] and start (pick-up) signals, (see the section on "Binary Inputs" in the SVERKER 900 user's manual).

Figure: connection of the ROCOF relay to SVERKER 900



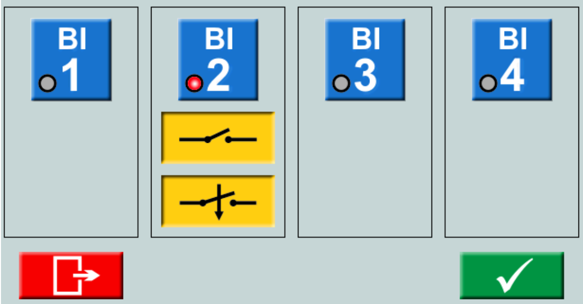
[2] According to IEC, the "trip" signal is called "operate" signal. The "pick-up" signal is called "start" signal. In this document we will try to use both names. Keep in mind that "operating" signal is wrong. The relay has an "operate time" (and not an "operating time"). ANSI/IEEE practice is more comfortable with the name "trip time". So, "trip time" and "operate time" are the same thing. "Operating time" is instead related to a circuit breaker and should not be used in relay context.

Testing the start level (pick-up level) for the low stage

Binary input trigger

For the following tests the ramp generated by SVERKER 900 is stopped by the start contact of the first stage of the ROCOF relay, connected to BI2. The trip contact is disabled (which is connected to BI1). See the next tests for the high stage if the start signal is not available.

Figure: BI settings for SVERKER 900. Reaction on START signal

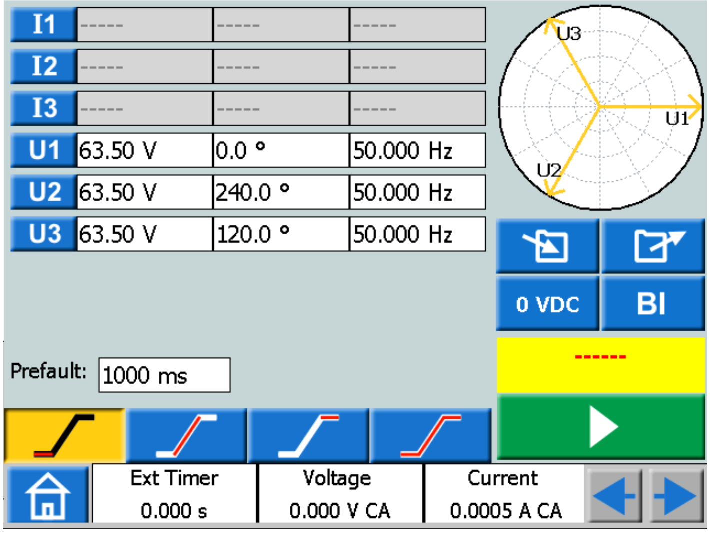


Start criteria

Set the start criteria according to system voltage, frequency and phase rotation. According to IEC 60255-181, the frequency ramp shall always start at the nominal power system frequency (50 Hz or 60 Hz). Obviously, the voltage level will be the nominal voltage level.

In the example below a pre-fault time is set before moving to the ramp (faulty) state. The pre-fault time can be easily set to one second[3].

Figure: pre-fault values for the test

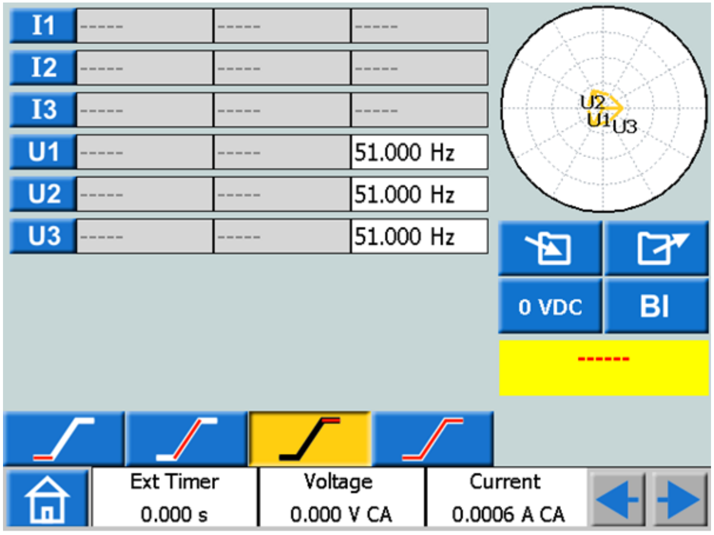


[3] *If in doubt, have a pre-fault time of 5 seconds. There is so far no protection relay that has not managed to be in steady conditions in measuring the frequency within 5 seconds.*

Stop criteria

We will use the stop criteria to make sure that the frequency ramp will be some 2 seconds long.

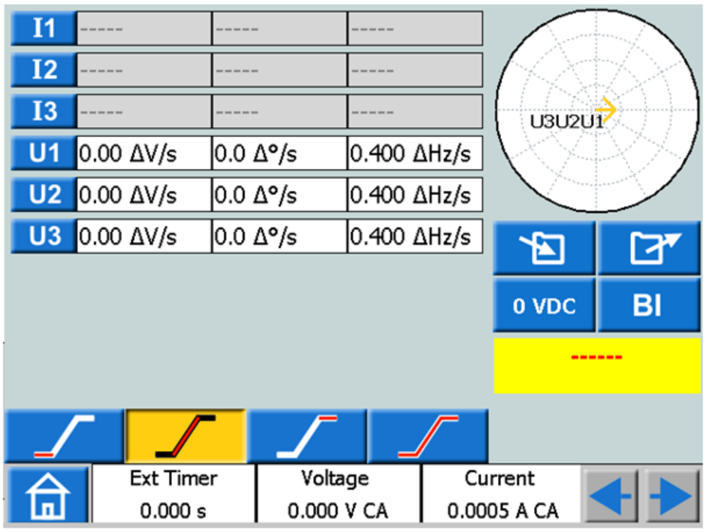
Figure: final value of the frequency ramp



No-Start test for the low stage (0,5 Hz/s)

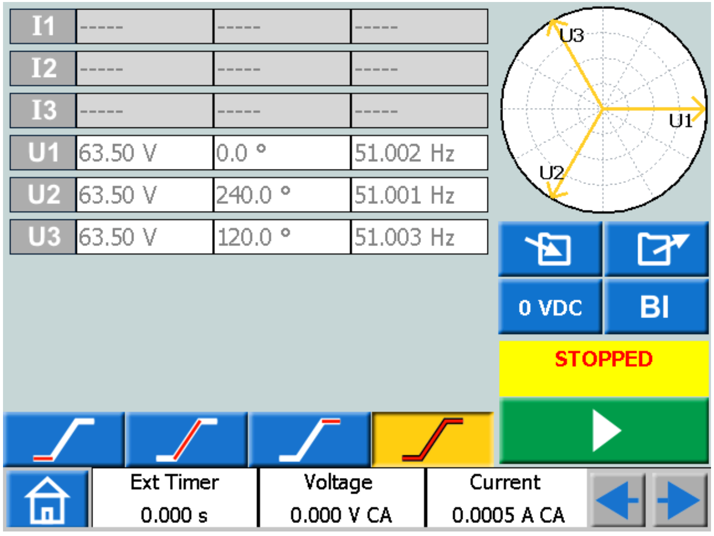
According to the relay manual, the relay tolerance for ROCOF is 0,1 Hz/s. The frequency ramp for this test will be set below the relay tolerance to 0,4 Hz/s (= 0,5 Hz/s - 0,1 Hz/s).

Figure: Ramp speed of 0,4Hz/s



In our case, there was no start within the full ramp, so the test is clearly passed: the relay did not start for the ramp of 0,4 Hz/s[4].

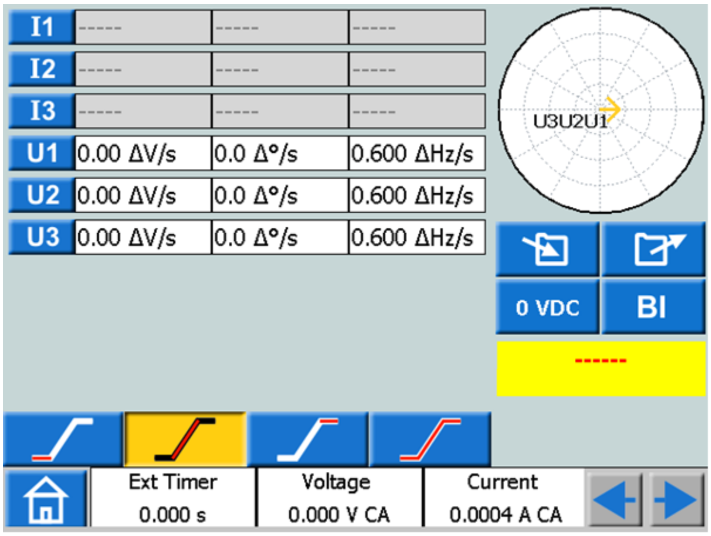
Figure: End value reached. No-start from ROCOF relay detected.



Start test for the low stage (0,5 Hz/s)

The frequency ramp for this test will be set above the relay tolerance, to 0,6 Hz/s (= 0,5 Hz/s + 0,1 Hz/s).

Figure: Ramp speed 0,6Hz/s



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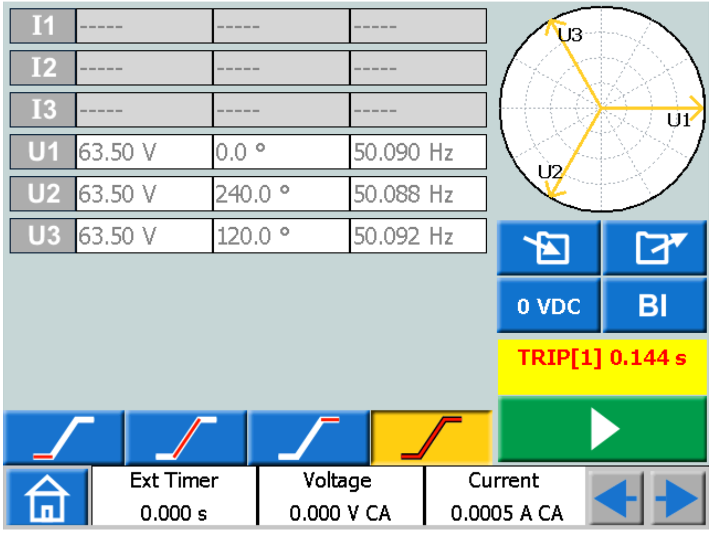
[4] If the start activation will be detected within less than one second (see the measurement from SVERKER 900), the start will be considered a “valid start”. If it will be detected within more than one second, it will not be considered a valid start. Note that this is a very precise consideration, according to IEC 60255-181; there is no need to be so precise for commissioning/maintenance, but in case of disagreement, it is good to be able to be precise. In our case the relay did not start for all the length of the frequency ramp, which is longer than one second.

The relay started in 144 ms, which means that the test is passed[5].

Figure: Time at the start operation of ROCOF

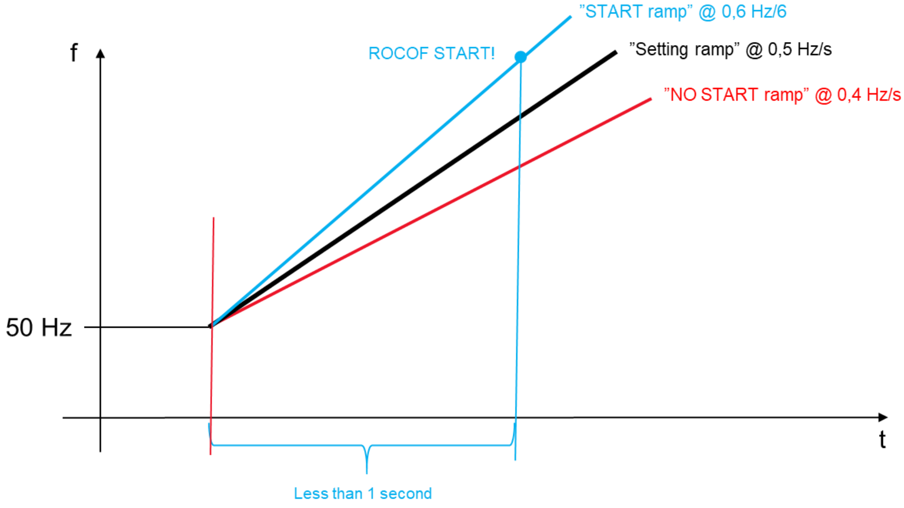


[5] *The IEC 60255-181 standard defines the period of time within the protection relay has the possibility to pick-up (to activate the start signal) to be the maximum value between 1 second and 1,5 times the typical start time of the ROCOF relay, which is in the order of magnitude of 100 ms, so 1 second can be easily used.*
This means that if start activation is detected within less than one second, the start will be considered a valid start. If it will be detected after more than one second, it will not be considered a valid start. In our case, the start was detected within 500 ms (actually in 144 ms), so this test is passed: the relay started for the ramp of 0,6 Hz/s.
There is no need to be so precise for commissioning/maintenance tests, but in case of disagreement in judging the results, it is good to know how things are.

Comments

The relay start threshold (pick-up level) has been tested. This test is considered enough for commissioning/maintenance purposes, where the EXACT level of the start border is not searched.

Figure: No-START and START checks for assessing the ROCOF threshold



It is enough to test a little below the tolerance (no-start test) and a little above the tolerance (start test). In this example we have tested at exact the tolerance levels. It is suggested to test a little bit away of them, for example 10% away, to avoid insignificant discussions. In case of doubts, always try to agree with the plant owner about the tolerance to be used for the test.

Remember that testing relays exactly "on the borders" is in general never recommended. There is no IEC standard defining how to test for commissioning / maintenance; this application note is written with competence on IEC 60255-181, reasonably interpreted for commissioning/maintenance tests.

Testing the operate time (trip time) for the low stage

Binary input trigger

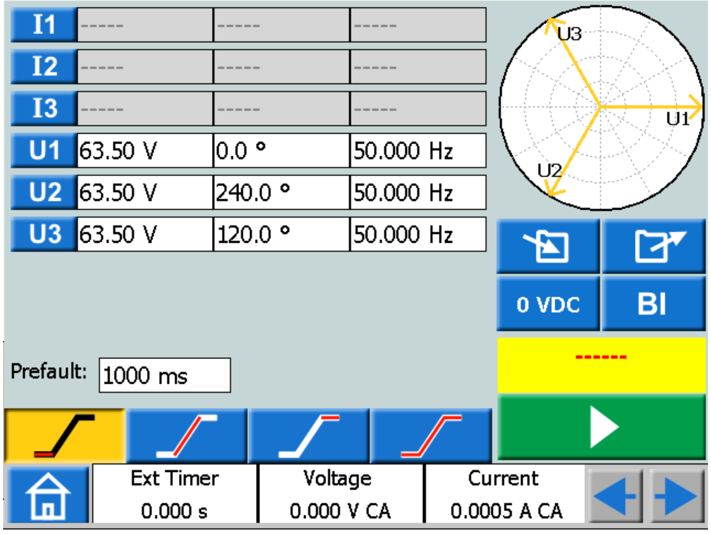
For testing the operate (trip) time, it is necessary to stop the SVERKER 900 with the trip contact from the relay, which is connected to binary input one of the SVERKER 900.

Figure: BI settings for SVERKER 900. Reaction on operate (trip) signal

Start criteria

According to IEC 60255-181, the frequency ramp shall always start at the nominal power system frequency (50 Hz or 60 Hz). Obviously, the voltage level will be the nominal voltage level.

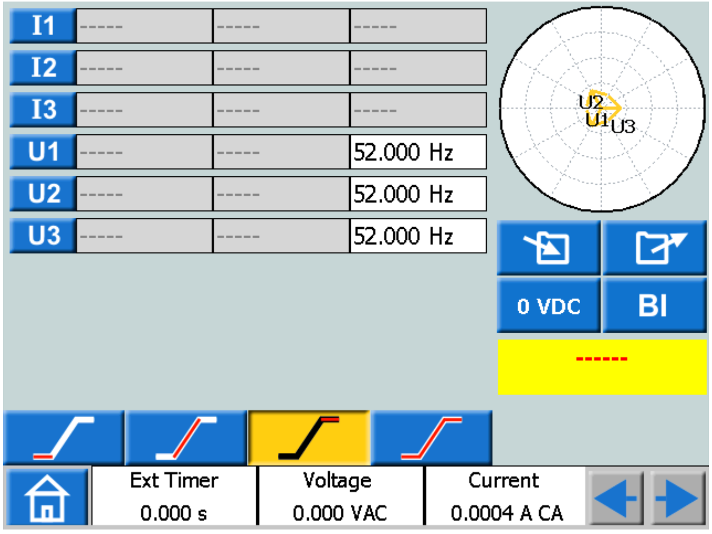
Figure: pre-fault values for the test



Stop criteria

The frequency ramp will be set to 1 Hz/s (see next paragraph) so starting at 50 Hz and ending at 52 Hz, will generate a 2 seconds ramp. The expected operate time is approximately 500 ms, so the ramp is long enough.

Figure: final value of the frequency ramp



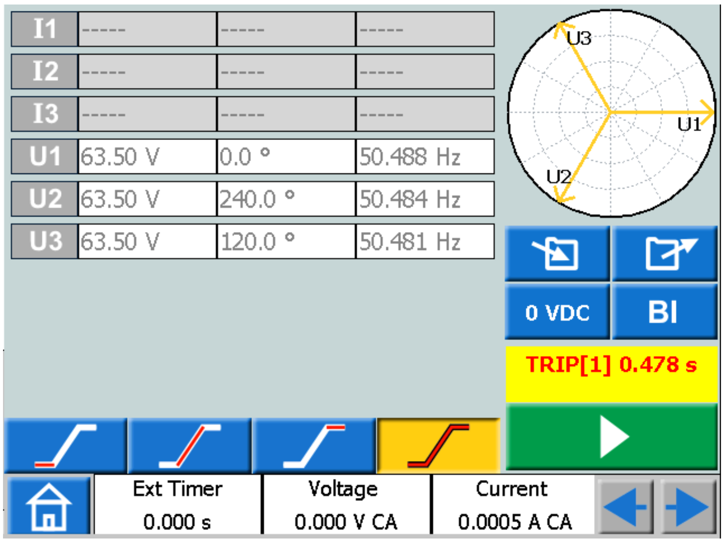
Operate (trip) time test for the low stage (0,5 Hz/s)

The frequency ramp for this test will be set at two times the relay setting: 1,0 Hz/s (=2 x 0,5 Hz/s).

The operate time (trip time) is measured by the SVERKER 900 as shown in the figure below:

The relay operate time was 478 ms, as it can be seen in the below figure.

Figure: measured operate time for the low stage



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Comments and questions

The IEC 60255-181 standard requires the tests of the operate time of ROCOF relays at 1,2, 2,0, 5,0 and 10 times the relay setting. For maintenance / commissioning tests it is reasonable to use the value at 2 times the relay setting, which is what we have done.

In case of doubts, the test should be repeated some 5 or 10 times and an average value of the results could be given.

The relay was set to 500 ms operate time, and the SVERKER 900 has measured 478 ms. Is this time correct or not?

According to the manual the ROCOF function has an accuracy in the operate time of +/- 2% OR +/- 25 ms. We measured an operate time within 25 ms from the setting (500 ms), and this is Ok.

Please note that he tests have been executed with the standardized frequency ramp according to IEC 60255-181. The manual of the relay does not state the test method that was used to assess the relay performance, as the relay was designed before the standard was published. It is always recommended to provide this information in your test report, to avoid misunderstandings.

Another question is:
How can the relay trip faster than the setting?

In general, high voltage relays see the time delay setting as an additional time delay.

The relay starts the timer when the fault is detected (in this example when the frequency derivative is higher than 0,5 Hz/s), and when the timer elapses, if the fault is still detected, the operate (trip) signal is activated.

The operate time of the relay is the start time (the relay needs time to detect that the fault has actually started) PLUS the additional settable time delay (which would be 500 ms in this case). This means that the expected trip time will never be below the time setting of 500 ms.

The Schneider relay used for this example (Sepam S84), is a medium voltage relay. Traditionally, medium voltage relays tend to compensate the time setting for the average start time of the relay.

If the average start time of the relay is, let’s say, 100 ms, and the user enters a time delay of 500 ms, the actual setting for that timer would be 400 ms (= 500 ms – 100 ms).

If the relay starts faster than the average value, the total trip time will be less than the setting, if the relay starts with a time higher than the average (fault very close to the border, for instance), the total operate time will be higher than the setting.

What has happened here is that the relay started probably faster than its average (typical) start time.

According to IEC 60255-181 standards, relay manufacturers shall inform the user about the functioning principle adopted for the timers. If there is an internal compensation, the manufacturer shall declare its value. This was done to minimize misunderstandings

Test of the high ROCOF stage with ramping instrument.

If a separate contact for the start and trip of the high stage is available, the tests would be done in the same way they have been done for the low stage.

Normally this is not the case, and only the trip signal is –unfortunately- available. The trip signal is often a cumulative trip signal between the operation of the high stage with the low stage. Sometimes the two stages provide separated trip signals for each stage.

It is anyway possible to discriminate the start and trip of each stage by the measured operate time, if the time difference between the two stages is large enough.

One frequency ramp will be done right below the protection function tolerance (0,1 Hz/s) of the high stage. This means at 2,5 Hz/s – 0,1 Hz/s = 2,4 Hz/s.

Under this ramp, the high stage is not expected to start, but the low stage will start of course. So the measured operate time will be the time of the low stage (approx. 500 ms).

Then a ramp at 2,5 Hz/s + 0,1 Hz/s = 2,6 Hz/s will be generated. In this case the high stage is expected to start and trip.

Note that the operate time could be higher than expected (approx.. 150 ms) as the ramp is very close to the border of 2,5 Hz/s (in reality the operate time will be higher because the start time will be higher).

Hopefully the high stage will manage to operate in less than 500 ms, otherwise it will be confused with the operate time of the low stage, that also will start and trip for that ramp (eventually, get help from the relay event recorder to make sure that really the high stage started and operated, and not the low stage one).

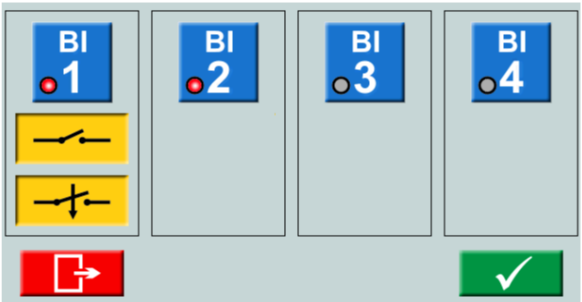
The above description was for testing the starting level of the high stage of ROCOF, by using an indirect information from the operate (trip) contact instead of using the direct information from the start contact.

For testing the operate time, it is necessary to run a frequency ramp at two times the setting value: 2 x 2,5 Hz/s = 5,0 Hz/s. This will give a reasonable value for the operate time as the ramp is “enough far away from the border” or “the injected fault is well inside the trip zone”, and 2 times the setting is also one of the test conditions described by the IEC 60255-181.

Binary input trigger

As only the operate (trip) signal is available, the SVERKER 900 binary input 1 is connected to the relay with only that signal, and binary input 1 is used to stop the test.

Figure: BI settings for SVERKER 900. Reaction on OPERATE signal



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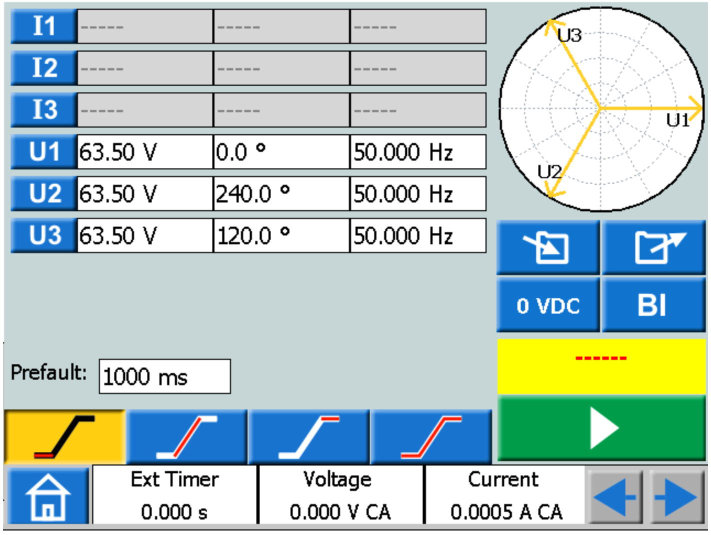
Start criteria

According to IEC 60255-181, the frequency ramp shall always start at the nominal power system frequency (50 Hz or 60 Hz). Obviously, the voltage level will be the nominal voltage level. A pre-fault time of one second[6] is set before moving to the ramp (faulty) state.

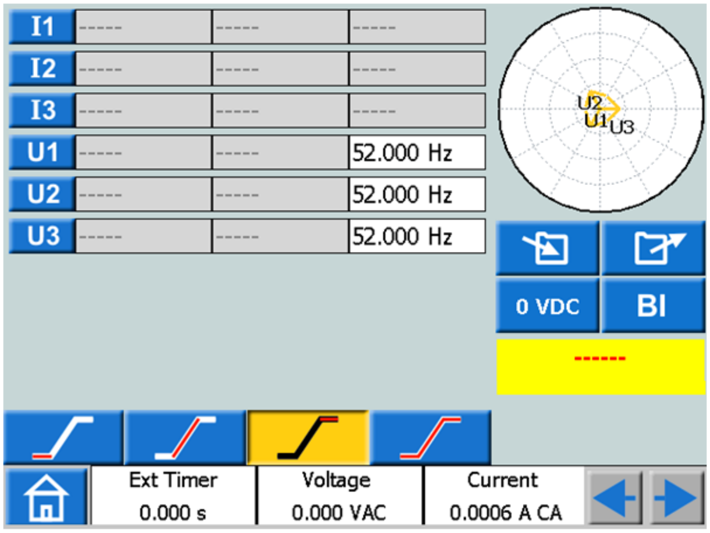
Figure: pre-fault values for the test



Stop criteria

The generated frequency ramps will be around 2,5 Hz/s (2,4 Hz/s and 2,6 Hz/s), so stopping at 52 Hz will give a ramp of approx.. 0,8 seconds. This duration should be enough to get the longest trip signal of approx. 500 ms.

Figure: final value of the frequency ramp



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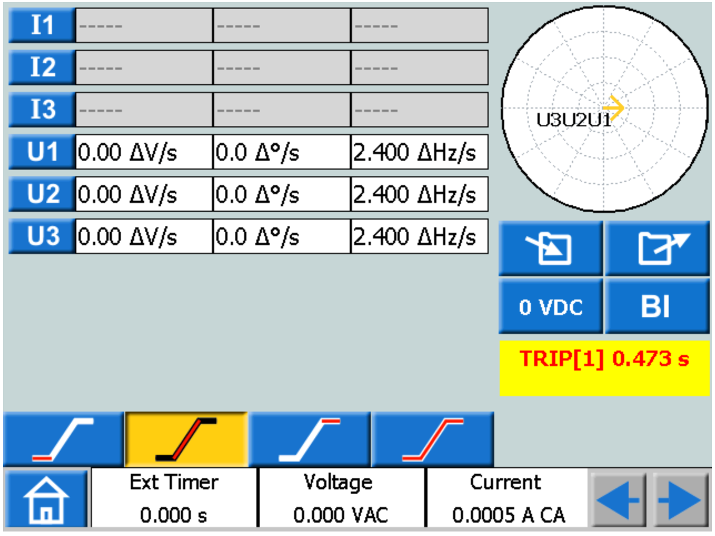
[6] *If in doubt, have a pre-fault time of 5 seconds. There is so far no protection relay that has not managed to be in steady condition in measuring the frequency within 5 seconds.*

No-Start test for the high stage (2,5 Hz/s)

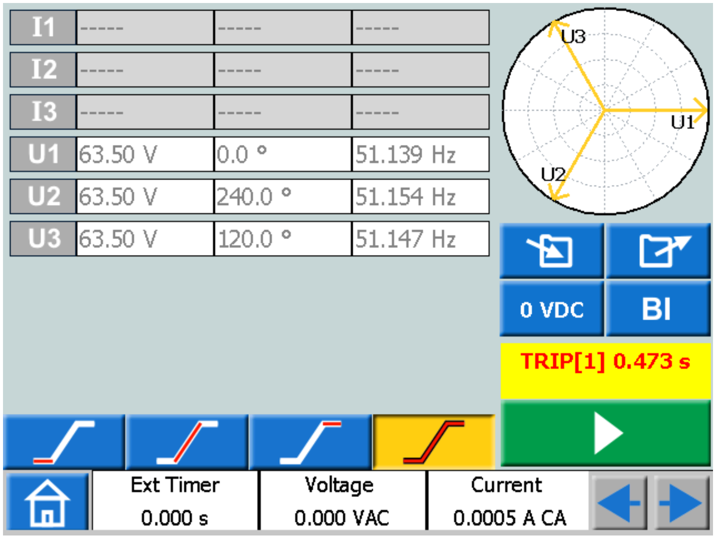
According to the relay manual, the relay tolerance is 0,1 Hz/s. The frequency ramp for this test will be 2,4 Hz/s (= 2,5 Hz/s - 0,1 Hz/s).

Figure: Ramp speed 2,4Hz/s



The generation of SVERKER 900 is stopped with the operate (trip) signal. If the relay will trip in approx. 500 ms, this will be a sign that the high stage did not start, which is expected. As it can be seen, there is a relay trip at approximately 500 ms (473 ms), so it is the low stage. This part of the test is passed.

Figure: measured operate time: it is the Low Stage!



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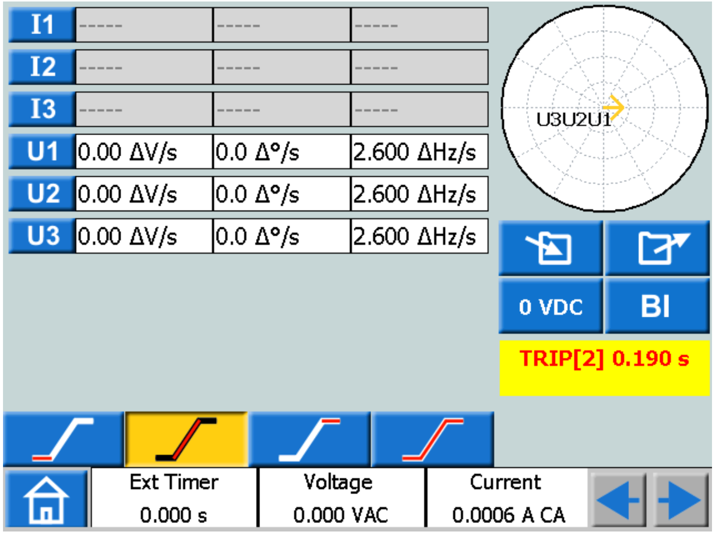
Start test for the high stage (2,5 Hz/s)

The frequency ramp for this test will be 2,6 Hz/s (= 2,5 Hz/s + 0,1 Hz/s).

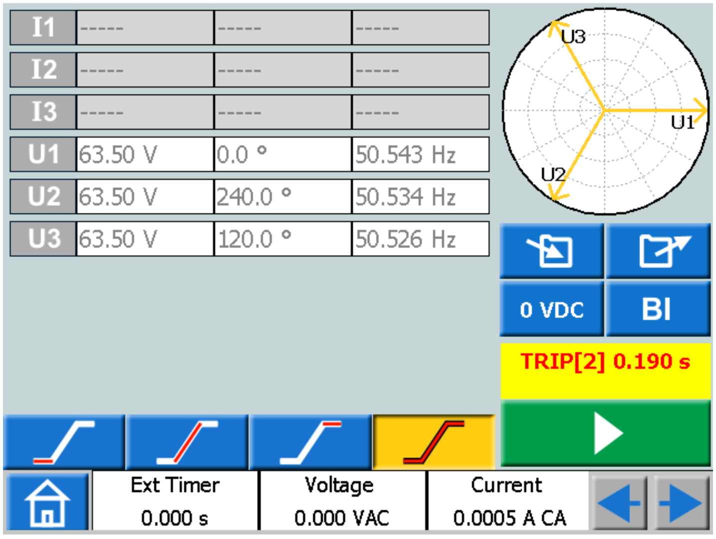
Figure: Ramp speed 2,6Hz/s



As SVERKER 900 is stopped by the operate (trip) contact, it is expected to have an operation of roughly 150 ms (operation of the high stage).

As the injected ramp is close to the border, a higher trip time of the typical trip time has to be expected (note that this test DOES NOT test the operate time, but the border/threshold of the relay); in fact an operation of 190 ms instead of expected 150 ms was measured. This is definitely the high stage of ROCOF.

Figure: measured operate time: it is the high stage!



We have managed to test the border/threshold of the high stage of ROCOF by using the trip contact only.

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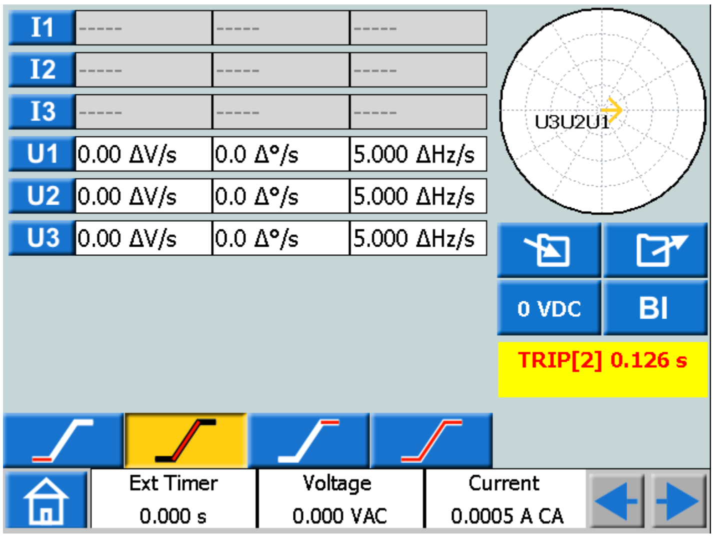
Operate time test for the high stage (2,5 Hz/s)

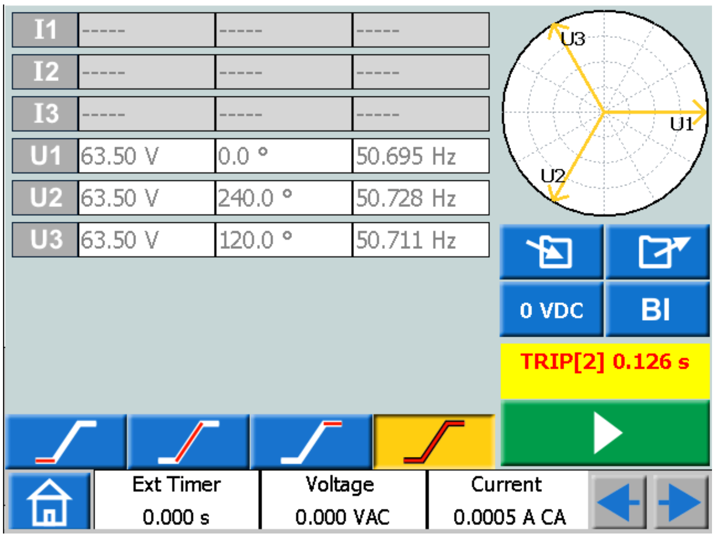
As the start level of the high stage has been identified and confirmed, it is easy now to test the operate time of it. Inject a ramp two times the setting value: 2 x 2,5 Hz/s = 5 Hz/s.

Figure: Ramp speed 5,0 Hz/s



This ramp is well above the threshold and this will give a reasonable result for the operate time: 126 ms were measured.

Figure: Measured operate time for the high stage



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Comments and questions

The relay was set to 150 ms operate time, and the SVERKER 900 has measured 126 ms. Is this time correct or not?

According to the manual the ROCOF function has an accuracy in the operate time of +/- 2% OR +/- 25 ms. We measured an operate time (126 ms) within 25 ms from the setting (150 ms), and this is Ok.

Note: The tests have been executed with the standardized frequency ramp according to IEC 60255-181. The manual of the relay does not state the test method that was used to assess the relay performance, as the relay was produced before the standard was published. It is always recommended to provide this information in your test report, to avoid misunderstandings.

Another question is:
How can the relay trip faster than the setting?

In general, high voltage relays see the time delay setting as an additional time delay.

The relay starts the timer when the fault is detected (in this example when the frequency derivative is higher than 2,5 Hz/s), and when the timer elapses, if the fault is still detected, the operate (trip) signal is activated.

The operate time of the relay is the start time (the relay needs time to detect that the fault has actually started) PLUS the additional settable time delay (which would be 150 ms in this case). This means that the expected trip time will never be below the time setting of 150 ms.

Relation between start (pick-up) and operate (trip) time for ROCOF protection

The Schneider relay used for this example (Sepam S84), is a medium voltage relay. Traditionally, medium voltage relays tend to compensate the time setting for the average start time of the relay.

If the average start time of the relay is, let’s say, 130 ms, and the user enters a time delay of 150 ms, the actual setting for that timer would be 20 ms (= 150 ms – 130 ms).

If the relay starts faster than the average value, the total trip time will be less than the setting, if the relay starts with a time higher than the average (fault very close to the border, for instance), the total operate time will be higher than the setting.

What has happened here is that the relay started probably faster than its average (typical) start time.

According to IEC 60255-181, relay manufacturers are required to report the average start time of ROCOF, with the shown mandatory table (reference to IEC 60255-181). Let’s suppose that the table below shows the values declared by the manufacturer for the tested relay.

Typical start time declaration according to IEC 60255-181:

Min value: 110ms

Mean value: 130ms

Max value: 150ms

Additionally: Relay manufacturers shall declare if, in the evaluation of the operate time delay, the reference value shall be:

1) the setting value of the time delay, if the time delay is a pure additional timer

OR

2) the setting value of the time delay minus a constant defined by the manufacturer if the time delay setting considers compensations for the start time of the protection function and/or for the response time of the output contact.

The time delayed used by the relay can easily be measured, with SVERKER 900, by using the extra timer. Start the extra timer with the start signal, stop the extra timer with the trip signal. Run a frequency ramp 2 times the ROCOF setting. This is the length of the time delay used by the relay.

When the relay was set to 500 ms, the result from the extra timer was 350 ms. This means that the relay compensates for 150 ms (=500 ms – 150 ms).. Also, note that the relay timer cannot be set less than 150 ms. This is a good indication of “how the relay things”.

That value of 150 ms would be reported by the manufacturer, avoiding us to discover it in the substation.

By setting the time delay to 150 ms, the real value of the timer will be 150 ms – 150 ms = 0 ms. By measuring an operate time of 126 ms, we can subtract to it the time delay (0 ms) and get the start time for that test: 126 ms. This value would be easily inside the relay declaration according to IEC 60255-181.

This way it would be easy to judge the operate time for all the relays that are conformant to IEC 60255-181:

1) The eventual compensation for the trip timer is known (in our example, 150 ms).
2) The Start time is declared (MAX, MIN and average values)
3) Calculate the additional time delay: setting time – compensation value (= 350 ms for the low stage, 0 ms for the high stage)
4) Measure the operate time at 2,0 times the threshold
5) Check that the measured value is inside the given tolerances.
   For the low stage: between 110 ms + 350 ms AND 150 ms + 350 ms = between 460 ms and 500 ms.
   For the high stage: between 110 ms + 0 ms AND 150 ms + 0 ms = between 110 ms and 150 ms