APPLICATION NOTE

Testing frequency relays with SVERKER 900 considering the IEC 60255-181 standard

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Contents

1. Introduction to this application note.

This application note is more than a description of how to use SVERKER 900 for testing frequency relays. It also wants to spread the knowledge about IEC standardization in relay protection. Many engineers often associate the IEC series of protection standards IEC 60255-1xx[1] to relay type testing, and believe that they do not need to have competence about this series of standards. This is a misunderstanding: many of the concepts, definitions and test procedures described in the standards are there to be used in relay technique, no matter if the role is relay manufacturer, user, or commissioning / maintenance testing engineer ([2], [3]).
Megger invests many resources in standardisation activities, with active participation to the IEC committees that produce the standards (TC 95/MT 4 and also TC 95/WG 2) and by performing several trainings and webinars about the standardization concepts. Of course, at the end there is an impact of the standardization on the test devices that Megger produces. SVERKER 900 is one example. Definitely and hopefully, many others will follow in the near future.

This application note wants to guide through the most important concepts described by the standard, how to use them for testing frequency protection relays, using the relay test equipment SVERKER 900.

The frequency relay used for this application note has not been tested by the manufacturer in accordance with the new standard IEC 60255-181, as it was manufactured before the standard was published. The relay manufacturer (ABB from Sweden, par.7.2) has kindly commented this application note and their contribution is included in this document.

This application note will be soon updated with the test for another relay, of “Type 2”, from another manufacturer, as RET670 relay is a relay of “Type 1”(see par.4.2.3).

A new application note will be released, as soon relays tested in accordance with IEC 60255-181 will be available.

2. The protection of the smart grid needs standards.

The IEC Technical Committee 95, Maintenance Team 4, (IEC TC 95/MT 4) “Measuring relays and protection equipment - Functional standards”, is responsible for producing and maintaining the functional standards related to relay protections.

In February 2019, the new IEC Standard for Frequency and ROCOF[2] protection functions was approved. Smart Grid requirements in the field of competence of TC 95 have been the fundamental motivations for the creation of this completely new standard for frequency related protection functions.

The IEC 60255-181 standard was approved without any negative vote and it has been recently (autumn 2019) ratified as European standard EN IEC 60255-181, to be used without modifications in 34 countries in Europe.

3. Introduction to the IEC 60255-181 standard.

The Scope of the IEC 60255-181:2019 [4] standard covers underfrequency, overfrequency and ROCOF (Rate of Change of Frequency) protection functions, as indicated in Figure 1:

	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

Figure 1. Protection functions in the scope of IEC 60255-181
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[1] *IEC 60255-1xx is the series of functional standards for relay protections.[1], [2]*

[2] *ROCOF: According to IEC 60255-181:2019: Rate Of Change Of Frequency*

As these functions are commonly implemented in one or more protection relays, it is expected the standard to cover the protection functions when they are hosted in the "traditional" protection relay. The standard also applies to such functions when they are embedded in different devices forming the smart grid, as such as the inverters powering the grid from distributed generators or trip units in low voltage circuit breakers [4], [5]. Customers and users should expect to receive a type test report and performances declaration from the manufacturer of these functions according to the IEC 60255-181 for those implementations "hidden" in devices that are not commonly considered protection relays, but that do perform a relay protection task and operate a circuit breaker (electromechanical or static).

One of the most important aspects of IEC 60255-181 is the standardization of realistic conditions to be applied to the protection function when assessing many performances related to dynamic behaviour of the power system. The use of a standardized formula to represent this dynamic behaviour wants to minimize important misunderstandings[3] related to the start time and/or operate time of the protection relay, two important concepts detailed very much in the standard, that can be very much affected by the different algorithms implemented to "measure the frequency"[7].

The IEC 60255-181 details about minimum requirements for protection relay type testing; so it is not directly a standard for maintenance/commissioning applications. However, it is important to understand definitions contained therein when performing commissioning and maintenance tests. This will bring to smoother testing, easier reporting and less misunderstandings between the parts involved in the testing[4].

The IEC 60255-181 standard contains many more definitions and tests than what presented in this document; for example there are tests defined for the protection stability in case of sudden voltage change (vector shift/phase shift and magnitude change). Also, the standard refers to frequency related functions. ROCOF, Rate Of Change Of Frequency, is included; so there are definitions and tests for that protection function as well [8], [9].

3.1. Standardized waveform for frequency changes

The way the frequency varies in what is generally called "frequency ramp" is defined in IEC 60255-181 by one exact formula. The formula corresponds to the analytical integration of the differential equation ([10],[11]) describing the voltage waveforms induced by a rotating generator that accelerates (or decelerates) with a constant net torque, i.e. with constant angular acceleration.

Considering a voltage waveform v(t) with frequency f(t) = f'_0 * t , amplitude V_{RMS} * SQRT(2) and phase angle φ_0, its exact representation in the time domain is:

$$v(t) = \sqrt{2} \cdot V_{RMS} \cdot \sin(2\pi f_0 + \pi f_0' \cdot t^2 + \varphi_0)$$

This is the formula of the waveform that shall be generated by the relay test set when testing the frequency protection function. The formula is in fact described in the normative (mandatory) Annex A of IEC 60255-181:2019.

Figure 2 show a graph of it, where also the linear and continuous behaviour of the frequency as function of time is shown in red colour; the waveform shown in the figure can be defined as a stepless (continuous) frequency ramp. At any time instant, the frequency has a different value.

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[3] The relay community has unfortunately experienced situations where frequency relays from different manufacturers, connected to the same busbar voltage and with the same settings (overfrequency or underfrequency thresholds) behaved very differently from each other's: some relays did not start at all for the event, some others started but tripped much faster than requested, some others started and tripped much slower than requested [6]

[4] This is a very old dilemma. Protection relay data sheets contain data (accuracy, typical operate time etc.) that are an extract of the results from the type tests. The type tests are performed according to IEC 60255-1xx definitions. If the commissioning engineers do not speak the same language of the relay manufacturers (which means for example to use the common definition of accuracy and use very similar test methods to assess it) there will be many misunderstandings at commissioning/maintenance that require many discussions to be clarified. The project will be delayed and will be more expensive than what was necessary. A common technical understanding mitigates these issues.

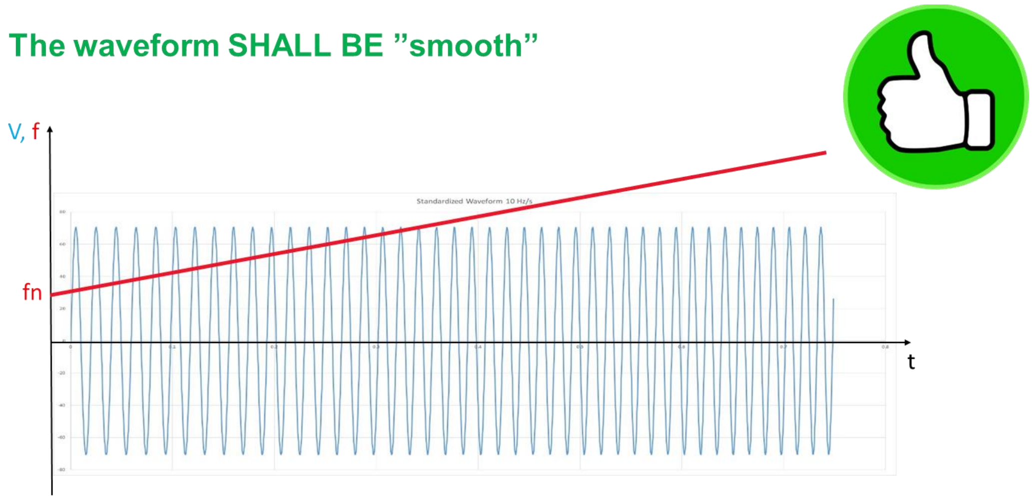

Figure 2. Graphical representation of the standardized “frequency ramp” .The frequency changes at any time instant (stepless frequency change). The blue line represents the voltage and the red line represents the frequency

No other methods to “reconstruct” or “simulate” the standardized waveform are allowed.

For example, some methods used in the past have tried to simulate the frequency ramp by changing the frequency of the signal at each period. This is a discontinuous change of the frequency (not stepless), and it is not allowed for having the same test method for all the frequency relays. Figure 3 shows an example of what is not allowed to do:

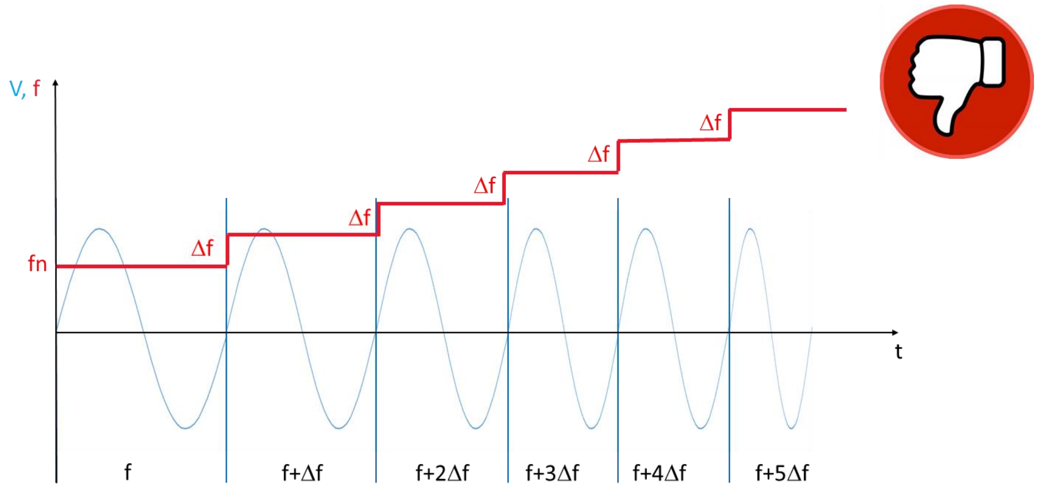

Figure 3. Graphical representation of a non-stepless “frequency ramp” .The frequency of the signal remains constant for some defined intervals, and suddenly changes to another value, for another interval of time.

3.2. SVERKER 900 and the standardized waveform

SVERKER 900 is designed [8] to produce the required waveform by IEC 60255-181 standard[5]. In this application note, we will make use of this capability. Do not underestimate this capability of SVERKER 900. The generation of such frequency ramp puts high requirements on the real time capabilities of the test set and on its computing capacity (Figure 4).

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[5] *From software release version 2.12, November 2018 (2.12.6896.14415). Contact Megger if you have an older software release to see if it is possible to perform the upgrade.*

Figure 4. The SVERKER 900 is able to generate the standardized frequency ramp. Check [5] that you have the correct software version.

3.3. Start time (pick-up time) for frequency relays

The following paragraphs describe the standardized methods for assessing and describing the start time (pick-up time[6]) of the frequency relays. This application note will make use of the standardized concepts, interpreted for commissioning/maintenance relay testing.

3.3.1. “Frequency ramp” tests to assess the start time

According to IEC 60255-181, the start time (pick-up time) of the frequency protection function (over- and/or underfrequency) is described with a graph, representing the behaviour of the protection relay when subjected to a set of different frequency variations (Hz/s).

Figure 5 shows one example for a frequency variation of 0,5 Hz/s from the steady value of 50 Hz, nominal frequency[7]. The voltage waveform is:

$$v(t) = \sqrt{2} \cdot V_{RMS} \cdot \sin(2\pi \cdot 50 + \pi \cdot 0{,}5 \cdot t^2 + \varphi_0)$$

The standardized waveform is injected and the time is measured from when the waveform has the frequency equal to the set value of the protection relay ($f>_{set}$ in Figure 5). The timer is stopped when the relay reaction is received by the test set (start contact of the relay activated).

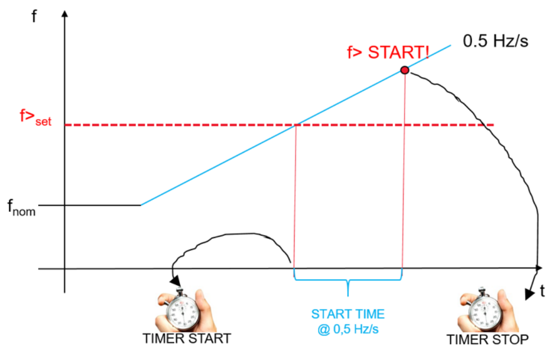

Figure 5. Example for the measurement of the start time of an overfrequency relay, according to IEC 60255-181, with use of one standardized “frequency ramp” of 0,5 Hz/s.

The start time is then measured for different dynamic conditions. The Figure 6 shows the same test for a frequency ramp of 2 Hz/s, for the same overfrequency relay:

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[6] 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).

[7] This is in practice a test with a frequency ramp of 0,5 Hz/s, starting from 50 Hz (f_{nom} in Figure 5).

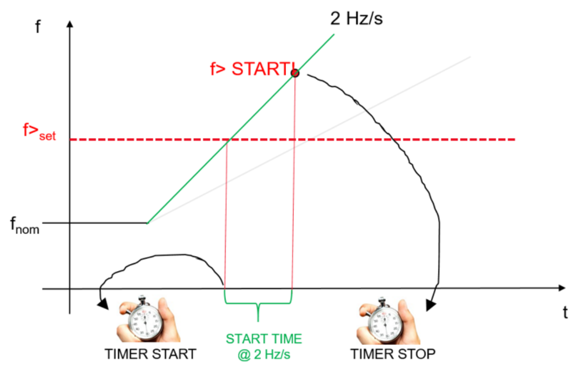

Figure 6. Example for the measurement of the start time of an overfrequency relay, according to IEC 60255-181, with use of another standardized "frequency ramp" of 2,0 Hz/s.

Each test is repeated for a standardized number of times (i.e. equal for each protection manufacturer) and then the results are shown in standardized table formats and standardized graphs, shown in Figure 7; please note that all quantities are just examples:

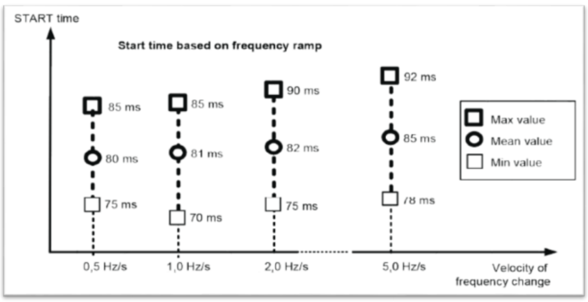

Figure 7. Example of diagram representing the start time of an overfrequency relay measured at the mandatory frequency ramps of 0,5; 1,0; 2,0 and 5,0 Hz/s. This diagram shall be published by the relay manufacturer.
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The graph in Figure 7 describes the performance (start time) of the overfrequency relay, as function of different dynamic behaviours of the power system frequency, that represent different accelerations (or decelerations for underfrequency relays) of the rotors governing the power generation in the electromechanic system.

Similar test methods and graphs shall be reported for underfrequency relays as well, where the frequency decreases with constant rate of changes, instead of increasing.

3.3.2. "Frequency jump" tests to assess the start time

This test is very similar to the way many engineers have always performed in the past. What does this test mean[8]? It is understood that for an electromechanical system, where the power system frequency is the result of the rotation of masses… the frequency cannot "jump", but considering a system where the generated frequency is the result of an algorithm that drives static inverters, the answer is YES: frequency can "jump"[9].

The behaviour of the protection relay when subjected to sudden discontinuous frequency changes can be quite different from the behaviour when the frequency changes continuously and that is the reason why this sudden frequency change test[10] is also considered by the IEC 60255-181.

Figure 8 describes the "frequency jump test" for assessing the start time of one overfrequency relay in that condition.

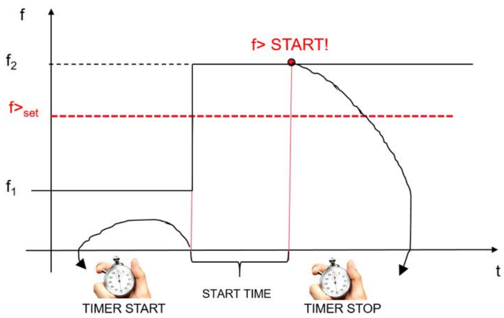

Figure 8. Example for the measurement of the start time of an overfrequency relay, according to IEC 60255-181, with use of the "frequency jump" test method.

The relay start time could be affected by the size of the frequency jump. Because of that, the IEC 60255-181 requires all frequency protection functions to be tested for a standardized set of frequency "jumps". The results are reported in the standardized format shown in Figure 9; please note that all quantities are just examples:

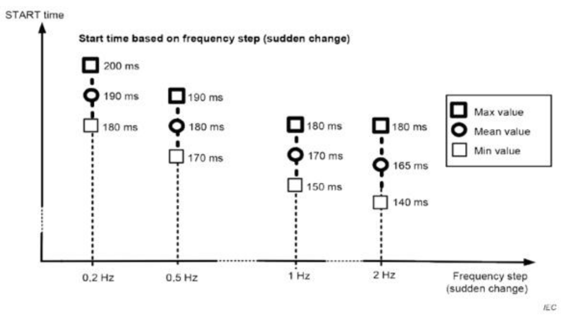

Figure 9. Example of diagram representing the start time of an overfrequency relay measured at the mandatory frequency "jumps" of 0,2; 0,5; 1,0 and 2,0 Hz/s. This diagram shall be published by the relay manufacturer.
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[8] *We should ask ourselves if the power system frequency can instantaneously "jump" from one value (i.e. 50 Hz) to another value (i.e. 52 Hz).*
Same question can be asked for a car: "can the speed of a car instantaneously "jump" from for example 100 km/h to 150 km/h?
The answer is no, speed and frequency, in mechanical systems, are continuous quantities. Frequency is associated to the angular velocity of a rotating mass ($\omega = 2\,\pi f$), while the speed of a car is a clear concept.
An instantaneous change in the speed would mean infinitive force (torque for rotations) applied to it, as the derivative of the speed is the acceleration (F = m a = m dv/dt for linear motion). In electromechanical systems, this is not possible. This is why the new test methods related to the standardized frequency ramp have been defined by IEC, where the frequency of the generated signal is a continuous function.

[9] *SVERKER 900 can simply do it. Every relay test set, not only SVERKER 900, is able to generate a signal with a certain frequency, and suddenly generate the signal with a completely different frequency. This means that one inverter, for some reasons, may generate voltage with frequency that has discontinuous jumps. For example because of sudden re-synchronisation issues, or simply by wrong control algorithms. In physics, this is known as "zero inertia". In fact, the renewable distributed power generations (solar, wind, battery) based on inverters, are known to have zero inertia* [12].

[10] *"Sudden frequency change" is the formal name of this test in IEC 60255-181:2019*

As mentioned before, the “sudden frequency change” test is very similar to how many protection relays have been tested in the past for commissioning/routine applications. This can partly explain the different behaviours of frequency protection relays when subject to dynamic power system changes [6]: their behaviour was not assessed for realistic power system changes, but rather for what today’s would be called “smart grid applications” (see par. 6.4 for a clarification of this term), where the inertia in the power system is very low (the stored kinetic energy in the rotating masses is very low [12].

There is anyway an important detail in this test, and it is that the injected signal needs be continuous, so there is no step change in its phase angle or magnitude except for its frequency. This condition maybe has not been considered in the tests performed in the past (see Figure 29, page 23, and Figure 30, page 23, for better understanding).

The “sudden frequency change” test has also a great importance for testing the time delay of the frequency relay (see par.4.7).

3.3.3. Operate time (trip time) for frequency relays

The IEC 60255-181 details very much about the definition of the operate time (trip time) for frequency relays, and clarifies a generic confusion in the relay community, not only related to frequency relays).
The operate time of a protection relay is the time interval from when the power system fault starts to when the relay operate contact is activated[11]. This time includes of course the time delay setting of the protection relay[12]

In few words, there are two possibilities, for relays manufacturers [4], to define their “operate time”:

Relay type	**Operate time is equal to**
Type 1	start time + time delay setting
Type 2	start time + (time delay setting – compensation constant). The compensation constant shall be declared by the relay manufacturer[13].

[11] *Similarly, the start time of a protection relay is the time interval from when the power system fault starts to when the relay issues the start (pick-up) contact.*

[12] *Frequency relays have at least two settings: one is the frequency threshold (frequency level, start level, pick-up level; for example f>, for overfrequency, and f<, for underfrequency) and the second is a “timed delay” setting, to allow protection selectivity strategies or load shedding* [13] *strategies based on time grading. This setting is a setting for a timer. There are 2 standardized ways for the behaviour of that timer, and relay manufacturers shall clearly state which is the philosophy adopted.*

[13] *These two philosophies are not new in relay protection technique; the IEC standard has simply formalized them and clarified that they need to be declared by the manufacturers, to minimize misunderstandings. Relays of “Type 1” are typically used in high voltage protection applications, while relays of “Type 2” are typically used in medium voltage applications. The denotations “Type 1” and “Type 2” are not used in IEC 60255-181. They are used in this application note for pedagogic purposes.*
Relays of “Type 2” usually allow a timer setting only greater than a minimum value. Relays of “Type 1” definitely allow setting the delay time to zero.
In relays of “Type 2”, the “compensation constant” is usually equal to the “average start time of the protection function plus the average reaction time of the output contact”. It also could just be equal to the “average start time of the protection function”, depending on manufacturer’s choice. Important is that the manufacturers shall declare the value of the compensation constant (which can be anyway estimated to be close to the minimum allowed setting of the timer)
Relays of “Type 2” can easily show operate times around the setting value (if the timer setting is 200 ms, it is possible to measure an operate time of 140 ms or 260 ms). Relays of “Type 1” instead will always give an operate time higher than the timer setting value, as the start time is always added to the set additional time delay. For the same example, a timer setting of 200 ms, will always give an operate time higher than 200 ms. Probable for frequency relays to be around 260 … 280 ms.

4. Testing ABB RET670 with SVERKER 900.

4.1. Introduction

The following steps are written for an overfrequency relay of "Type 1" (par.3.3.3), the ABB RET670 version 1.2, Figure 10:

Figure 10. ABB Relay RET670

It should be easy to implement the same guidelines for an underfrequency relay.

Hopefully all the paragraphs above (par.3) have been understood. If not, please read the following procedures, try to follow them, and after that please read the par.3.

4.2. About the overfrequency relay under test: ABB RET670.

4.2.1. Relay settings.

The overfrequency relay in RET670 (SAPTOF) has a start level (threshold) of 51,30 Hz, with a time delay of 300 ms (Figure 11).

RET670_IED2 - Parameter Setting

Group / Parameter Name	IED Value	PC Value	Unit	Min	Max
SAPTOF: 1					
Setting Group1					
Operation	On	On			
UBase	220,00	220,00	kV	0,05	2000,00
StartFrequency	**51,30**	**51,30**	Hz	35,00	75,00
TimeDlyOperate	**0,300**	**0,300**	s	0,000	60,000

Figure 11. Settings for the first stage of the overfrequency in ABB RET670 relay (StartFrequency and TimeDlyOperate).

4.2.2. Relay accuracy for frequency measurement.

The accuracy of the frequency measurement of the protection relay is 2 mHz (Figure 12)

Technical data

Table 234: SAPTOF technical data

Function	Range or value	Accuracy
Operate value, start function	(35.00-75.00) Hz	± 2.0 mHz at symmetrical three-phase voltage

Figure 12. Measurement accuracy of the frequency for ABB overfrequency protection, according to RET670 user's manual (Technical Reference Manual) [14].

4.2.3. Relay operate time: "Type 1" or "Type 2"?

The tested ABB RET670 was manufactured before the IEC 60255-181 standard was published in 2019. It is therefore not expectable to have answers to all the declarations that the manufacturer shall provide according to the standard, in the relay manual. For example, it is not clearly specified if the relay timers behave according to "Relay 1" or to "Relay 2" descriptions (see par.3.3.3).
As the time delay setting can be set to 0 ms, it is clear that the relay behaves according to the "Relay 1" concept[14]:
The operate time of the relay is given by the start time + set time delay[15].

4.2.4. Relay start time

RET670 manual indicates a typical start time for the overfrequency relay of 100 ms (Figure 13)

Technical data

Table 285: SAPTOF technical data

Function	Range or value	Accuracy
Operate time, start function	100 ms typically at f_{set} -0.5 Hz to f_{set} +0.5 Hz	-
Operate time, definite time function	(0.000-60.000)s	± 0.5% ± 10 ms

Figure 13. Details about start time and timers error for frequency protection in RET670 (Technical Reference Manual) [14].

What the word "typical" means it is not fully clear[16].

We will anyway test the relay with the standardized methods and will draw our conclusions afterwards.

4.3. Connecting SVERKER 900 to the ABB RET670.

The voltage generators of SVERKER 900 are star-connected to the phase voltage inputs of RET670 to generate 3 three phase symmetrical voltages.

Connect the start and operate signals of overfrequency protection in RET670 to SVERKER 900. Figure 14 shows the connections.

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[14] *A good indicator that the relay is of "type 1" is from the setting range of timer. See in Figure 11 that the timer can be set to zero. Relays of "Type 2" do not allow to set the timer to zero*

[15] *If RET670 had been tested according to IEC 60255-181, this information would have been clearly stated in the user's manual.*

[16] *It is reasonable to think that the relay needs some 100 ms to start, or that it typically needs less than 100 ms to start. After having contacted ABB, we know that the start time was actually declared for ramping frequency as the tested ABB RET670 does not "support" applications with frequency jumps.*

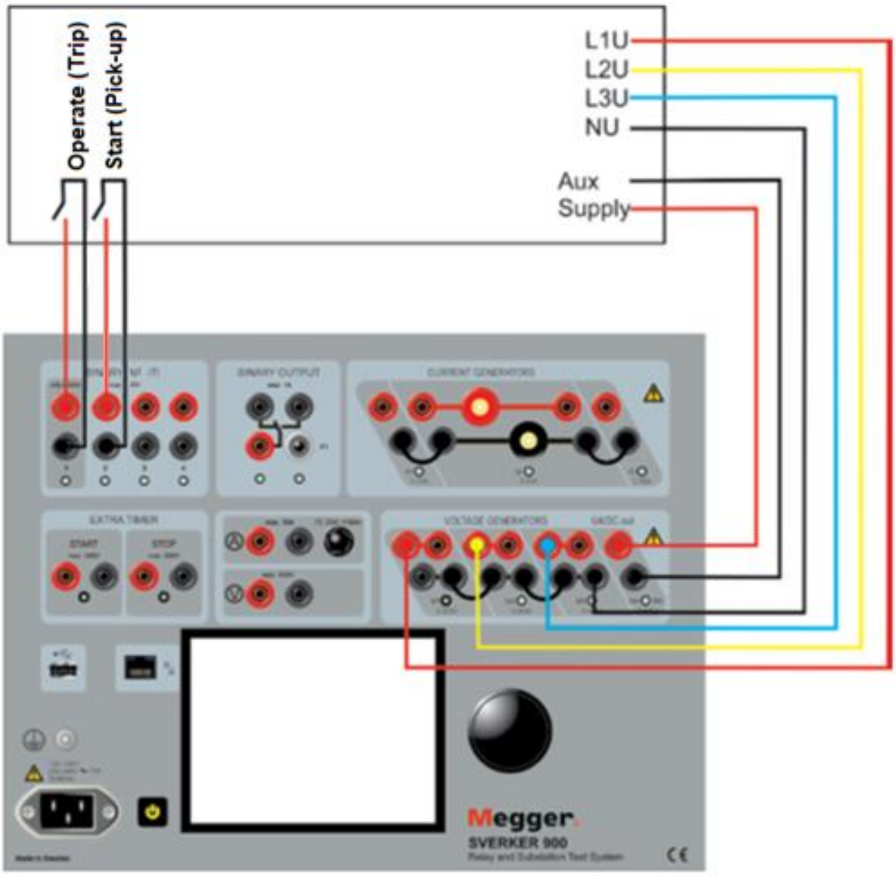

Figure 14. Schematic diagram representing the connections of the 3 voltage generators of SVERKER 900 to ABB protection relay RET670, together with the start and operate signals of the overfrequency protection function.

4.4. Testing the START level of overfrequency relay.

For testing the start level (threshold) of the overfrequency relay, the procedure is simple.

The idea is to generate a "manual frequency ramp", with the minimum step allowed by SVERKER 900. Start to inject nominal voltage(s) with a frequency below the start level, typically 2 or 3 times the tolerance (2 mHz), and **slowly** increase the frequency with the knob, until the relay starts (picks-up). As the typical start time is around 100 ms, wait approximately 5 times this value before increasing the frequency with the knob: at least half second.

Set SVERKER 900 to stop the generation at the activation of binary input 2 (start contact), free contact sensing, as shown in Figure 15.

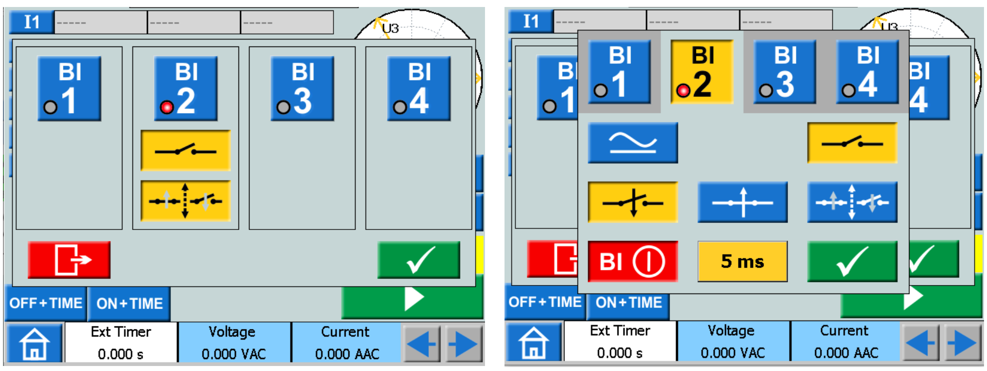

Figure 15. SVERKER 900 stops the generation on the start (pick-up) contact, which is connected to Binary Input 2, in "free contact sense mode".

We will start generating a three phase voltage system of secondary 63,5 V (secondary rated voltage of the relay) at a frequency of 51,30 Hz – 3 x 2 mHz = 51300 mHz – 6 mHz = 51,294 Hz.

Press . The generation from SVERKER 900 starts with the setup shown Figure 16:

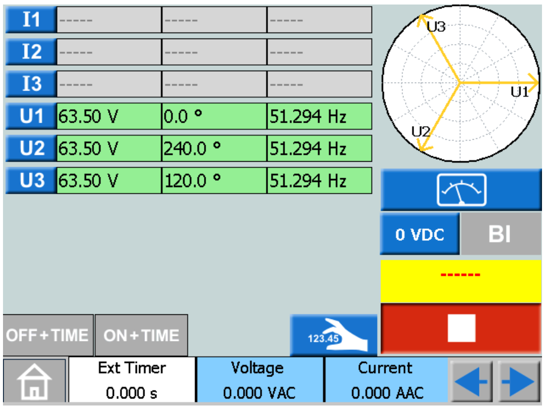

Figure 16. Start of the "manual frequency ramp at nominal voltage level, at 51,294 Hz.

Press now  and select the frequencies for the three voltages (by tapping on them) (Figure 17):

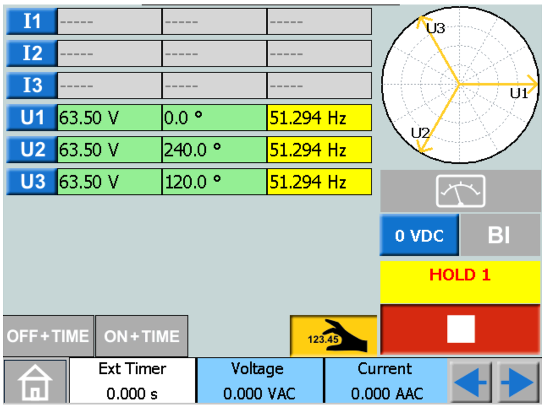

Figure 17. Selecting the frequencies for voltages U1, U2 and U3 and pressing "HOLD".

The frequency is incremented by the knob rotation. Slowly rotate the knob (1 mHz at a time), waiting for at least 0,5 seconds from one step to the next step. The test will be stopped when the relay activates its start contact.

The relay starts (picks-up) at exactly 51,3 Hz, as Figure 18 shows, and the test is stopped:

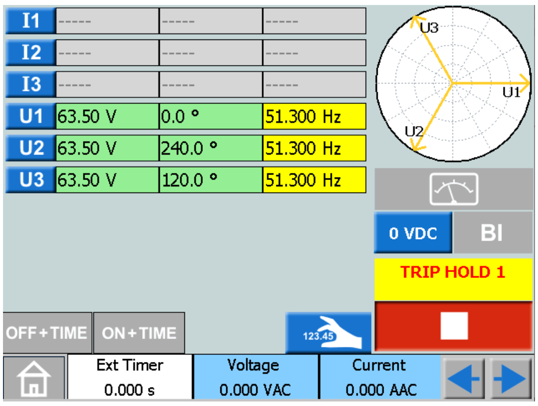

Figure 18. Start (pick-up) of overfrequency protection. The start threshold has been detected

Press now  and see the test results, that can be saved in the report, if you want (Figure 19).

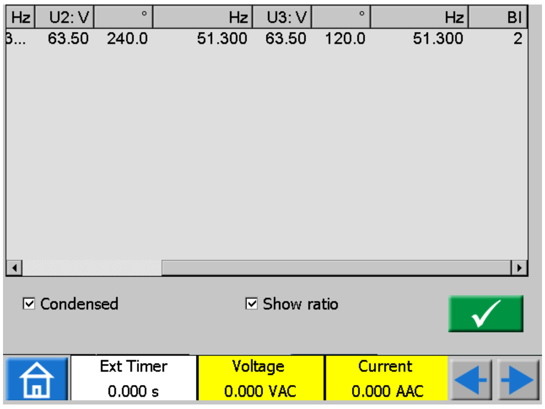

Figure 19. Test results after stopping the test

The test was repeated several times, and the measurement is confirmed.

4.4.1. Conclusions for the start level.

The relay threshold has been tested to be 51,3 Hz. The setting is 51,3 Hz.
Error is 0 mHz and the given accuracy is 2 mHz.
The test is passed[17].

[17] *With such small tolerance of the relay, it is a good practice to measure this threshold 5 times and report the average value of this measurement.*

4.5. Testing the start time of overfrequency relay with standardized frequency ramp.

4.5.1. Introduction.

IEC 60255-181 requires to perform the test of the start time with 4 different frequency ramps (par.3.3.1). For commissioning/maintenance, it is reasonable to choose only one or two of the possible ramps; for example the two central ramps (1 Hz/s and 2 Hz/s).

In this application note we will test all the 4 frequency ramps[18].

The frequency ramp is setup in the Ramp tool of SVERKER 900, in paragraphs 4.5.2, 4.5.3 and 4.5.4.

4.5.2. Pre-fault values.

The pre-fault value is the power system nominal frequency (50 Hz in our example), and it shall be injected for at least 1 second[19].

Figure 20 shows the pre-fault value of 1 second, at power system nominal frequency of 50 Hz[20] and rated secondary voltage of 63,5 V.

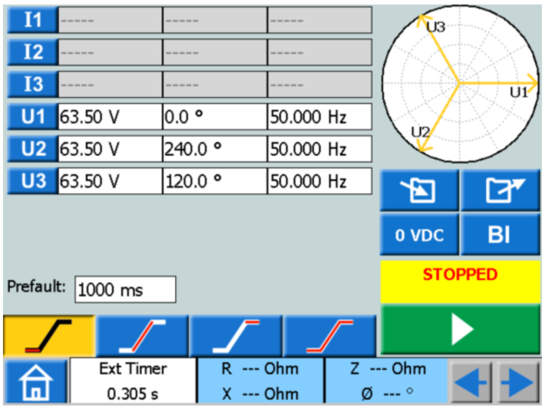

Figure 20. Pre-fault values for the standardized frequency ramp in SVERKER 900

4.5.3. Setup the frequency ramp of 0,5 Hz/s.

The relay will be tested with the standardized frequency ramp of 0,5 Hz/s.
Just write 0,5 Hz/s in the ramp conditions (Figure 21),

---

[18] *Commissioning/maintenance tests are a small sub-set of the type tests* [15]*. Common sense suggests avoiding over-testing for commissioning/maintenance. Considering that the IEC 60255-181 is a new standard, it is expected to see more than strictly necessary tests for frequency protections. When the standard will be better known, the number of tests will probably be reduced. We are following this idea by testing all the 4 ramps, as there is a certain "curiosity" in understanding the relay behaviour. Also a statistical approach is described in many of IEC 60255-1xx relay protection series, and it is worth to get used to this approach* [3]*.*

[19] *The pre-fault condition is meant to let the protection relay to stabilize the frequency measurement, before the power system fault occurs (the frequency ramp starts). If in doubt on how long to set the pre-fault, set it to 5 seconds. So far, no protection relays have been observed to need more than 5 seconds to stabilize the frequency measurement.*

[20] *For 60 Hz power systems, it will be 60 Hz. Note that that for these tests, the frequency ramp shall always start at the nominal power system frequency (per IEC 60255-181)*

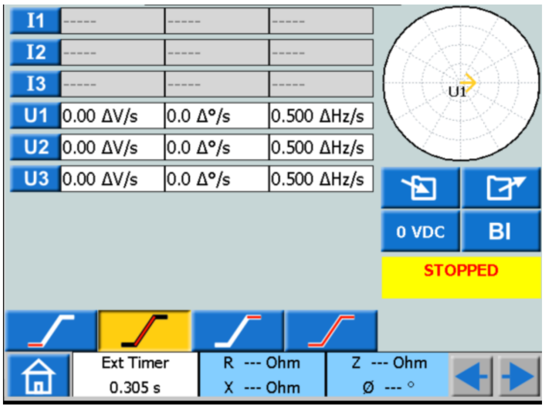

Figure 21. Setting the ramp values of 0,5 Hz/s in SVERKER 900

4.5.4. Setup the final point of the frequency ramp.

The final point of the frequency ramp is set to 2 Hz above the relay setting of the start value. The final value will be 51,3 Hz + 2 Hz = 53,3 Hz, as shown in Figure 22.

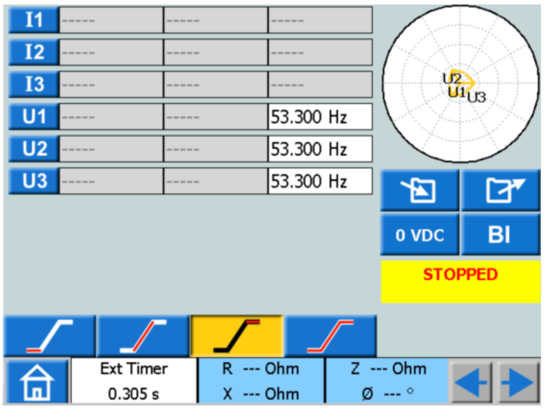

Figure 22. Setting the final state of the frequency ramp to 2 Hz above the relay setting for the start level (53,3 Hz).

4.5.5. Run the ramp and measure the start time from SVERKER 900.

By tapping on  and then on , the test will start (Figure 23):

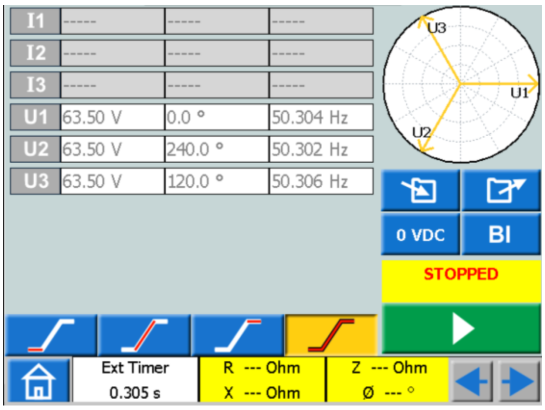

Figure 23. Initial situation right before starting the ramp.

The ramp is stopped when the start contact has activated, as shown in Figure 24. SVERKER 900 reports the duration of the ramp, from when it started to when it was stopped.

SVERKER 900 reported a ramp duration of 2,688 s (2688 ms).

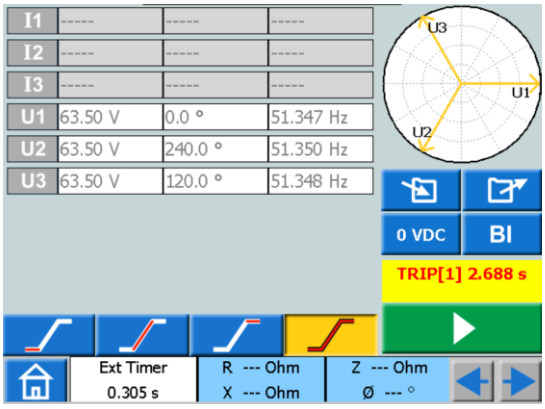

Figure 24. Final situation shown by SVERKER 900 after relay start activation.

Remove from this result, the time that SVERKER 900 needed to go from 50 Hz to the relay setting, 51,3 Hz. This time is 2,6 seconds and needs to be manually calculated, with this formula:

$$Start\ Time\ (s) = SVERKER\ 900\ Time\ (s) - \frac{(Relay\ setting\ start\ f\ (Hz) - Nominal\ f\ (Hz))}{Frequency\ Ramp\ Speed\ \left(\frac{Hz}{s}\right)}$$

That can be simplified into:

$$Start\ Time\ (s) = SVERKER\ 900\ Time\ (s) - K\ (s)$$

Where the variable K is calculated by;

$$K(s) = \frac{(Relay\ setting\ start\ f\ (Hz) - Nominal\ f\ (Hz))}{Frequency\ Ramp\ Speed\ \left(\frac{Hz}{s}\right)}$$

With the following data:

SVERKER 900 Time = 2,688 s (See Figure 24)
Relay setting start = 51,3 Hz
Nominal f = 50 Hz (the beginning of the frequency ramp, always equal to the nominal frequency)
Frequency Ramp Speed = 0,5 Hz/s

The variable K is:

$$K\ (s) = \frac{(Relay\ setting\ start\ f\ (Hz) - Nominal\ f\ (Hz))}{Frequency\ Ramp\ Speed\ \left(\frac{Hz}{s}\right)} = \frac{(51{,}3\ Hz - 50\ Hz)}{0{,}5\ Hz/s} = 2{,}6s = 2600\ ms$$

and the start time:

$$Start\ Time\ (s) = 2688\ (ms) - 2600\ ms = 88\ \text{ms}$$

Figure 25 shows graphically the numbers just calculated.

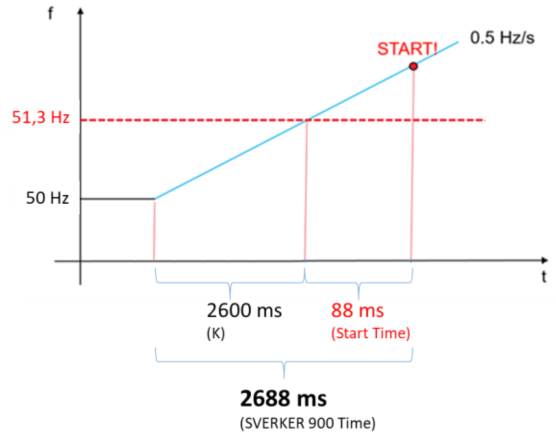

Figure 25. Graphical representation of the calculated values with SVERKER 900.

By performing the same test 5 times, we get the following results from SVERKER 900:

Test Nr. 0,5 Hz/s ramp	Result from SVERKER 900	K	Relay Start time
1	2688 ms	2600 ms	88 ms
2	2688 ms	2600 ms	88 ms
3	2685 ms	2600 ms	85 ms
4	2688 ms	2600 ms	88 ms
5	2690 ms	2600 ms	90 ms
AVERAGE	**2687,8 ms → 2688 ms**		**87,8 ms → 88 ms**

4.5.6. Testing the start time of overfrequency for the other 3 frequency ramps.

The test performed for the frequency ramp of 0,5 Hz/s have been repeated for all the other 3 ramps (1,0 Hz/s, 2,0 Hz/s and 5,0 Hz/s) as indicated in par 3.3.1 and as it was done in par.4.5.2 to 4.5.5:

Test Nr. 1 Hz/s ramp	Result from SVERKER 900	K	Relay Start time
1	1388 ms	1300 ms	88 ms
2	1386 ms	1300 ms	86 ms
3	1382 ms	1300 ms	82 ms
4	1384 ms	1300 ms	84 ms
5	1386 ms	1300 ms	86 ms
AVERAGE	**1385,2 ms → 1385 ms**		**85,2 ms → 85 ms**

Test Nr. 2 Hz/s ramp	Result from SVERKER 900	K	Relay Start time
1	733 ms	650 ms	83 ms
2	739 ms	650 ms	89 ms
3	741 ms	650 ms	91 ms
4	734 ms	650 ms	84 ms

5	737 ms	650 ms	87 ms
AVERAGE	**736,8 ms → 737 ms**		**86,8 ms → 87 ms**

Test Nr. 5 Hz/s ramp	**Result from SVERKER 900**	**K**	**Relay Start time**
1	347 ms	260 ms	87 ms
2	344 ms	260 ms	84 ms
3	344 ms	260 ms	84 ms
4	344 ms	260 ms	84 ms
5	350 ms	260 ms	90 ms
AVERAGE	**345,8 ms → 346 ms**		**85,8 ms → 86 ms**

4.5.7. Summary of relay start time for all 4 frequency ramps.

All the results are reported in the following table:

Ramp	**Result from SVERKER 900 (average on 5 tests)**	**K**	**Relay Start time (average on 5 tests)**
0,5 Hz/s	2688 ms	2600 ms	88 ms
1,0 Hz/s	1385 ms	1300 ms	85 ms
2,0 Hz/s	737 ms	650 ms	87 ms
5,0 Hz/s	346 ms	260 ms	86 ms

4.5.8. Conclusions for start time with standard frequency ramps

As mentioned previously, for commissioning/maintenance tests it is probably enough to test only some of the frequency ramps (for example 1,0 Hz/s and 2,0 Hz/s), especially if data according to IEC 60255-181 in the relay manual are given, so that results can be immediately verified.
As no data according to IEC 60255-181 are given for this relay, as it was manufactured before this standard existed, we have performed tests for all the ramps to better understand the relay from IEC 60255-181 point of view, and to add more information that can help the reader.

Note also that since this relay is a “Type 1” relay (par.4.2.3), it would have been possible to test the start time by stopping the SVERKER 900 with the operate contact, by setting the delay time in the relay to 0 ms.

The relay manual informs about a typical start time of 100 ms (par.4.2.4).

We have measured a start time of approximately 90 ms, using all the 4 standardized frequency ramps.
The start time that we have measured is compatible with the given 100 ms and we declare the test passed.

4.6. Testing the start time of overfrequency relay with standardized "frequency jump".

4.6.1. Introduction

The test with the sudden frequency change is relatively easy, but one thing is important: the test must not introduce any phase shift (par.3.3.2). For this we need to use some phase shift corrections for the phase voltages in the fault in the "pre-fault and fault test" from SVERKER 900 (later on in this application note –par.5.6- we will describe a simplified method, useful especially when data from the relay, with reference to IEC 60255-181 are given or when the relay behaviour is more or less already known).

The phase angle correction, **for one second pre-fault** (at the nominal frequency) is given by the formula:

$$PHI_{correction}(°) = (f_{nom} - f_{fault})\ (Hz) \times 360\ (°)$$

Where

f_{nom} is the nominal frequency at the pre-fault

f_{fault} is the fault frequency; it depends on the relay setting and on the level of the "frequency jump" requested by the test.

Please note that the formula above is ONLY valid for a pre-fault duration of 1 second.

If we want to consider all the 4 "frequency jumps" requested by the standard we can have this table, for the overfrequency relay setting of 51,3 Hz:

"Frequency Jump" above relay setting	Fault Frequency	PHI_correction for fault voltages
0,2 Hz	51,3 Hz + 0,2 Hz = 51,5 Hz	- 1,5 * 360 = -180 deg
0,5 Hz	51,3 Hz + 0,5 Hz = 51,8 Hz	- 1,8 * 360 = -288 deg = 72 deg
1 Hz	51,3 Hz + 1 Hz = 52,3 Hz	- 2,3 * 360 = -108 deg = 252 deg
2 Hz	51,3 Hz + 2 Hz = 53,3 Hz	- 3,3 * 360 = -108 deg = 252 deg

The test for a "frequency jump" test of 0,5 Hz is shown below. All other cases are then repeated in the same way and the results are summarized in a table.

4.6.2. Pre-fault values

Set the pre-fault values in the pre-fault and fault instrument of SVERKER 900. Note that the pre-fault values have to be the nominal power system frequency (50 Hz or 60 Hz).

Be careful and **set the pre-fault values to be 1 second long** (par.4.6.1) as shown in Figure 26.

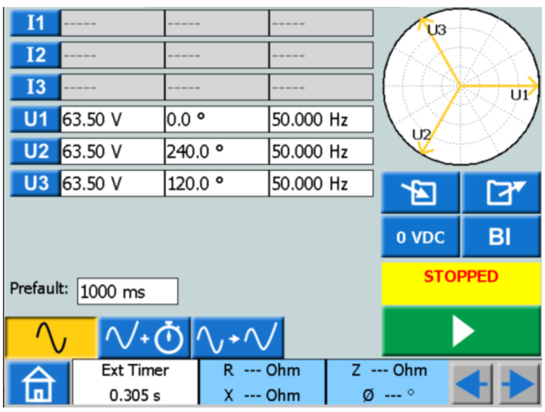

Figure 26. Pre-fault values for the standardized frequency "jump" in SVERKER 900. Set the duration of the pre-fault to 1 second so you can use the values calculated in 4.6.1 for the correction for the phase angles for the fault

4.6.3. Fault values

Set the fault values, considering the phase correction that was calculated for the frequency jump of 0,5 Hz (fault frequency = 51,8 Hz), as in Figure 27

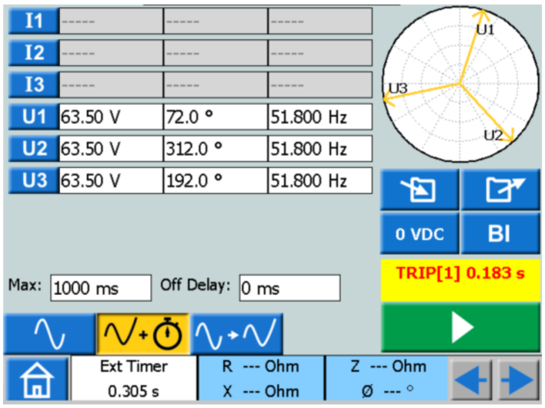

Figure 27. Fault values for the standardized frequency "jump" of 0,5 Hz in SVERKER 900. Note the phase angle correction calculated in 4.6.1.

4.6.4. Run the test and measure the start time from SVERKER 900.

Presse and then run the test by pressing , the result is clearly shown in Figure 28.

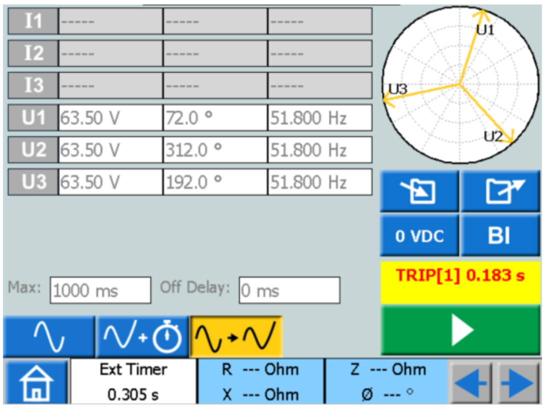

Figure 28. Start time (pick-up time) result for a standardized frequency jump of 0,5 Hz.

By performing the same test 5 times, we get the following results from SVERKER 900:

Test Nr. 0,5 Hz Jump	**Result from SVERKER 900**
1	183 ms
2	190 ms
3	185 ms
4	178 ms
5	183 ms
AVERAGE	**183,8 ms → 184 ms**

Figure 29 shows that the injected voltages are continuous, if injected with the correct phase correction:

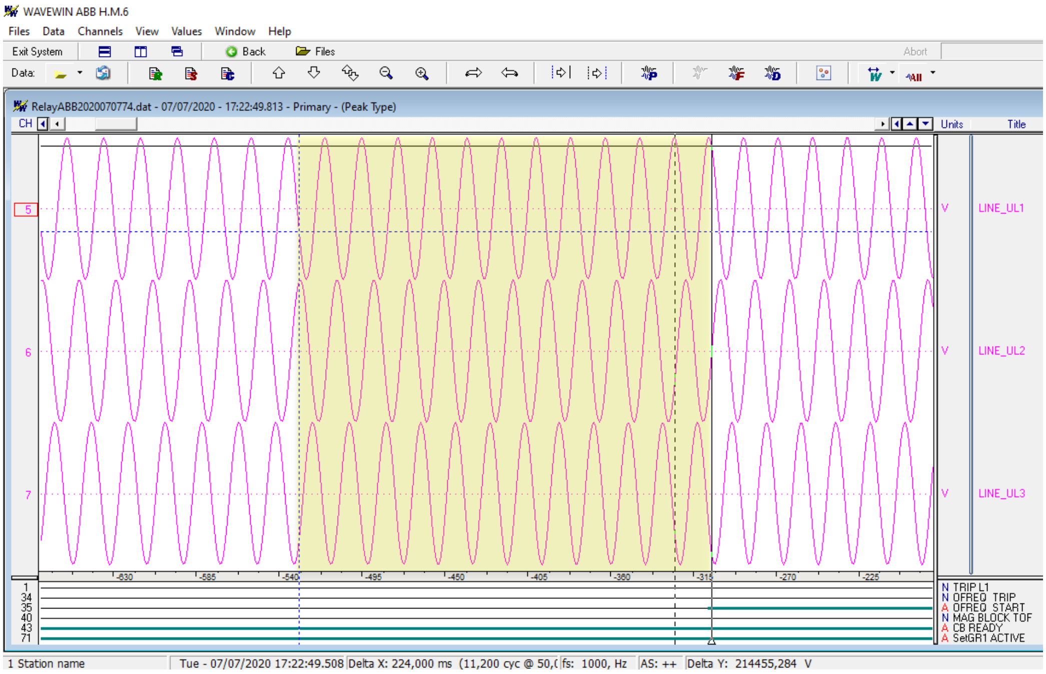

Figure 29. Note the voltages are fully continuous when the frequency changes from pre-fault to fault, which is somewhere around 190 ms from the start signal. The two cursors show approximately 225 ms from when the start signal triggered.

The same test, performed without phase angle correction, shows the discontinuity at the instant of the frequency jump (Figure 30):

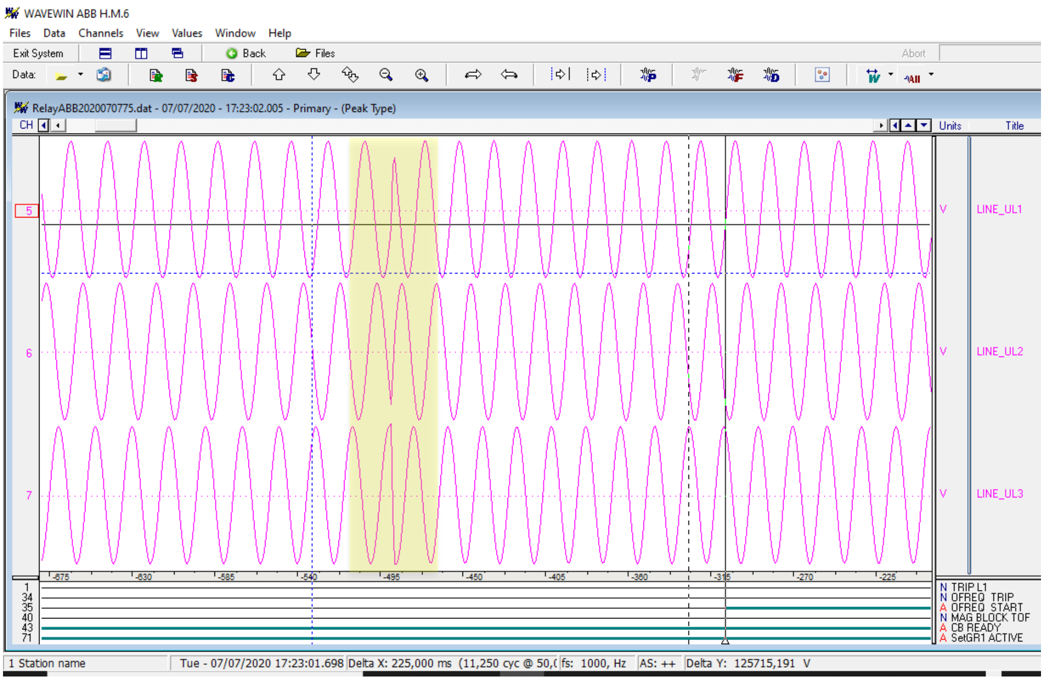

Figure 30. Note the voltages are discontinuous (phase shift jump) when the frequency changes from pre-fault to fault, which is exactly the discontinuity at approx. 190 ms from the start signal. The two cursors show approximately 225 ms from when the start signal triggered.

4.6.5. Testing the start time of overfrequency for the other 3 frequency jumps.

The test performed for the frequency jump of 0,5 Hz have been repeated for all the other 3 jumps (0,2 Hz, 1,0 Hz/s and 2,0 Hz) as indicated in par.3.3.2 and as it was done in par.4.6.2 to 4.6.4:

Test Nr. 0,2 Hz jump	**Result from SVERKER 900**
1	181 ms
2	190 ms
3	183 ms
4	189 ms
5	181 ms
AVERAGE	**184,8 ms → 185 ms**

Test Nr. 1 Hz jump	**Result from SVERKER 900**
1	185 ms
2	186 ms
3	189 ms
4	185 ms
5	179 ms
AVERAGE	**184,8 ms → 185 ms**

Test Nr. 2 Hz jump	**Result from SVERKER 900**
1	183 ms
2	185 ms
3	182 ms
4	182 ms
5	180 ms
AVERAGE	**182,4 ms → 182 ms**

4.6.6. Summary of relay start time for all 4 frequency jumps.

All the results are reported in the following table:

Jump	**Result from SVERKER 900 (average on 5 tests)**
0,2 Hz	185 ms
0,5 Hz	184 ms
1,0 Hz	185 ms
2,0 Hz	182 ms

4.6.7. Conclusions for start time with standard frequency jumps

As previously mentioned, for commissioning/maintenance tests it is probably enough to test only some of the frequency jumps (for example 0,5 Hz and 1,0 Hz), especially if data according to IEC 60255-181 in the relay manual are given, so that results can be immediately verified.
As no data according to IEC 60255-181 are given for this relay, as it was manufactured before the standdard was published, we have performed tests for all the jumps to better understand the relay from IEC 60255-181 point of view, and to add more information that can help the reader.

Note also that since this relay is a "Type 1" relay (par.4.2.3), it would have been possible to test the start time by stopping the SVERKER 900 with the operate contact, by setting the delay time in the relay to 0 ms.

The relay manual informs about a typical start time of 100 ms (par.4.2.4). We have measured a start time of approximately 185 ms, using all the 4 standardized frequency jump methods.

The start time that we have measured is away from what ABB declares (185 ms against 100 ms).

We have contacted ABB and the interesting reply is in par. 4.8.

4.7. Testing the operate time of the overfrequency relay.

4.7.1. Introduction

The best way to test the operate time of the overfrequency relay without interpreting too much the IEC standard, is to measure the time distance between the start (pick-up) signal and the operate (trip) signal. This is the measurement of the "relay time delay".

As the relay is of "Type 1", this time is then added to the start time that was measured in the previous paragraphs by using two clear and well-defined testing methodologies[21], to get the operate time (par.3.3.3).

For this test it is not important to create any type of realistic test condition, as the simple functionality (and eventually accuracy, if wished[22]) of the overfrequency relay internal timer is measured..

As consequence of this concept, the simplest test that is able to cause the protection function to start (pick-up) and operate (trip) can be used[23].

With SVERKER 900 we will use the pre-fault and fault sequence, where only the frequency changes from the nominal value (or any other value below the threshold, if really wished) to a value well above the threshold to be 100% sure the relay operates (for example, 1 Hz above the threshold). The phase angle will not be corrected, so the test will create a phase shift when the frequency changes.

The time difference between start and operate signals is measured by using the extra timer available in SVERKER 900. The Extra Timer is set to start with activation of the start (pick-up) contact, and to stop by activation of the operate (trip) contact.

4.7.2. Connections

Figure 31 shows the connections to the SVERKER 900.

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[21] *based on the application: where there is a prevalence of rotating masses (inertia), the standardized ramps will be considered, where there is prevalence of static generation, smart grid (very low inertia), the sudden frequency change will be considered.*

[22] *The accuracy of digital timers is today so high, that there is no practical need to measure it in commissioning/maintenance tests, unless the test results are suspicious and deeper investigations are required*

[23] *IEC 60255-181 requires using the sudden change frequency test (par.3.3.2), which introduces the complexity of correcting the phase angles to make sure the generated voltages are continuous. Once the intention of this test is understood, it is non-controversial to provide a test with a frequency jump where the phase angles are not corrected at all. This has impact (eventually) on the start time, but we are not measuring the start time, we are measuring the time difference between the activation of the start and operate signals.*

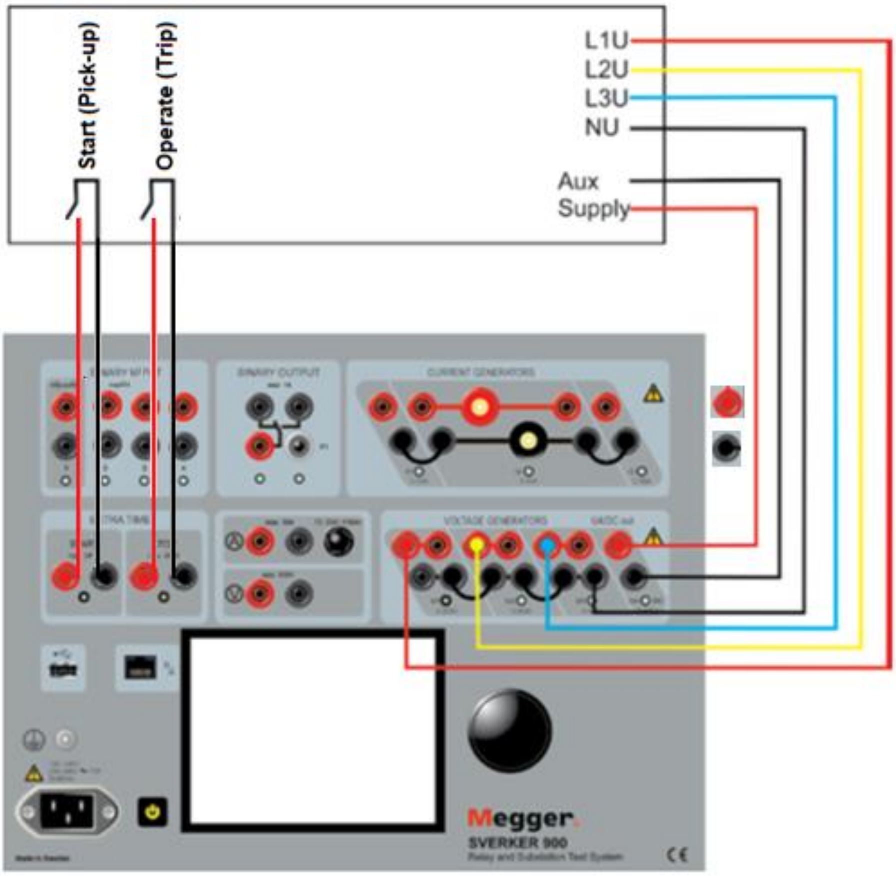

Figure 31. Schematic diagram representing the connections of the 3 voltage generators of SVERKER 900 to ABB overfrequency protection relay in RET670. The start signal is connected to the “START BI” of the Extra Timer. The operate signals is connected to the “STOP BI” of the Extra Timer.

Figure 32 show the settings for starting and stopping the Extra Timer of SVERKER 900:

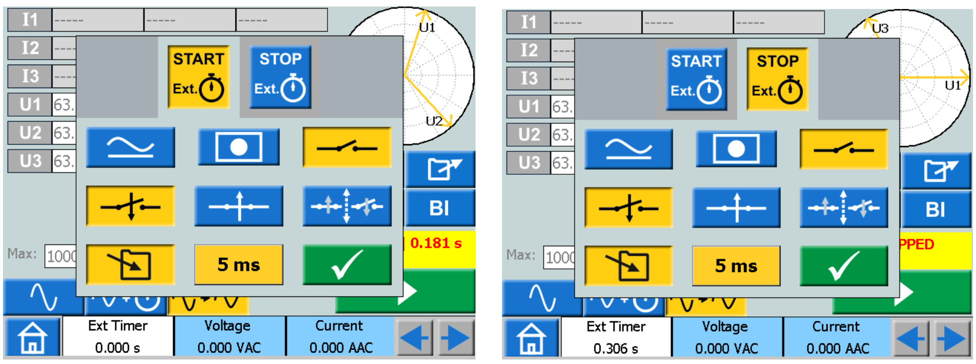

Figure 32.Settings for the Extra Timer to be started on activation of start signal of the relay and to be stopped on activation of operate signal of the relay.

4.7.3. Setting pre-fault and fault values

The pre-fault value is chosen to be 50 Hz frequency, nominal rated voltage of the RET 670, for one second. Fault frequency is chosen to be 1 Hz over the frequency threshold (51,3 Hz), and to underline that there is no need to be exact on this value, 52 Hz will be chosen.

Note that there are no corrections on the phase angles between pre-fault and fault, which means that the injected voltages will not be continuous (Figure 33) and will be similar to what shown in Figure 30 page 23.

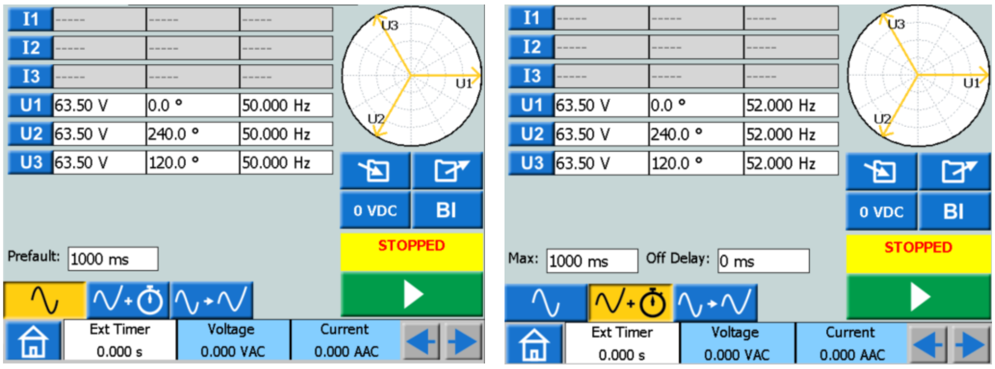

Figure 33.Pre-fault and fault settings for measuring the internal relay delay time.

4.7.4. Test execution and results

By tapping on  and then on , the test will start. The test result is given by the value of the Extra Timer (Figure 34).

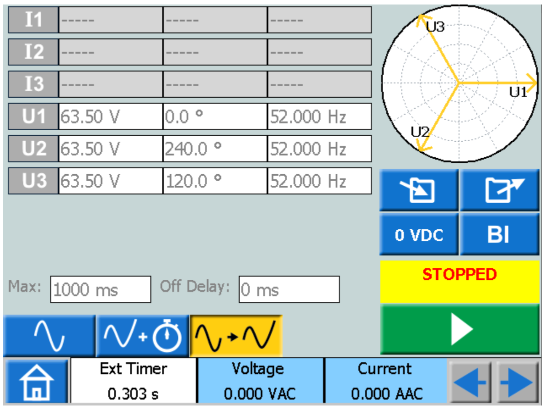

Figure 34.Test result is shown by the Extra Timer (303 ms).

This test has been repeated 5 times and the test results are available in the following table, where also the average value is calculated:

Test Nr.	**Result from Extra Timer** **(Time difference between Start and Operate)**	**Error from 300 ms**
1	306 ms	6 ms
2	303 ms	3 ms
3	306 ms	6 ms
4	306 ms	6 ms
5	303 ms	3 ms
Average	**304,8 ms**	**4,8 ms**

4.7.5. Conclusions for delay operate time

ABB RET 670 declares a timer error of +/- 0,5% of setting value +/- 10 ms (par.4.2.4).
This means an error of:
0,5% (300 ms) +/- 10 ms = +/-1,5 ms +/-10 ms = **+/- 11,5 ms**

Considering that this measurement is conditioned by the variation of the response time of the contacts, and considering this variation to be of the order of 1 ms, our measurement shows that the protection relay timer is well inside the accuracy declaration, and the test is passed.

4.8. Conclusions for RET670 relay.

The overfrequency relay in RET670 has a start time of approximately 90 ms for conventional applications (test with standardized frequency ramps) and a start time of approximately 185 ms for “smart grid” applications (tests with sudden frequency jump).

For the operate time, we need to add the time delay to the start time and get the final table, which gives a clear description of the protection function.

Application	RET670 Start Time	RET670 Operate time (time delay setting 300 ms)
Rotating masses, inertia	Approx. 90 ms (par.4.5.7)	Approx. 390 ms
Static generation, no inertia	Approx. 185 ms (par.4.6.6)	Approx. 485 ms

4.8.1. Explanations from Hitachi ABB Power Grids

We have contacted the relay manufacturer (par. 7.2) for having an explanation about the results of our tests and here the interesting reply:

For the start time/operate time at frequency jumps:

Frequency shall not jump in the traditional power system. If this happens in the invertor based system this might mean actually a fault (inverters do strange staff then), islanding etc and is not an event for which the frequency relay shall react except if this condition do not persist for a longer time.

In Hitachi ABB Power Grids opinion, the frequency is a statistical quantity. It cannot be calculated instantaneously; otherwise, the relay would possibly react even during CB switching in the power system, which can have disastrous consequences, especially during more complex conditions in the power system, such is for example an under-frequency load-shedding event, when multiple/many CBs will open throughout the network in relatively short time[13]. Therefore, appropriate measures have been done in the relay algorithm, which ensure that the frequency function reacts in accordance with regulation and requirements, existing at the beginning of this millennium when the relay was designed. Consequently the start time as given in this document are observed during testing.

For the relay documentation according to IEC 60255-181:2019:

Hitachi ABB has performed the type tests of their frequency relays according to the IEC standard and the future version of protection IEDs will have the performance declarations according to the requirements of IEC 60255-181.

5. Simplified testing of RET670 with SVERKER 900.

5.1. Introduction.

The following paragraphs are difficult to understand without that the previous par.3 and par.4 are understood.

One time in the life, please make sure you have gone through them. Later on, feel confident to use this simplified test method.

In this method we will not use the start (pick-up) signal of the relay, but only the operate (trip) signal[24].

5.2. About the overfrequency relay under test: ABB RET670.

The overfrequency relay is the same relay (RET670) we tested in par.4, and also the settings are the same.

Additionally to the settings, repeated here for convenience (see par.4.2.1):

- f_start = 51,3 Hz
- Timer = Definite time = 300 ms

we know that the relay is of "Type 1" (see par.3.3.3 and par.4.2.3). This means that the settable delay time of 300 ms has to be added to the relay start time to get the operate time.

The relay start time is approximately 90 ms (from par.4.5.8) for tests with "frequency ramp" and it is of approximately 185 ms (from par.4.6.7) for tests with "frequency jump".

The relay operate time has to be reasonably expected as:

- Approx. 90 ms + 300 ms = approx. 390 ms for tests with "frequency ramp"
- Approx. 185 ms + 300 ms = approx. 485 ms for tests with "frequency jump"

5.3. Connecting SVERKER 900 to the ABB RET670.

The voltage generators of SVERKER 900 are star-connected to the phase voltage inputs of RET670 to generate 3 three phase symmetrical voltages.

Connect the operate signal of overfrequency protection in RET670 to SVERKER 900. Figure 35 shows the connections.

---

[24] *Be aware that the start signal is a very important signal for frequency and frequency related protections (ROCOF), as it is often used to block some other protection relays or start some load shedding logics. You should consider "strange" that the start signal is not available for testing.*

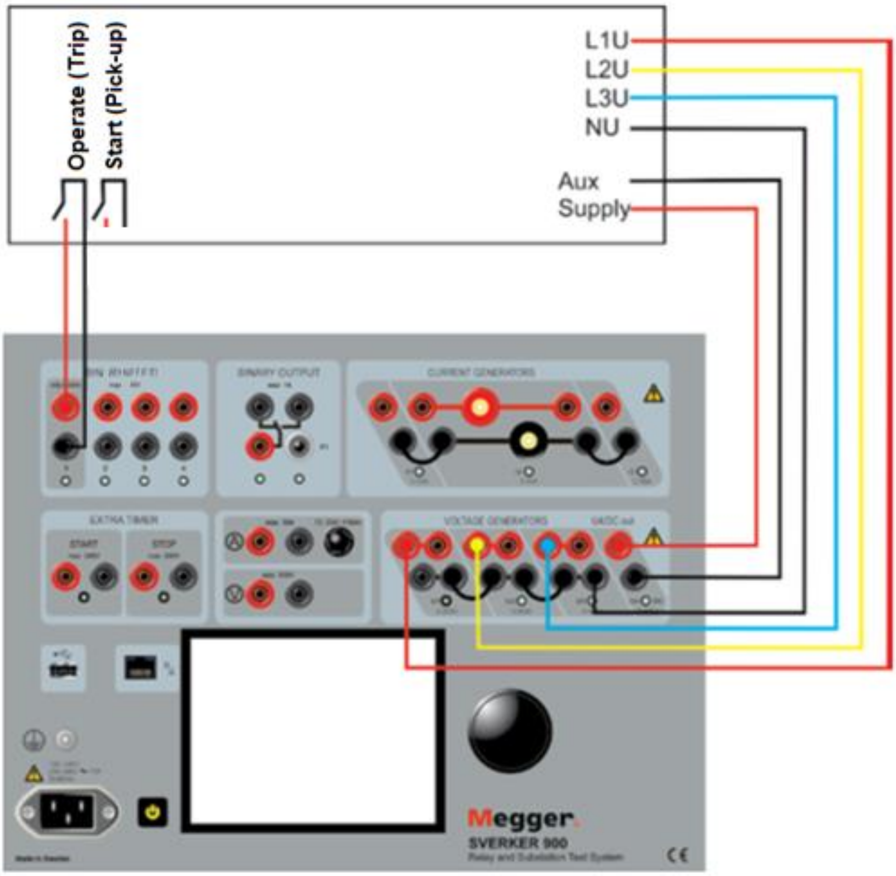

Figure 35. Schematic diagram representing the connections of the 3 voltage generators of SVERKER 900 to ABB protection relay RET670. Only the operate (trip) signal of the overfrequency protection function is connected to SVERKER 900.

5.4. Testing the Start level of overfrequency relay.

The idea is to generate a "manual frequency ramp", with the minimum step allowed by SVERKER 900. Start to inject nominal voltage(s) with a frequency below the start level, typically 2 or 3 times the tolerance (2 mHz), and **slowly** increase the frequency with the knob, until the relay operates (trips). As the expected operate time of the relay is not more than 500 ms (par.5.2), wait approximately 2 or 3 times this value before increasing the frequency with the knob: between one or 2 seconds.

Set SVERKER 900 to stop the generation at the activation of binary input 1 (operate contact), free contact sensing, as in Figure 36.

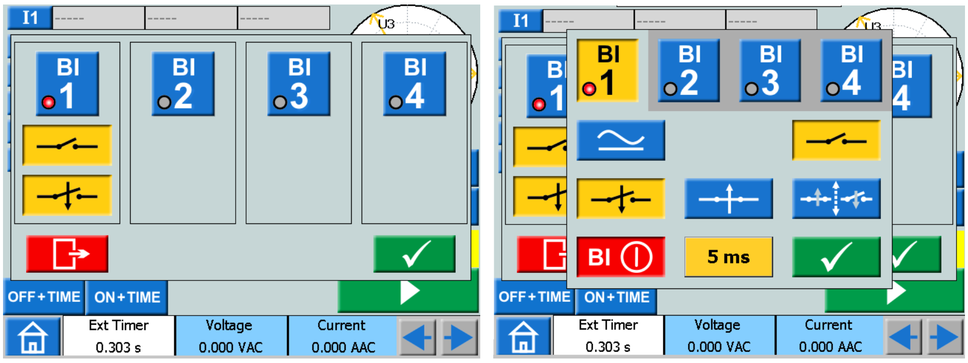

Figure 36. SVERKER 900 stops the generation on the operate (trip) contact, which is connected to Binary Input 1.

We will start generating a three phase voltage system of secondary 63,5 V (secondary rated voltage of the relay) at a frequency reasonably far away from the tripping level of 51,30 Hz. In general every frequency relay has a tolerance better than 20 mHz, so starting 50 mHz away is a safe margin.: 51300 mHz – 50 mHz = 51250 mHz = 51,25 Hz[25]

Press . The generation from SVERKER 900 starts with the setup shown in Figure 37.

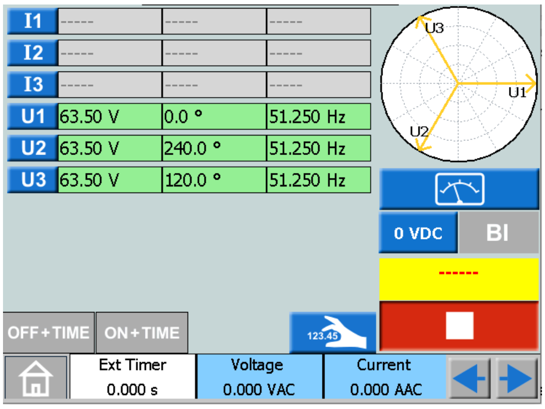

Figure 37. Start of the "manual frequency ramp at nominal voltage level, at 51,250 Hz.

Press now and select the frequencies for the three voltages (by tapping on them) (Figure 38):

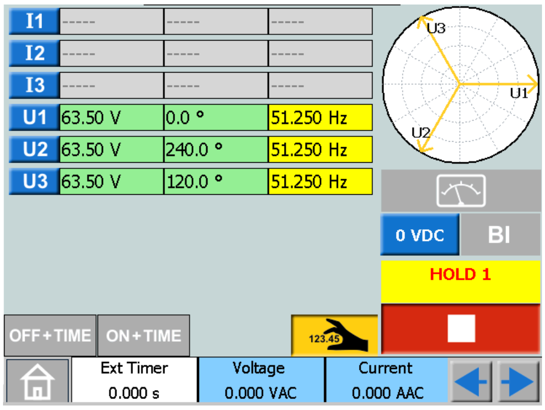

Figure 38. Selecting the frequencies for voltages U1, U2 and U3 and pressing "HOLD".

The frequency is incremented by the knob rotation. Slowly rotate the knob (1 mHz at a time), waiting between 1 and 2 seconds from one step to the next step. The test is stopped when the relay activates the operate contact.

The relay operates (trips) at exactly 51,3 Hz, as Figure 39 shows:

---

[25] *If the relay trips at the first generation, start a little bit more far away.*

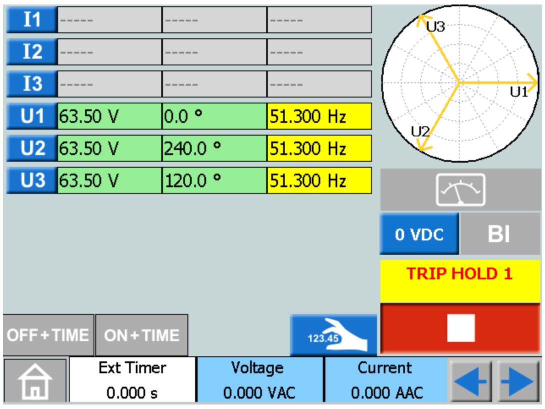

Figure 39. Operate (trip) of overfrequency protection. The threshold has been detected.

Press now  and see the test results, that can be saved in the report, if you want (Figure 40).

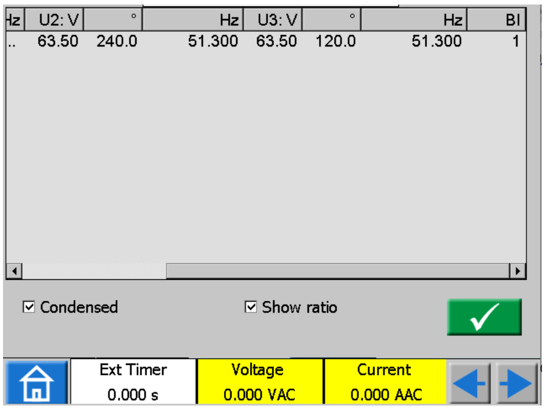

Figure 40. Test results after stopping the test

The test was repeated several times, and the measurement is confirmed.

5.4.1. Conclusions for start level

The relay threshold has been tested to be 51,3 Hz. The setting is 51,3 Hz.
Error is 0 mHz and the given accuracy is 2 mHz.
The test is passed[26].

---

[26] *With such small tolerance of the relay, it may be good practice to measure this threshold 5 times and report the average value of this measurement.*

5.5. Testing the operate time of overfrequency relay with standardized frequency ramp.

5.5.1. Introduction.

Unless we have indications for using a special frequency ramp, we will use the standardized ramp of 1 Hz/s. Indications for using other ramps can be given by the presence of ROCOF relay. Look at the settings of the ROCOF relay and stay below that setting to avoid ROCOF to operate[27].

The frequency ramp is setup in the Ramp tool of SVERKER 900, in paragraphs 5.5.2, 5.5.3 and 5.5.4.

5.5.2. Pre-fault values.

The pre-fault value is the power system nominal frequency (50 Hz in our example), and it shall be injected for at least 1 second[28].

Figure 41 shows the pre-fault value of 1 second, at power system nominal frequency of 50 Hz[29] and rated secondary voltage of 63,5 V.

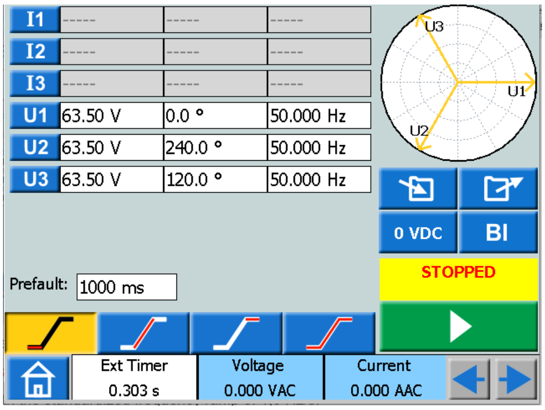

Figure 41. Pre-fault values for the standardized frequency ramp in SVERKER 900

5.5.3. Setup the frequency ramp of 1,0 Hz/s.

The relay will be tested with the standardized frequency ramp of 1,0 Hz/s.
Just write 1,0 Hz/s in the ramp conditions (Figure 42),

27 *ROCOF operates on the frequency rate of change, and not on the frequency* [9]

28 *The pre-fault condition is meant to let the protection relay to stabilize the frequency measurement, before the power system fault occurs (the frequency ramp starts). If in doubt on how long to set the pre-fault, set it to 5 seconds. So far, no protection relays have been observed to need more than 5 seconds to stabilize the frequency measurement.*

29 *For 60 Hz power systems, it will be 60 Hz. Note that for these tests, the frequency ramp shall always start at the nominal power system frequency (per IEC 60255-181)*

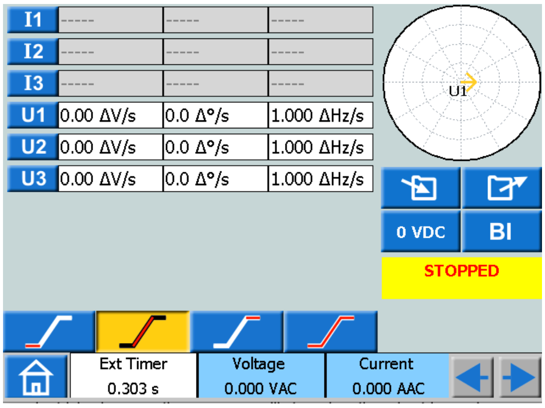

Figure 42. Setting the ramp values of 1,0 Hz/s in SVERKER 900

5.5.4. Setup the final point of the frequency ramp.

The final point of the ramp can be tricky, because the ramp now will stop when the relay trips and not when the relay starts. Set the ramp at the highest setting value the relay allows. It is very probable that the relay can well measure the frequency at that value (and even more of course, but we do not need to be exact here). RET670 allows a setting of 75 Hz (par.4.2.1).

The final point of the frequency ramp is set to 75 Hz[30], as shown in Figure 43.

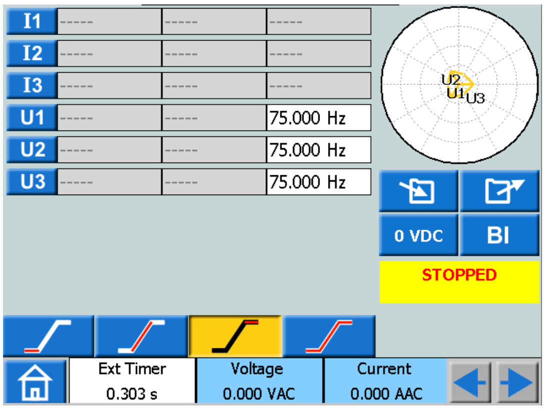

Figure 43. Setting the final state of the frequency ramp to 75 Hz.

5.5.5. Run the test and measure the operate (trip) time from SVERKER 900.

By tapping on  and then on , the test will start (Figure 44):

---

[30] *In case the relay will not trip for any reason (wrong connections for example), the ramp will stop at 75 Hz. So we do not risk to "Inject" into the relay frequencies that the relay is not able to measure correctly. As said, RET670 will of course measure correctly higher frequencies than 75 Hz, but we are not searching for the limit. We just want a comfortable frequency to stop without risking that the relay measures wrongly (with risk of causing false trips or starts)*

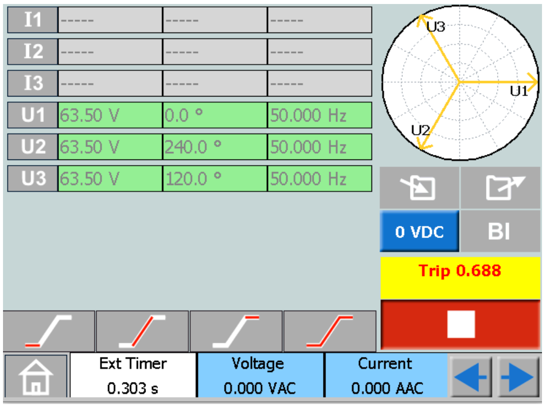

Figure 44. Initial situation right after the ramp started. The timer "Trip" is counting.

The ramp stops when the trip contact activates, as shown in Figure 45. SVERKER 900 reports the duration of the ramp, from when it started to when it was stopped.

SVERKER 900 reported a ramp duration of 1,691 s (1691 ms).

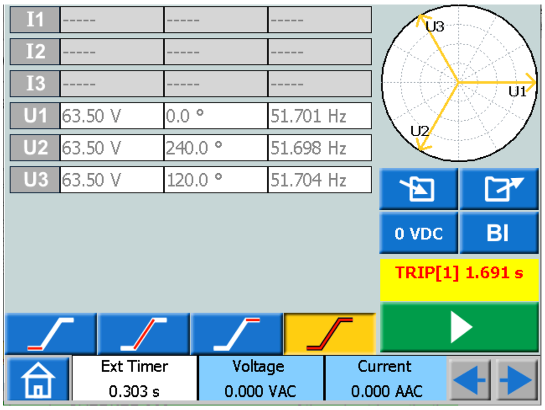

Figure 45. Final situation shown by SVERKER 900 as consequence of the relay trip.

Remove from this result, the time that SVERKER 900 needed to go from 50 Hz to the relay setting, 51,3 Hz. This time is 1,3 seconds and needs to be manually calculated, with this formula:

$$Operate\ Time\ (s) = SVERKER\ 900\ Time\ (s) - \frac{(Relay\ setting\ start\ f\ (Hz) - Nominal\ f\ (Hz))}{Frequency\ Ramp\ Speed\ \left(\frac{Hz}{s}\right)}$$

That can be simplified into:

$$Operate\ Time\ (s) = SVERKER\ 900\ Time\ (s) - K\ (s)$$

Where the variable K is calculated by;

$$K(s) = \frac{(Relay\ setting\ start\ f\ (Hz) - Nominal\ f\ (Hz))}{Frequency\ Ramp\ Speed\ \left(\frac{Hz}{s}\right)}$$

With the following data::

SVERKER 900 Time = 1,691 s (See Figure 45)
Relay setting start = 51,3 Hz
Nominal f = 50 Hz (the beginning of the frequency ramp, always equal to the nominal frequency)
Frequency Ramp Speed = 1,0 Hz/s

The variable K is:

$$K\ (s) = \frac{(Relay\ setting\ start\ f\ (Hz) - Nominal\ f\ (Hz))}{Frequency\ Ramp\ Speed\ \left(\frac{Hz}{s}\right)} = \frac{(51{,}3\ Hz - 50\ Hz)}{1{,}0\ Hz/s} = 1{,}3s = 1300\ ms$$

And the start time:

$$Operate\ \ Time\ (s) = 1691\ (ms) - 1300\ ms = 391\ \text{ms}$$

Figure 46 shows graphically the numbers just calculated.

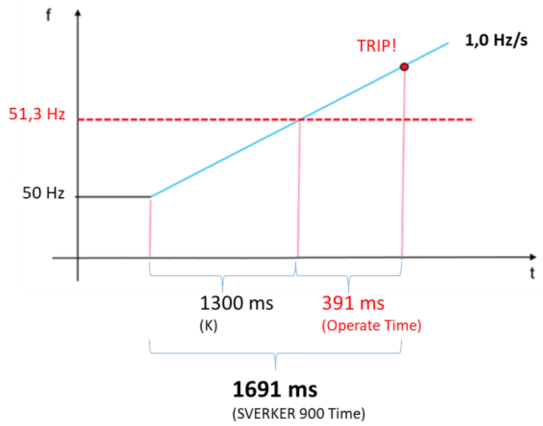

Figure 46. Graphical representation of the calculated values with SVERKER 900.

By performing the same test 5 times we get the following results from SVERKER 900:

Test Nr. 1,0 Hz/s ramp	**Result from SVERKER 900**	**K**	**RET670 Operate (trip) time**
1	1691 ms	1300 ms	391 ms
2	1690 ms	1300 ms	390 ms
3	1690 ms	1300 ms	390 ms
4	1688 ms	1300 ms	392 ms
5	1687 ms	1300 ms	394 ms
AVERAGE	**1689,2 ms → 1689 ms**		**389,2 ms → 389 ms**

5.5.6. Conclusions for operate time with standardized frequency ramps

We have measured an operate time of approximately 390 ms, which is in line with what we expected (par.5.2)
The operate time that we have measured is reasonable and we declare the test passed.

5.6. Testing the operate time of overfrequency relay with “frequency jump”.

5.6.1. Introduction

Even if the IEC 60255-181 standard requires the frequency jump to have a continuous waveform (which means consider a phase correction for the jump), we will “risk” and will not create that condition, to have the test simpler and faster. The voltage waveforms will be discontinuous or, better said, we create a phase shift when we do the frequency jump (see Figure 29 and Figure 30 for better understanding).

If we get results far away from the expected results, we will redo the test without phase shift (see par.4.6.1) because maybe the relay start time (and operate time as consequence) is affected by the phase shift.

The test for a “frequency jump” of 0,5 Hz is chosen.
We know (par.5.2) that the expected operate time should be approximately 490 ms.

5.6.2. Pre-fault values

Set the pre-fault values in the pre-fault and fault instrument of SVERKER 900. Note that the pre-fault values have to be the nominal power system frequency (50 Hz or 60 Hz).

Set the pre-fault values to be 1 second long or more (Figure 47):

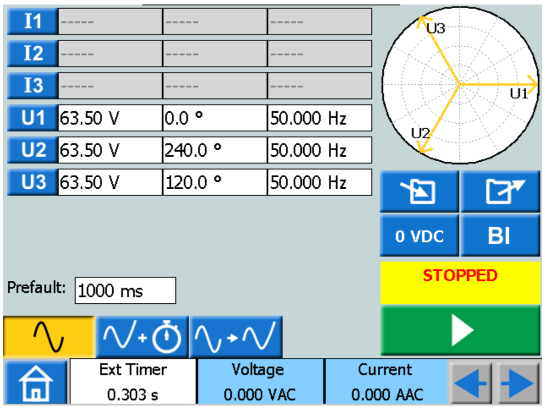

Figure 47. Pre-fault values for the frequency “jump” in SVERKER 900. Set the duration of the pre-fault to 1 second (or more).

5.6.3. Fault values

Set the fault values, (fault frequency = 51,8 Hz), as in Figure 48. Keep the same phase angles as for the pre-fault (no phase shift correction).

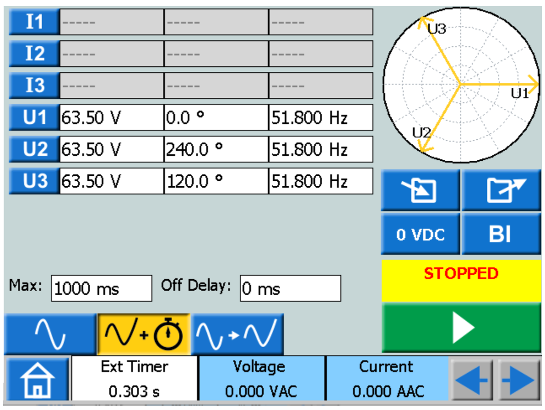

Figure 48. Fault values for the frequency “jump” of 0,5 Hz in SVERKER 900.

5.6.4. Run the test and measure the operate time from SVERKER 900.

Press  and then run the test by pressing , the result is clearly shown in Figure 49.

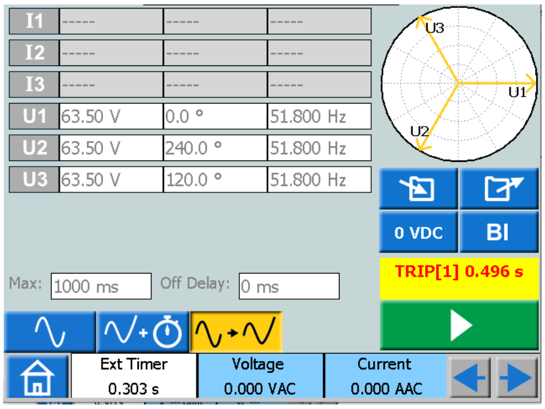

Figure 49. Operate time (trip time) result for a frequency jump of 0,5 Hz.

By performing the same test 5 times, we get the following results from SVERKER 900:

Test Nr. 0,5 Hz Jump	**Result from SVERKER 900**
1	496 ms
2	487 ms
3	489 ms
4	489 ms
5	490 ms
AVERAGE	**490,2 ms → 490 ms**

5.6.5. Conclusions for operate time with frequency jumps

We have measured a trip time of approximately 490 ms. This is in line with what we know from the previous tests (more rigorous tests, par.4.5, 4.6 and 4.7) but not according to what the manual declares.

The manual declares a start time of typically 100 ms. 300 ms of time delay + 100 ms of “start time” would make 400 ms, and we have measured 490 ms, confirming the tests done.

We have contacted ABB and the interesting reply is in par.5.7

We have also seen that the operate time (and as well the start time) in ABB RET670 are not affected by the phase shift, when performing frequency jump tests, because the operate time measured with the simplified tests is in accordance to the operate time calculated with the more rigorous tests (start time + time delay settings, see par.4.6.7, 4.7.5 and 4.8).

5.7. Conclusions for simplified tests RET670.

The overfrequency relay in RET670 has an operate time of approximately 390 ms for conventional applications (test with standardized frequency ramp), and an operate time of approximately 490 ms for “smart grid” applications (tests with sudden frequency jump), as shown in the table below:

Application	**RET670 Operate time (for a time delay setting 300 ms)**
Rotating masses, inertia	Approx. 390 ms
Static generation, no inertia	Approx. 490 ms

We have not measured the “start time”, but we know that the relay is of “Type 1”, so the start time can be obtained by removing the setting value of the time delay (300 ms) from the operate time, getting the following measurements:

Application	RET670 Start time
Rotating masses, inertia	Approx. 90 ms
Static generation, no inertia	Approx. 190 ms

Confirming the measurements obtained in a more rigorous way, in par.4.8.

5.7.1. Explanations from Hitachi ABB Power Grids

We have contacted the relay manufacturer (par. 7.2) for having an explanation about the results of our tests and here the interesting reply:

For the start time/operate time at frequency jumps:

Frequency shall not jump in the traditional power system. If this happens in the invertor based system this might mean actually a fault (inverters do strange staff then), islanding etc and is not an event for which the frequency relay shall react except if this condition do not persist for a longer time.

In Hitachi ABB Power Grids opinion, the frequency is a statistical quantity. It cannot be calculated instantaneously; otherwise, the relay would possibly react even during CB switching in the power system, which can have disastrous consequences, especially during more complex conditions in the power system, such is for example an under-frequency load-shedding event, when multiple/many CBs will open throughout the network in relatively short time[13]. Therefore, appropriate measures have been done in the relay algorithm, which ensure that the frequency function reacts in accordance with regulation and requirements, existing at the beginning of this millennium when the relay was designed. Consequently the start time as given in this document are observed during testing.

For the relay documentation according to IEC 60255-181:2019:

Hitachi ABB Power Grids has performed the type tests of their frequency relays according to the IEC standard and the future version of protection IEDs will have the performance declarations according to the requirements of IEC 60255-181.

6. Conclusions.

6.1. Two test approaches: one "conservative", one "simplified"

In this application note, we have followed different approaches. In par.4 we have followed testing methods very close to the descriptions and definitions of IEC 60255-181 standard ("conservative"). The number of tests performed compared to the standard is still simplified; for example the relay is only tested with the actual setting and not for all the setting range, which is typical of type testing, but the definitions of start time, setting of the time delay and operate time are kept. Nevertheless, the relay under tests were produced before the IEC 60255-181 standard was published, so the relay manuals do not obviously give information related to the standard. As the relays were somehow "unknown" from IEC 60255-181 point of view, we spent more time in testing many details.

The tests also required the use of both start contact and trip contact from the relays.

In par.5 we have followed a simplified procedure. In this method, the definitions of start time, setting of delay for the operate time and operate time are also kept, but merged together in the operate time. It is recommended to follow this simplified procedure when the "relay behaviour" is more or less known. Possibly after having done the tests according to par.4 (if the relay under test is produced before the standard was published), or when the relay is tested according to IEC 60255-181, because many information are available on its behaviour already from the user's manual, similar to what described in par.5.2.

Comparing the results from par.4 and 5, we have also seen that the phase shift at frequency jump tests seems to not have impact on the start/operate times of the ABB RET670.
It is good to know how the test should be formally carried (par.3.3.2) in case such relays are encountered in the future.

6.2. One shot is not enough

Even with the risk to be pedantic, "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.

When test results are Ok, 5 "shots" are usually enough. If it is necessary to show/report that something is wrong, at least 10 shots are recommended.

IEC 60255-1xx uses a statistical approach in many relay performances and relay manufacturers will follow this concept the more they will follow IEC 60255-1xx standards [3]

6.3. I have always tested with the "frequency jump". What should I do now?

In the commissioning and maintenance tests of the past, frequency relays have been tested with a sort of "sudden frequency jump method". "Sort of" because the jump level is usually unclear, and eventually the phase shift generated in the jump is also unclear.

When approaching the same relay again, it can be recommended to ask to the plant/relay owner if the relay has always behaved correctly in the past. If the answer is yes, perform the test in the same way as it was done before. If the answer is "doubtful", maybe there have been some unwanted operations.

In agreement with the relay owner, perform the tests in the same way it was done in the past (in order to confirm the same behaviour of the relay for that test), and additionally perform the test according to the IEC 60255-181 by using the standardized frequency ramp. If strange behaviour is detected, it is worth to have a look to that relay … will the relay behave correctly in case of an eventual frequency dynamic scenario with similar rate of change (Hz/s) of what was tested?

If the test results are not adequate for the application, it is recommended to not blame the relay manufacturer, nor the customer that has bought it and installed many years ago. The competence on frequency related protection functions has grown with the experience of the last years, especially when more smart grid applications have been implemented. The relay was with any probability designed before the IEC 60255-181 standard was published. Accept the situation and start the procedures to replace it with another relay that better performs dynamically, if unwanted operations cannot be tolerated.

If you feel you have problems in explaining the IEC 60255-181 standard to your customer or colleagues, feel free to contact Megger, we are always available, as IEC members, to give explanations to anybody interested in standardisation topics.

6.4. About “smart grid applications

In this document, there is many times the reference to “smart grid applications”. Especially associated to frequency jump tests. Hitachi ABB Power Grids correctly reacted on that and asked for a more rigorous explanation, with this comment:

Please note that the “frequency jump test” is not a “smart grid test”. It is just a strange test when a single inverter change frequency what can happen in a quite small system, but it cannot be said that it is representative for a smart grid system. A smart grid system may have situations that are more complex, for example, when several inverters in the system do their own frequency jump as they are “pleased”. What should do a frequency relay in these situations?

The above comment is fully correct. Frankly speaking we do not know today what really means “smart grid applications”, in the given context. We do not know yet what it is required to the relay to do when and if those “frequency jumps” will occur. We only know that they can occur and that it is important to describe the relay behaviour for those situations as well.

In the IEC standard 60255-181:2019 there is no reference to smart grid applications (even if in the beginning there was). The tests with frequency jumps are referred as (Figure 50):

> Such tests represent a power system condition that changes its frequency with a certain speed, a typical condition in a power system having electromechanical inertia.
>
> The upper limit of this condition is the “frequency jump”, which may occur in an environment, where the power generation is predominantly carried by static inverters. In this condition the power system frequency can suddenly change from one initial nominal value to the final value, above or below the protection setting respectively for overfrequency and underfrequency functions,

Figure 50. Extract from IEC 60255-181:2019, the description of the “Frequency jump tests”. Smart Grid application is not mentioned, but the reference to it is clear.
From IEC 60255-181:2019 ed.1.0 “Copyright © 201x IEC Geneva, Switzerland. www.iec.ch”

We have preferred to keep the simplification “smart grid applications” in the document and have a clarification note here. One important message of the standard is that not only the classical protection relays need to follow the standard (as the two relays we have tested here), but also embedded frequency functions in inverters or other equipment that are often part of a distributed generation system (smart grids) must follow this standard, of course with the necessary interpretations. I also know that “smart grid applications” was the main topic that has driven the publication of this standard, so with the risk to simplify too much, I think the link to smart grid should remain.

7. Acknowledgments

7.1. IEC

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7.2. Former ABB (Hitachi ABB Power Grids from 2020-07-01)

Thanks to Zoran Gajic, from Hitachi ABB Power Grids in Västerås, Sweden, for having commented our test results on ABB RET670.

Zoran Gajic is Senior Application Engineer at Hitachi ABB Power Grids, Grid Automation Products in Vasteras, Sweden. He received his MSEE degree with honours from the University of Belgrade, Serbia in 1990 and PhD degree in electrical engineering from Lund University, Sweden

in 2008. Since 1993 he has been working in the area of power system protection and control within ABB Group of companies, where he had various engineering positions. From 2008 to 2015 he was ABB Global Product Manager for Generator and Transformer Protection. He has published many technical papers in the relay protection area and holds more than fifteen patents. Zoran has participated in different CIGRE, IEC and PSRC/IEEE working groups and was the Convenor for CIGRE Working Group "Modern techniques for Protecting Busbars in HV Networks". In 2014 he received Technical Committee Award from Cigré Study Committee B5 (Protection and Automation).

Zoran is member of IEC TC 95/MT 4 (par.2).

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8.3. Stefan Larsson

Stefan Larsson is product manager for relay test equipment and tools at Megger Sweden AB

9. Revisions.

9.1. Revision 1.

This is the first revision of the application note.

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