

# INTERNATIONAL STANDARD

## NORME INTERNATIONALE



**Measuring relays and protection equipment –  
Part 181: Functional requirements for frequency protection**

**Relais de mesure et dispositifs de protection –  
Partie 181: Exigences fonctionnelles relatives aux protections de fréquence**



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**Relais de mesure et dispositifs de protection –  
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ICS 29.120.70

ISBN 978-2-8322-6496-6

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| FDIS        | Report on voting |
|-------------|------------------|
| 95/402/FDIS | 95/409/RVD       |

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 60255 series, published under the general title *Measuring relays and protection equipment*, can be found on the IEC website.

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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<br>function numbers | IEC 61850-7-4 logical<br>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).

This document does not cover synchronizing or synchronism-check functions.

This document does not specify the functional description of additional features often associated with frequency functions such as undervoltage blocking,  $df/dt$  or  $\Delta f/\Delta t$  supervision, current supervision or power supervision (f/P function). Only their influence on the frequency protection function is covered in this document.

Frequency and rate of change of frequency measurement outputs provided by protection devices are not in the scope of this document.

Additionally, this document does not explicitly cover the frequency relays based on current as the input energizing quantity but the principles covered by this document can be extended to provide guidance for these applications.

The general requirements for measuring relays and protection equipment are defined in IEC 60255-1.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60255-1, *Measuring relays and protection equipment – Part 1: Common requirements*

IEC 60050-103, *International Electrotechnical Vocabulary – Part 103: Mathematics – Functions*

IEC 60050-447, *International Electrotechnical Vocabulary – Part 447: Measuring relays*

IEC 60050-601, *International Electrotechnical Vocabulary – Chapter 601: Generation, transmission and distribution of electricity – General*

IEC 61850 (all parts), *Communication networks and systems for power utility automation*

IEC 61869 (all parts), *Instrument transformers*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-103, IEC 60050-447, IEC 60050-601, and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

### 3.1

#### **input energizing quantity**

energizing quantity which either by itself constitutes the characteristic quantity or helps to constitute it

Note 1 to entry: For the frequency protection function, the input characteristic quantity could be voltage.

[SOURCE: IEC 60050-447:2010, 447-03-02, modified – The note to entry has been replaced by a new note.]

### 3.2

#### **characteristic quantity**

electric quantity, or one of its parameters, the name of which characterizes a measuring relay or protection equipment and the values of which are the subject of accuracy requirements

Note 1 to entry: For underfrequency protection and overfrequency protection, the characteristic quantity is frequency; for rate of change of frequency protection (ROCOF), the characteristic quantity is rate of change of frequency.

[SOURCE: IEC 60050-447:2010, 447-07-01, modified – The examples have been replaced by a new note to entry.]

### 3.3

#### **characteristic curve**

curve which represents the relationship between the theoretical specified operate time and the characteristic quantity

### 3.4

#### **setting value of the characteristic quantity**

$G_s$

value of the characteristic quantity used as the reference for the definition of the characteristic curve

### 3.5

#### **start value**

value of the characteristic quantity at which a measuring relay or protection equipment starts (picks up)

Note 1 to entry: Start value is also called "pick-up value".

### 3.6

#### **reset value**

value of the characteristic quantity at which a measuring relay or protection equipment resets

### 3.7

#### **start time**

time interval between the instant a specified change is made in the value(s) of the input energizing quantity(ies) which will cause the measuring relay or protection equipment in initial condition or reset condition to start and the instant it starts

Note 1 to entry: Start time is also called "pick-up time".

### 3.8

#### **operate time**

time interval between the instant a specified change is made in the value(s) of the input energizing quantity(ies) which will cause the measuring relay or protection equipment in initial condition or reset condition to operate and the instant it operates

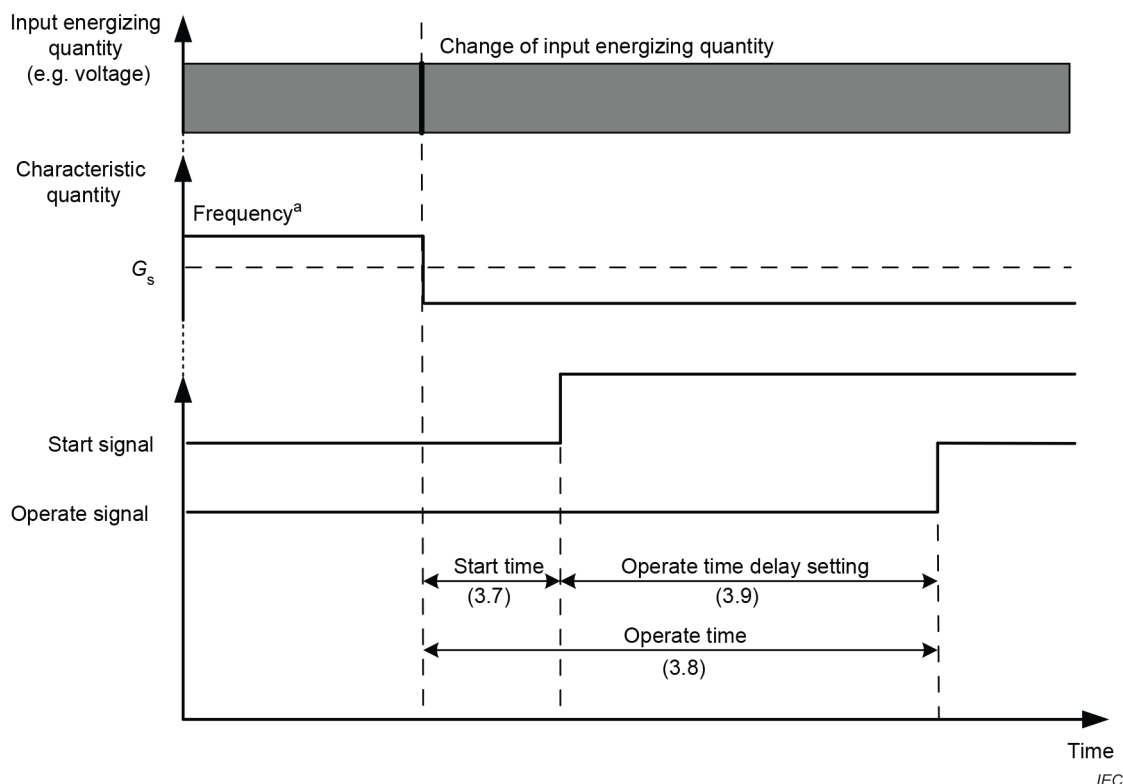
Note 1 to entry: The operate time of the protection function is the sum of the start time and the operate time delay setting.

### 3.9

#### **operate time delay setting**

intentional time delay defined by a user setting which is activated by the start signal to assert the operate signal

Note 1 to entry: The operate time of the frequency protection function is the sum of the start time (pick-up time) and the operate time delay setting. The difference between operate time and operate time delay setting is specified in Figure 1. Figure 1 is based on a sudden frequency change only to simplify the definition of start time initialization.



<sup>a</sup> Take underfrequency protection as an example.

**Figure 1 – Operate time and operate time delay setting**

### 3.10 disengaging time

time interval between the instant a specified change is made in the value(s) of the input energizing quantity(ies) which will cause the measuring relay or protection equipment in operate condition to disengage and the instant it disengages

### 3.11 reset time

duration between the instant a specified change is made in the value(s) of the input energizing quantity(ies) which will cause the measuring relay or protection equipment to reset and the instant it resets

[SOURCE: IEC 60050-447:2010, 447-05-06, modified. See figure 6.]

### 3.12 reset hysteresis

absolute value of the difference between the reset value and the start value of the protection function

### 3.13 reset ratio

ratio between the reset value and the start value of the protection function

Note 1 to entry: Reset ratio is used for rate of change of frequency, as defined in 4.4.2 and 5.8.

### 3.14

#### **operating range**

range for which the measuring relay under specified conditions is able to perform its intended function(s) according to the specified requirements

Note 1 to entry: When accuracy requirements have to be met, see effective range (IEC 60050-447:2010, 447-07-08).

Note 2 to entry: A minimum level of input energizing quantity, such as voltage, is required in order to calculate the power frequency correctly.

[SOURCE: IEC 60050-447:2010, 447-03-16, modified – Note 2 to entry has been added.]

### 3.15

#### **effective range**

part of the operating range of an input energizing quantity or characteristic quantity within which the accuracy requirements are met

Note 1 to entry: This note applies to the French language only.

[SOURCE: IEC 60050-447:2010, 447-07-08]

### 3.16

#### **rate of change of frequency protection**

##### **ROCOF**

protection function intended to operate when frequency changes by a given amount per unit of time

Note 1 to entry: This note applies to the French language only.

### 3.17

#### **period**

##### **$T$**

smallest positive difference between two values of the independent variable at which the values of a periodic quantity are identically repeated

Note 1 to entry: If  $f(t)$  denotes a periodic quantity, then  $f(t + T) = f(t)$ .

Note 2 to entry: The term "period duration" is sometimes used in the case of a function of time.

Note 3 to entry: The symbol  $T$  is mainly used for the period when the independent variable is time.

[SOURCE: IEC 60050-103:2009, 103-06-01]

### 3.18

#### **frequency**

##### **$f$**

reciprocal of the period

Note 1 to entry: The symbol  $f$  is mainly used when the period is a time. The symbol  $\nu$  (nu) is mainly used in optics.

Note 2 to entry: For a sinusoidal waveform, frequency is the first derivative of the phase angle (see IEC/IEEE 60255-118-1: 2018). A detailed description can be found in Annex D.

[SOURCE: IEC 60050-103:2017, 103-06-02, modified – Note 2 to entry has been replaced by a new note.]

### 3.19

#### **power frequency**

conventionally, the values of frequency used in the electricity supply systems

[SOURCE: IEC 60050-601:1985, 601-01-05]

## 4 Specification of the function

### 4.1 General

An example of the protection function with its inputs, outputs, measuring element, time delay characteristics and functional logic is shown in Figure 2. The manufacturer shall provide the functional block diagram of the specific implementation.

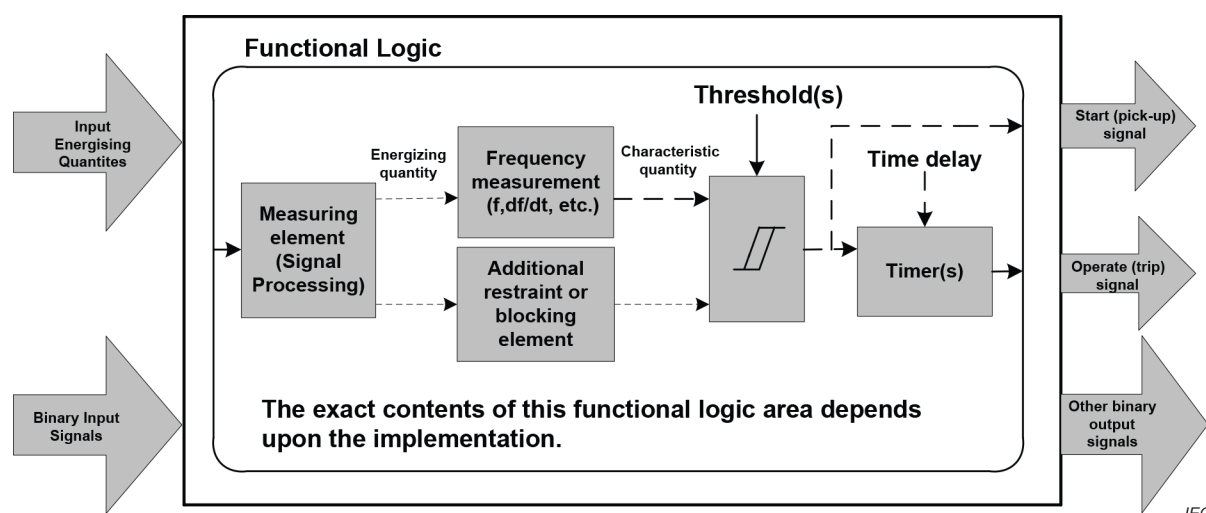


Figure 2 – Simplified protection function block diagram

### 4.2 Input energizing quantities / energizing quantities

The input energizing quantities are the measuring signals, for example, voltages. In the case of analogue entries, their ratings and relevant standards are specified in IEC 60255-1. Input energizing quantities can be acquired via direct connection with primary conductors (for example, low-voltage busbars) or from instrument transformers – for example, voltage transformer, VTs, according to IEC 61869 (all parts) – or as a data packet over a communication port using an appropriate communication protocol (such as that of IEC 61850-9-2 and, more specifically, IEC 61869-9).

The protection function documentation shall state the type of input energizing quantities used by the protection function. Examples are:

- single or multi phase-to-earth or phase-to-neutral voltage measurement;
- single or multi phase-to-phase voltage measurement;
- phase (line) currents.

The manufacturer shall specify which energizing quantities are used for the operation of the frequency protection. As illustrated in Figure 2, the energizing quantities can differ to that of the input energizing quantities, for example:

- use of phase-to-earth or phase-to-phase voltage;
- use of two different voltage sources;
- use of derived signals from phase quantities, for example, positive sequence voltage or calculated phase-to-phase voltages, etc.;
- use of current, such as phase current or positive sequence current, etc.

The manufacturer shall specify which characteristic quantity is used for the operation of frequency protections. Examples are:

- power frequency measurement;
- rate of change of frequency ( $df/dt$ ) measurement (ROCOF).

Power frequency and  $df/dt$  quantities can be measured over a different time period (for example, one or several power frequency cycle(s)). This time period can be fixed or adjustable according to a user setting. When this time period is adjustable, the setting value has an impact on the time characteristic (for example, start time).

The manufacturer shall advise if the frequency or ROCOF measurement is impacted by a user setting (for example, frequency averaged over selectable number of cycles). In such case, the manufacturer shall declare the impact of these settings on the function performances and recommend settings for the relevant functional tests and for applications.

All of these characteristic quantities are based on a basic frequency measurement. Different algorithms exist and a selection of them are described in Annex C.

When the protection device is not equipped with voltage inputs, or when voltage signals are not present or under a blocking threshold, frequency measurement could be performed on line current inputs. Such a feature is generally used to manage the frequency tracking and not recommended to manage frequency protections. The manufacturer shall declare if phase currents are used as input energizing quantities within their frequency protections. Performances of frequency protection based on phase current are not covered by type tests defined in Clause 6, but the test principle may be extended to provide guidance for these applications.

### 4.3 Binary input signals

If any binary input signals (externally or internally driven) are used, their influence on the protection function shall be clearly described on the functional logic diagram. An additional textual description may also be provided if this can further clarify the functionality of the input signals and their intended usage.

Binary input signals to this function may emanate from a number of different sources. Examples include:

- traditionally wired to physical (typically optically isolated) inputs;
- via a communications port from external devices (e.g. using IEC 61850 GOOSE signals);
- via internal logical connections from other functional elements within the relay; for example, undervoltage blocking,  $df/dt$  or  $\Delta f/\Delta t$  supervision, current supervision and power supervision (f/P function);
- via internal logic within the frequency protection elements.

The method of receiving the signal is largely irrelevant except to conform to operational requirements. Definitions, ratings and standards for binary input signals are specified in IEC 60255-1.

### 4.4 Functional logic

#### 4.4.1 Operating characteristics

##### 4.4.1.1 General

The relationship between operate time and characteristic quantity can be expressed by means of a characteristic curve. The shape of this curve shall be declared by the manufacturer via an equation (preferred) or graphical means.

This document specifies an independent time characteristic (i.e. definite time delay).

The independent time characteristic is defined in terms of the setting value of the characteristic quantity  $G_S$  and the operate time delay setting  $t_{\text{delay}}$ . When no intentional time delay is used, then the protection function is denoted as an instantaneous function.

#### 4.4.1.2 Characteristic for underfrequency function

For the underfrequency function,  $t_{(G)} = t_{\text{delay}}$  when  $G < G_S$ . The independent time characteristic is presented in Figure 3.

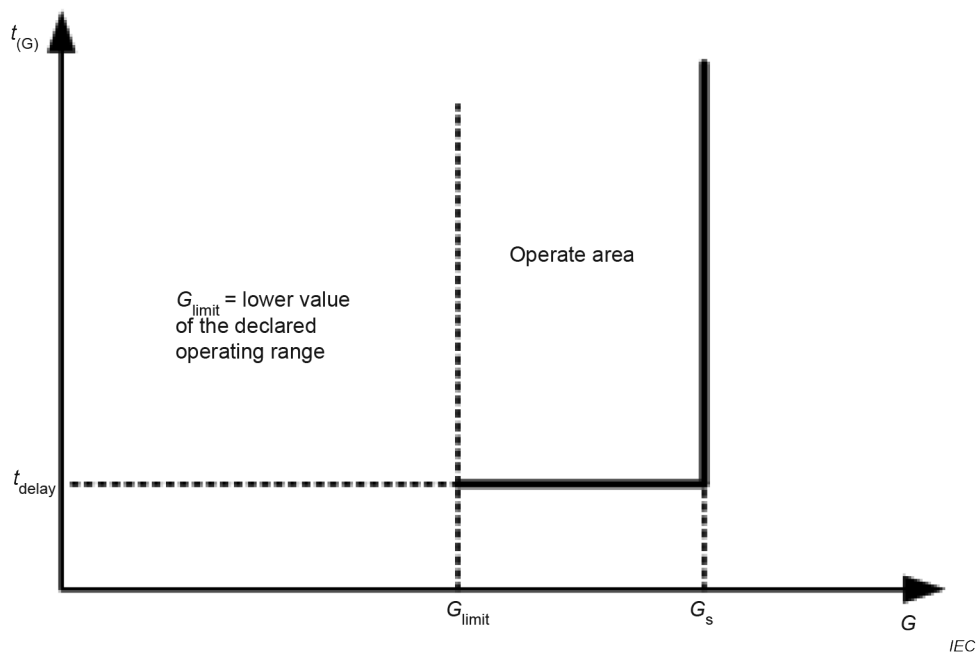


**Figure 3 – Underfrequency independent time characteristic**

NOTE The accuracy of time characteristics is guaranteed over the effective range, but the function is expected to operate over the operating range, as described in 5.2.

#### 4.4.1.3 Characteristic for overfrequency function

For the overfrequency function,  $t_{(G)} = t_{\text{delay}}$  when  $G > G_S$ . The independent time characteristic is presented in Figure 4.

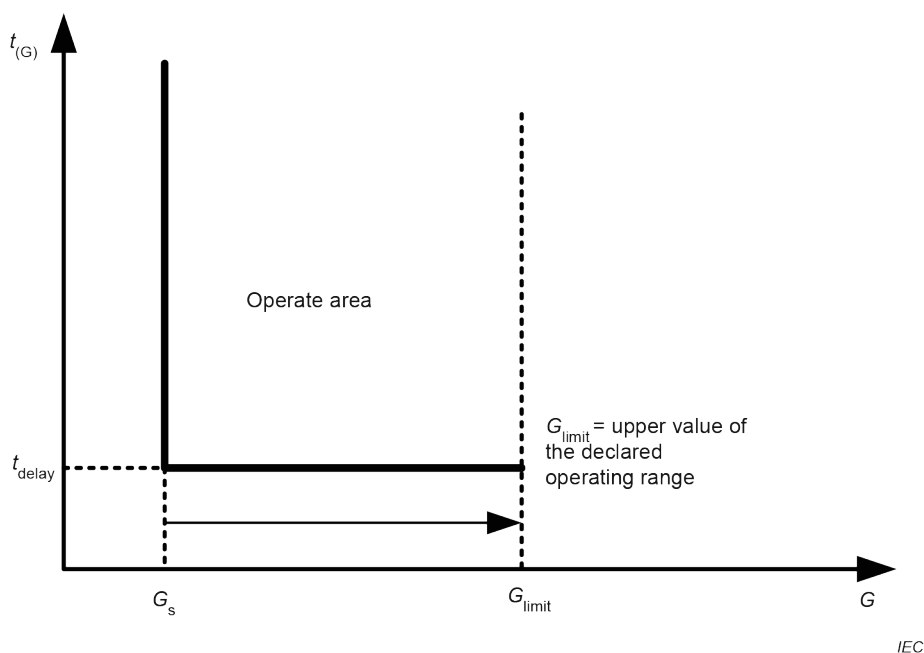


**Figure 4 – Overfrequency independent time characteristic**

NOTE The accuracy of time characteristics is guaranteed over the effective range, but the function is expected to operate over the operating range, as described in 5.2.

#### 4.4.1.4 Characteristic for rate of change of frequency (ROCOF)

For ROCOF function,  $t_{(G)} = t_{\text{delay}}$  when  $|G| > |G_S|$ . The independent time characteristic is presented in Figure 5.

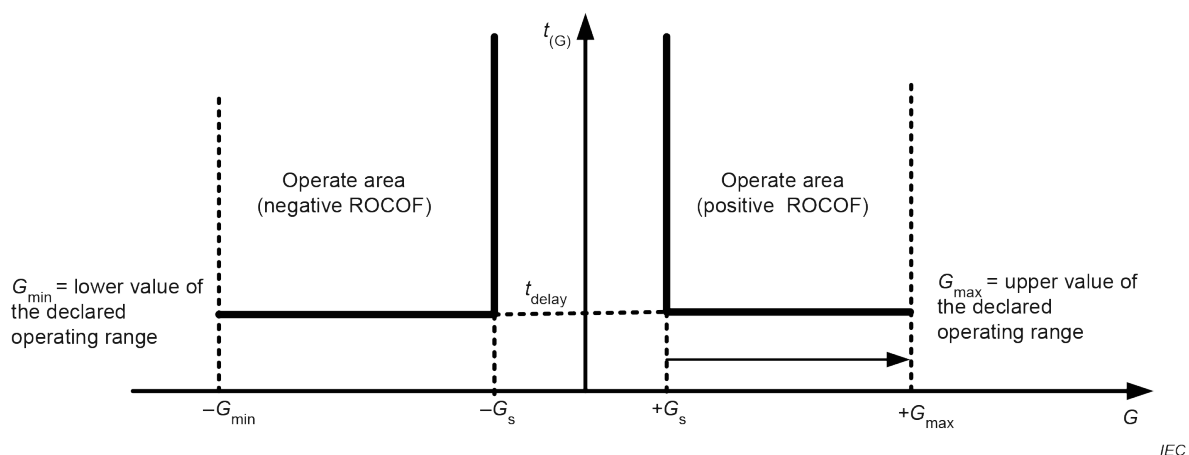


**Figure 5 – ROCOF independent time characteristic (for negative or positive ROCOF)**

NOTE The accuracy of time characteristics is guaranteed over the effective range, but the function is expected to operate over the operating range, as described in 5.2.

The operate characteristic can be defined only for a positive, a negative or both for positive and negative ROCOF, according to a user setting. Such an operate characteristic shall be declared by the manufacturer. The positive and negative thresholds can be different and managed with two different ROCOF elements.

#### 4.4.2 Reset characteristics

Generally, there is no intentional delay on reset. The function shall return to its reset state when:

- $G > G_s + (\text{reset hysteresis})$ , for the underfrequency function;
- $G < G_s - (\text{reset hysteresis})$ , for the overfrequency function; and
- $|G| < (\text{reset ratio}) \times |G_s|$  or  $|G| < |G_s| - (\text{reset hysteresis})$ , for ROCOF function, or for the applicable formula when signed  $df/dt$  is used.

And

$$\text{reset hysteresis} = |\text{reset value} - \text{operate value}|$$

$$\text{reset ratio} = \frac{\text{reset value}}{\text{operate value}}$$

For ROCOF functions, the reset ratio can be associated with an absolute minimum reset hysteresis applicable for lower threshold values. In that case, the reset value is the greater value between the declared reset ratio and reset hysteresis (for example, reset ratio 98 % with minimum reset hysteresis 40 mHz/s).

With frequency protections, only the disengaging time shall be declared. An intentional reset time characteristic is generally not provided with frequency functions. The difference between disengaging time and reset time is recalled in Figure 6.

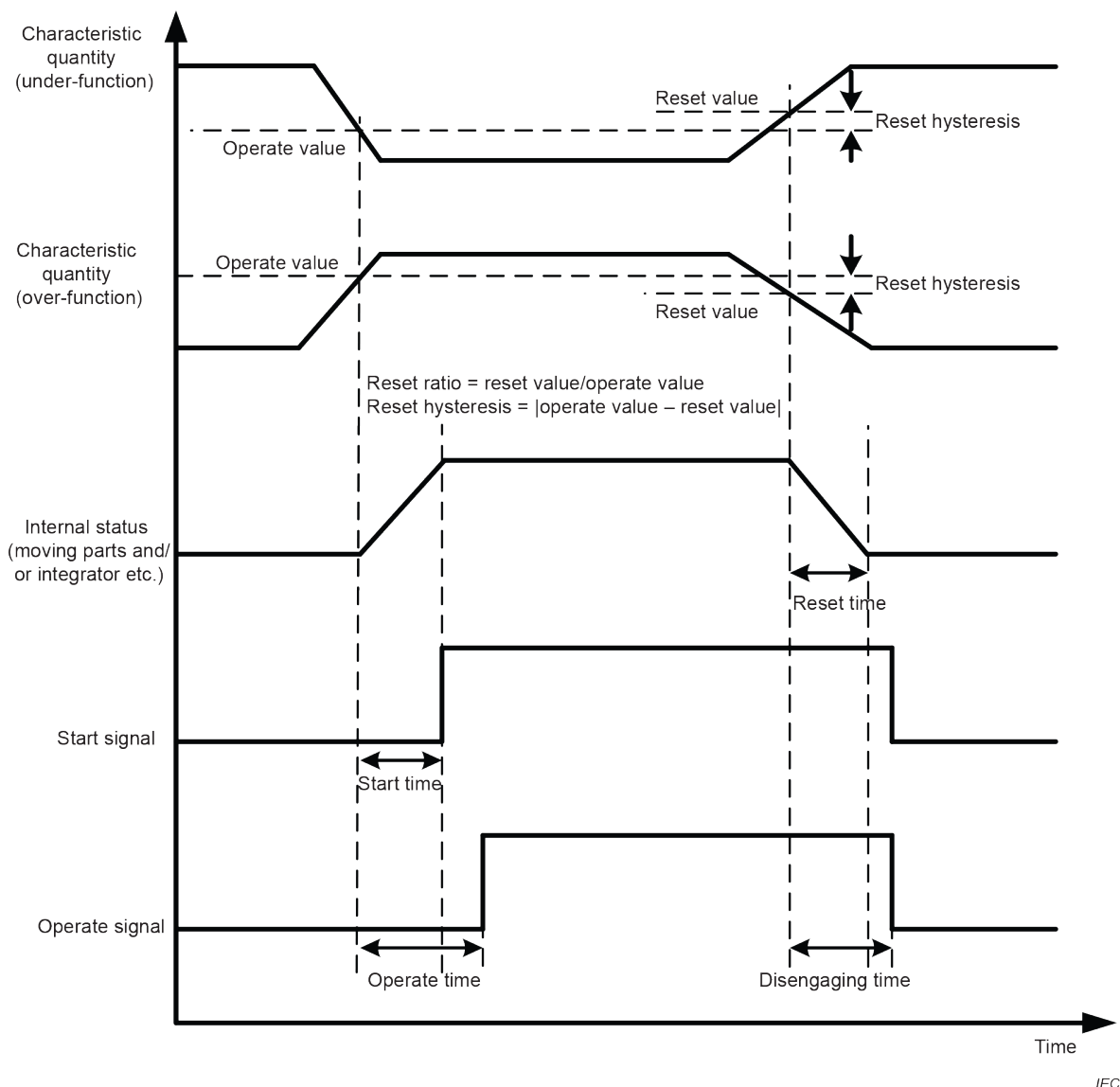


**Figure 6 – Explanatory diagram for start, operate, disengage and reset**

## 4.5 Additional influencing functions/conditions

### 4.5.1 General

The following conditions may affect the behaviour of the frequency function. These conditions can be detected by additional function elements which then interact with the frequency protection through binary inputs in pre-defined ways, for example, blocking frequency protection when the voltage levels are below prescribed limits. The performance of these specific characteristics shall be described by the manufacturer in the documentation. The associated functional tests are not described in this document, but the test methods used to check these characteristics shall be described by the manufacturer in the type test report.

### 4.5.2 Specific characteristics for under/over frequency function

Examples of specific characteristics for under/over frequency function are:

- undervoltage blocking;
- three-phase unbalance supervision;
- $df/dt$  supervision;

- current supervision;
- power supervision (f/P function).

#### **4.5.3 Specific characteristics for rate of change of frequency (ROCOF) function**

Examples of specific characteristics for ROCOF function are:

- undervoltage blocking;
- three-phase unbalance supervision;
- under/over frequency supervision;
- current supervision.

### **4.6 Binary output signals**

#### **4.6.1 General**

Binary output signals from this function may be available in a number of different forms. Examples include:

- traditionally wired from physical protection device output contacts;
- via a communications port to external devices;
- via internal logical connections to other functional elements within the protection device;
- via internal logic within the frequency protection elements.

The method of providing the signal is largely irrelevant except to conform to operational requirements. Definitions, ratings and standards for binary output signals using contacts are specified in IEC 60255-1.

#### **4.6.2 Start (pick-up) signal**

The start signal is the output of measuring and threshold elements, without any intentional time delay.

The manufacturer shall specify, to the extent required for proper application and testing, the information about the start signals, characteristic and logic used for the starting/fault detection element, required setting parameters, meaning and usage of settings, and output signals asserted by the function.

If a start signal is not provided, the manufacturer shall give information on how to conduct testing related to the start signal as defined in Clause 6.

#### **4.6.3 Operate (trip) signal**

The operate signal is the output of measuring and threshold elements, after completion of any intentional operating time delay. In the case of instantaneous elements, this signal may occur at the same time as the start signal (if provided).

#### **4.6.4 Other binary output signals**

If any other binary output signals are available for use, their method of operation shall be clearly shown on the functional logic diagram. Additional textual description may also be provided if this can further clarify the functionality of the output signal and its intended usage.

## 5 Performance specification

### 5.1 General

Since this document specifies the minimum requirements for frequency protection, only the performance specifications appropriate for meeting these minimum requirements are considered and presented here. This document also defines how the performance related to these minimum requirements shall be documented by the manufacturer.

### 5.2 Effective and operating ranges

Tables 2 and 3 show examples on how the effective range and operating range shall be declared by the manufacturer for under/over frequency and ROCOF protections. Depending on the frequency function technology, the range can differ from the given table, where the values are given as an example to indicate the format of the data. The effective and operating ranges shall be declared by the manufacturer and the data shall be published in accordance with the format shown in Tables 2 and 3. When effective and operating ranges are expressed according to rated voltage or nominal frequency, the manufacturer shall declare the values of rated voltages or nominal frequencies authorized by the protection function.

**Table 2 – Example of effective and operating ranges for over/under frequency protection**

| Quantity                                                                                                                                                                                                                                                                                                                                  | Effective range                           | Operating range                            |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|--------------------------------------------|
| Voltage                                                                                                                                                                                                                                                                                                                                   | 5 % to 150 % of rated voltage             | 2 % to 200 % of rated voltage              |
|                                                                                                                                                                                                                                                                                                                                           | 2,9 V to 86,6 V<br>(VT secondary voltage) | 1,5 V to 115,5 V<br>(VT secondary voltage) |
| Power frequency                                                                                                                                                                                                                                                                                                                           | 0,95 to 1,05 of nominal frequency         | 0,9 to 1,1 of nominal frequency            |
|                                                                                                                                                                                                                                                                                                                                           | 47,5 Hz to 52,5 Hz                        | 45 Hz to 55 Hz                             |
| NOTE The voltage range can be expressed in percent of rated voltage value or in absolute voltage value (VT secondary voltage). In the case of ranges declared with absolute values, the upper limit of the effective range is higher than accepted rated values (for example, rated value of 57,7 V for an effective range up to 86,6 V). |                                           |                                            |

**Table 3 – Example of effective and operating ranges for ROCOF protection**

| Quantity                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Effective range                           | Operating range                            |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|--------------------------------------------|
| Voltage                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 5 % to 150 % of rated voltage             | 2 % to 200 % of rated voltage              |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 2,9 V to 86,6 V<br>(VT secondary voltage) | 1,5 V to 115,5 V<br>(VT secondary voltage) |
| Power frequency <sup>a</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 0,95 to 1,05 of nominal frequency         | 0,9 to 1,1 of nominal frequency            |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 47,5 Hz to 52,5 Hz                        | 45 Hz to 55 Hz                             |
| ROCOF                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | –5 Hz/s to +5 Hz/s                        | –10 Hz/s to +10 Hz/s                       |
| NOTE The voltage range can be expressed in percent of rated voltage value or in absolute voltage value (VT secondary value). In the case of ranges declared with absolute values, the upper limit of the effective range is higher than accepted rated values (for example, rated value of 57,7 V for an effective range up to 86,6 V).                                                                                                                                                                                                                                                             |                                           |                                            |
| <sup>a</sup> In the event that the algorithm to measure the rate of change of frequency is not affected by the value of the frequency itself, the manufacturer shall write "not applicable". The behaviour of the ROCOF protection outside of the effective range of the power frequency shall be declared by the manufacturer. In any case, the power frequency range shall be consistent with the declared start time and the ROCOF setting range to perform the functional type tests described in Clause 6, where the initial power frequency used for the tests is equal to the nominal value. |                                           |                                            |

When phase currents are used as input energizing quantities for the frequency protection, the manufacturer shall declare the effective and operating ranges for the currents.

When the rating of the voltage inputs of the protection device have a withstand value associated with the value of flux (V/Hz), the manufacturer shall declare the maximum V/Hz curve versus the time that the voltage input can withstand.

### 5.3 Accuracy related to the characteristic quantity

The manufacturer shall declare the accuracy related to the characteristic quantity along with a setting value range over which it is applicable. In addition, the manufacturer shall also declare the behavior of the function over the declared operating range.

For under/over frequency, the accuracy shall be declared with an absolute frequency value (for example,  $\pm 10$  mHz). In addition to the absolute value, a relative value with respect to the setting value ( $G_s$ ) can be declared, and the accuracy error shall be the maximum of the two terms (for example, " $\pm 0,01$  % or  $\pm 10$  mHz, whichever is the greater").

For a ROCOF function, the accuracy shall be declared with a relative value with respect to the setting value ( $G_s$ ) or an absolute  $df/dt$  value or the combination of both values (for example, " $\pm 5$  % or  $\pm 15$  mHz/s, whichever is the greater"). The manufacturer can declare variable accuracies over the ROCOF setting range.

The test procedure to assess the accuracy related to the characteristic quantity is described in 6.2.1.

### 5.4 Start time for under/over frequency function

The start time of under/over frequency functions depends on several factors:

- initial power frequency value (generally close to the nominal frequency);
- final power frequency value (under simple steady state test conditions);
- the type of transition from the initial to the final value;
- the frequency measuring method, for example, frequency measurement based on an average over a sliding time period.

The start time shall be published by the manufacturer as a result of two different test methods:

- with a sudden change between the initial test frequency value and the final frequency value;
- with different constant frequency slopes ( $df/dt$ ) between the initial frequency value and the final frequency value.

More comprehensive information about test methodology and defined test points is provided in 6.3.2.

For each test method, the manufacturer shall provide the minimum, average (mean) and maximum start time based on the complete test points defined in 6.3.2. In addition, a graphical representation of the complete set of test results shall be provided. Clarification of the statistical terminology is provided in Annex B.

When the frequency measurement is based on an adjustable time period defined by a user setting, the start time shall be declared with the default setting value of such an adjustable time period.

### 5.5 Start time for rate of change of frequency (ROCOF) function

The start time of ROCOF functions depends on different factors, similar to under/over frequency functions. The start time shall be published by the manufacturer as a result of tests based on different slopes with constant frequency rate of change between the initial test frequency value and the end test frequency value.

More comprehensive information concerning test methodology and defined test points is provided in 6.3.3.

The manufacturer shall provide the mean (average), minimum and maximum start time based on the complete test points defined in 6.3.3. In addition, a graphical representation of the complete set of tests shall be provided with the mode and median values indicated. Clarification of the statistical terminology is provided in Annex B.

When the frequency measurement is based on an adjustable time period defined by a user setting, the start time shall be declared with the default setting value of such an adjustable time period.

## 5.6 Accuracy related to the operate time delay setting

The operate time delay is the time interval from the instant when the start (pick-up) signal is activated, to the instant when the operate signal is activated. This time is fixed by the operate time delay setting ( $t_{\text{delay}}$ ), defined in 3.9.

The maximum permissible error of the operate time delay setting shall be expressed as either:

- a percentage of the time setting value, together with a fixed maximum time error (where this may exceed the percentage value), whichever is greater (for example,  $\pm 5\%$  or  $\pm 20$  ms, whichever is greater); or
- a fixed maximum time error (for example,  $\pm 20$  ms).

The manufacturer shall declare the maximum limiting error related to the operate time delay setting along with the setting range of the time delay over which it is applicable.

The test procedure to assess the operate time delay setting is described in 6.4.

In some implementations, the internal measurement time may be included in the operate time and not be in addition to the time delay setting as defined above. The manufacturer shall declare how the operate time is managed in frequency functions.

## 5.7 Disengaging time

In frequency protection applications, it may be important to consider the disengaging time of the frequency protection stages when the frequency returns to normal conditions. This information has an impact on the time grading of different protection stages, on coordination of grid protection and generator protection, etc.

The manufacturer shall declare the disengaging time according to the test procedure described in 6.5.

If frequency protection is proposed with an intentional reset time, the manufacturer shall declare how the reset time is managed, and the associated test procedure shall be described in the type test report.

## 5.8 Reset hysteresis and reset ratio

For an under/over frequency function, the manufacturer shall declare the reset hysteresis reported in mHz (for example, reset hysteresis: 5 mHz).

For a ROCOF function, the manufacturer shall declare the reset value, which can be limited to a reset ratio (for example, reset ratio 98 %), or defined with a reset ratio associated with an absolute minimum reset hysteresis applicable for lower threshold values (for example, reset ratio 98 % with minimum reset hysteresis 40 mHz/s).

The test procedure to assess the reset hysteresis and the reset ratio is described in 6.2.2.

**NOTE** There is no direct relationship between the declared accuracy (5.3) and the declared reset hysteresis or reset ratio. The reset hysteresis or reset ratio is defined to hide the instability of the measurement and to avoid the chattering of the start signal. For example, the reset hysteresis can be below or above the declared accuracy of the characteristic quantity. The higher the measurement instability, the higher the reset hysteresis. The magnitude of the measurement instability is not directly linked to the measurement accuracy.

## **5.9 Accuracy related to restraint/blocking elements**

The manufacturer shall declare the restraint/blocking elements that are used. When the restraint/blocking elements are based on specific thresholds, as described in 4.5, the manufacturer shall declare the accuracy of these elements.

## **5.10 Performance with harmonics**

Non-linear load conditions or nearby presence of an HVDC network may create the presence of harmonics superimposed on the fundamental frequency of the voltages (and currents) measured by the frequency functions. The presence of harmonics on a steady state load can be simulated by steady state injection, and may affect the accuracy related to the characteristic quantity of the frequency functions.

The accuracy of frequency or ROCOF measurement in the presence of harmonics shall be checked according to the test procedure described in 6.6.

## **5.11 Stability in case of sudden voltage change (phase shift and magnitude shift)**

For under/over frequency and ROCOF functions, the manufacturer shall declare if the start signal is stable (no false operation) for a voltage change (magnitude or phase-shift) without a frequency change.

The influence of a voltage magnitude change and a voltage phase shift shall be checked according to the test procedure described in 6.7.

These tests are based on two typical scenarios:

- one test as set out in 6.7.2, based on voltage phase shift and magnitude change to be representative of a fault occurrence followed by fault clearing;
- one test as set out in 6.7.3, based on a total voltage drop followed by a voltage restoration to be representative of a complete voltage collapse representative of a close-up fault.

If the function is not stable (i.e. start signal occurs), the manufacturer shall declare the minimum time delay setting required to ensure the stability of the operate signal.

## **5.12 Voltage input requirements**

If voltage instrument transformers are used, the manufacturer shall declare the types of voltage transformers, according to IEC 61869 (all parts), which are required to maintain the claimed performance levels of frequency protections.

If direct low voltage connections are used, the rated voltage range shall be defined by the declared effective and operating voltage ranges, as defined in 5.2.

## 6 Functional test methodology

### 6.1 General

Clause 6 gives a detailed description of the tests to be performed to verify the frequency function accuracy and performance specification described in Clause 5. These tests are not intended for protection relay field commissioning or routine tests, where the manufacturer's instructions shall be used as a reference, although several test methodologies and performance requirements described in this document can also be applicable for commissioning/maintenance tests.

These tests are, as explained in Clause 5, a mandatory part of the type tests for the protection function. Detailed descriptions of the test conditions and of how test results shall be published in the manufacturer's documentation are provided. This allows a comparison of the technical requirements of the user with the protection function specifications given in the manufacturer's documentation.

These tests are designed in such a way to exercise all aspects of the hardware and firmware (if applicable) of the frequency protection function. This means that the injection of voltage (or current) shall be at the interface to the protection device, either directly into the conventional voltage transformer input terminals, or an equivalent digital signal with the appropriate protocol at the appropriate interface. Similarly, operation shall be taken from output contacts wherever possible or equivalent signals at an appropriate interface.

For the tests linked to time performance, the manufacturer shall declare with which output the start and operate time has been measured – for example, trip binary output contact, or solid state output, or GOOSE message according to IEC 61850 (all parts). If the protection device can provide different output media, then the manufacturer shall declare how the time performances are affected.

For protection devices where some or all settings are in primary values, one voltage transformer ratio shall be selected for performing the tests (if applicable).

In order to determine the accuracy of the frequency functions under steady state conditions, the injected characteristic quantity shall be a sinusoid of rated voltage amplitude and its frequency should be varied according to the test requirements. During transitions, the injected signal shall be continuous, with no step change in its phase angle or magnitude, except in its frequency, unless otherwise specified. It is allowed to adjust the voltage level to keep within the withstand requirements of voltage inputs related to the rated volt/hertz level. If the frequency functions are based on phase current, the same test methodology shall be followed, and the test conditions shall be fully described in the type test report.

Several functional tests described in Clause 6 are based on waveform signals with a constant frequency slope. The equation of these test waveforms is specified in the normative Annex A. When the test signal is based on a COMTRADE file (or other binary format test files) and replayed using a test device, the sampling frequency of the test waveform shall be at least 4 800 Hz. The sampling rate shall meet the Nyquist criteria depending on frequency content of tested signals.

The sampling frequency of 4 800 Hz is based on the preferred sampling rate defined for instrument transformers with a digital interface (IEC 61869-9). The sample rate of 4 000 Hz is authorized for legacy equipment, according to Table 902 in IEC 61869-9:2016.

In 6.1 to 6.7, the test settings to be used are expressed as a percentage of the available setting range.

For under/over frequency functions, the minimum/maximum values of the setting range can have a significant difference to the nominal values. To limit the number of test points and to focus on typical settings, the tested setting range shall be defined as being from the frequency rated value to the upper setting range value (with positive percentage values) or lower setting range value (with negative percentage values). The actual setting to be used can be calculated using the following formula:

For test points defined with positive percentage values:

$$G_s = (f_{\max} - f_R) \times X + f_R$$

For test points defined with negative percentage values:

$$G_s = (f_R - f_{\min}) \times X + f_R$$

where

- $G_s$  is the setting value; the tested value can be rounded according to the step size of the frequency function;
- $f_{\max}$  is the maximum available setting value;
- $f_{\min}$  is the minimum available setting value;
- $f_R$  is the nominal frequency (for example, 50 Hz, 60 Hz);
- $X$  is the test point percentage value divided by 100 expressed in test methodology (see Tables 4, 9, 13, 14, 27).

For example, based on the frequency settings defined in Table 4, and assuming the setting range is 40 Hz to 70 Hz (setting range not dependent on the nominal frequency  $f_R$ ), the actual frequency settings to be used would be (the rounded values can be used according to the setting step size):

- with 50 Hz nominal power frequency: 40 Hz, 49 Hz, 49,5 Hz, 49,75 Hz, 49,9 Hz, 50 Hz, 50,2 Hz, 50,5 Hz, 51 Hz, 52 Hz, 70 Hz;
- with 60 Hz nominal power frequency: 40 Hz, 58 Hz, 59 Hz, 59,5 Hz, 59,8 Hz, 60 Hz, 60,1 Hz, 60,25 Hz, 60,5 Hz, 61 Hz, 70 Hz.

For ROCOF functions, the actual setting to be used can be calculated using the following formula:

$$G_s = (G_{s\_max} - G_{s\_min}) \times X + G_{s\_min}$$

where

- $G_s$  is the setting value; the tested value can be rounded according to the step size of the frequency function;
- $G_{s\_max}$  is the maximum available setting value;
- $G_{s\_min}$  is the minimum available setting value;
- $X$  is the test point percentage value divided by 100 expressed in test methodology (see Tables 7, 11, 16, 24, 28).

For example, based on the ROCOF setting defined in Table 7, and assuming the setting range is 0,1 Hz/s to 10 Hz/s, the actual ROCOF settings to be used would be: 0,1 Hz/s, 0,595 Hz/s, 1,09 Hz/s, 3,07 Hz/s, 6,04 Hz/s, 10 Hz/s. The rounded values can be used according to the setting step size.

## 6.2 Determination of steady state errors related to the characteristic quantity

### 6.2.1 Accuracy of the start value

#### 6.2.1.1 Under/over frequency

##### 6.2.1.1.1 Description of the generated frequency ramp

The test method shall be based on a pseudo-continuous frequency ramp.

The ramp starts at the initial frequency  $f_{\text{initial}}$ . The initial frequency shall be above/under the expected start value  $G_s$  for under/over frequency function, with a minimum difference equal to 5 times the declared frequency accuracy (example: for the overfrequency function, with a declared accuracy of  $\pm 10$  mHz, the initial frequency is equal to  $G_s - 0,05$  Hz).

The ramp can be interrupted after the activation of the start signal. The activation of the start signal shall be a "solid activation"; this means no chattering of the signal with several transitions high–low–high during the injection of the step. The only chattering allowed in the signal is by the output contact, which has a reasonable bouncing time of less than 4 ms. If the start signal oscillates for more than 4 ms, the start activation shall not be considered and the ramp shall continue with the next step. For other output media, such as IEC 61850 GOOSE or static output, no chattering at all shall be present in the transition of the start signal, in order to be considered valid.

The test method is illustrated in Figure 7, which is applicable to an overfrequency function.

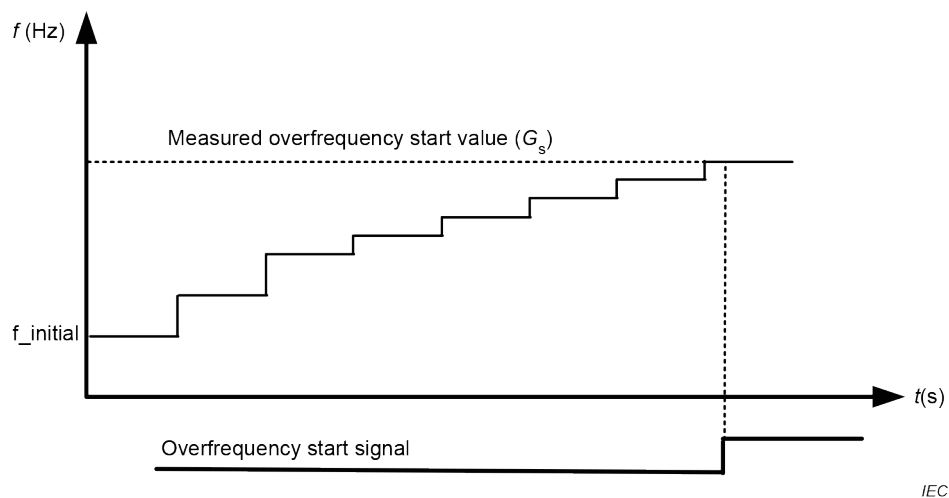


**Figure 7 – Example of test method for overfrequency**

Each step of the ramp has a duration of: MAX (500 ms; 5 times the maximum start time).

If frequency tracking is performed, this time step is normally sufficient to allow for frequency adjustment.

During the transition between successive frequency steps, the injected signal shall be continuous, and there is no step change in its phase angle or magnitude except its frequency.

To reduce the length of the test, the frequency increment can be higher at the beginning of the test, with the following rules:

- For the overfrequency function, this increment can be equal to  $G_s$  minus 3 times the "declared frequency accuracy".

- For the underfrequency function, this increment can be equal to  $G_s$  plus 3 times the "declared frequency accuracy".

The declared frequency accuracy is based on the requirements specified in 5.3.

Once the above value is reached, the frequency increment will be less than or equal to 10 % of the declared frequency accuracy until the end of the ramp caused by the operation of the start signal.

#### **6.2.1.1.2 Protection function settings**

Start frequency settings shall be varied in the setting range as shown in Table 4.

If some protection functions have a setting for the definition of the window length to measure the frequency, the setting value shall be the default value, unless the manufacturer has a special recommendation for the window length as a function of the frequency setting ( $G_s$ ) that is tested. In this case, the manufacturer's recommendation shall be followed.

#### **6.2.1.1.3 Test points and calculation of frequency accuracy**

Even if the setting range is independent of the nominal frequency setting (typically 50 Hz or 60 Hz), the tests are repeated for each nominal power frequency value of the protection function with the setting test points defined in Table 4 and according to the rule defined in 6.1.

The frequency is measured for the following test points (Table 4). Each test is repeated 5 times and the test results are reported as shown in Table 4.

All test points are carried out at nominal voltage. In addition, the first test (–100 % min. setting) and the last test (+100 % max. setting) points are repeated at the maximum and the minimum voltage of the effective range. The results of the test points at minimum and maximum effective range of the voltage have to be documented in line with the other test points at nominal voltage.

For each test, the measured start frequency shall be within the declared accuracy. The accepted values are calculated for each measured value in the manner described below.

The start of the protection function shall occur within the frequency band around the expected start value ( $G_s$ ). The band has the following borders:

higher accepted value = ( $G_s$  + declared frequency accuracy);

lower accepted value = ( $G_s$  – declared frequency accuracy).

**Table 4 – Test points for under/over frequency function**

| Test point value<br>$x^a$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Frequency setting (start threshold, $G_s^a$ )<br>Hz | Voltage magnitude<br>$c$ | Test 1<br>Hz | Test 2<br>Hz | Test 3<br>Hz | Test 4<br>Hz | Test 5<br>Hz | Acceptance criteria<br>Hz |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|--------------------------|--------------|--------------|--------------|--------------|--------------|---------------------------|
| -100 %<br>(min. setting)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                     | Min. $U$                 |              |              |              |              |              | $G_s \pm f\_accuracy$     |
| -100 %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                     | Max. $U$                 |              |              |              |              |              | $G_s \pm f'\_accuracy$    |
| -100 %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                     | $U_n$                    |              |              |              |              |              | $G_s \pm f'\_accuracy$    |
| -10 %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                     | $U_n$                    |              |              |              |              |              | $G_s \pm f\_accuracy$     |
| -5 %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                     | $U_n$                    |              |              |              |              |              | $G_s \pm f\_accuracy$     |
| -2,5 %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                     | $U_n$                    |              |              |              |              |              | $G_s \pm f\_accuracy$     |
| -1 %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                     | $U_n$                    |              |              |              |              |              | $G_s \pm f\_accuracy$     |
| 0 %<br>( $f_R = 50$ Hz,<br>60 Hz) <sup>b</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                     | $U_n$                    |              |              |              |              |              | $G_s \pm f\_accuracy$     |
| +1 %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                     | $U_n$                    |              |              |              |              |              | $G_s \pm f\_accuracy$     |
| +2,5 %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                     | $U_n$                    |              |              |              |              |              | $G_s \pm f\_accuracy$     |
| +5 %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                     | $U_n$                    |              |              |              |              |              | $G_s \pm f\_accuracy$     |
| +10 %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                     | $U_n$                    |              |              |              |              |              | $G_s \pm f\_accuracy$     |
| +100 %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                     | $U_n$                    |              |              |              |              |              | $G_s \pm f'\_accuracy$    |
| +100 %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                     | Min. $U$                 |              |              |              |              |              | $G_s \pm f'\_accuracy$    |
| +100 %<br>(max. setting)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                     | Max. $U$                 |              |              |              |              |              | $G_s \pm f\_accuracy$     |
| <sup>a</sup> Test points are expressed in % to compute frequency settings (threshold $G_s$ ) according to the common rules defined in 6.1. Setting ranges of under/over frequency function can be defined with values under and above the nominal frequency. Test points are defined to cover all possible setting ranges.<br><sup>b</sup> If the setting defined at the nominal power frequency is not available, this test point can be omitted.<br><sup>c</sup> $U_n$ is the nominal voltage, and "Min. $U$ " and "Max. $U$ " are the minimum and maximum values of the declared voltage effective range. |                                                     |                          |              |              |              |              |              |                           |

#### 6.2.1.1.4 Reporting of the frequency accuracy

The frequency accuracy is reported as a measurement error, as per the example shown in Table 5, where the value is provided as an example.

**Table 5 – Reporting of the frequency accuracy**

| Overfrequency protection |           |
|--------------------------|-----------|
| Frequency accuracy       | ±10,0 mHz |

Alternatively, the manufacturer can choose to express the accuracy error using the maximum of the two values, as shown in Table 6.

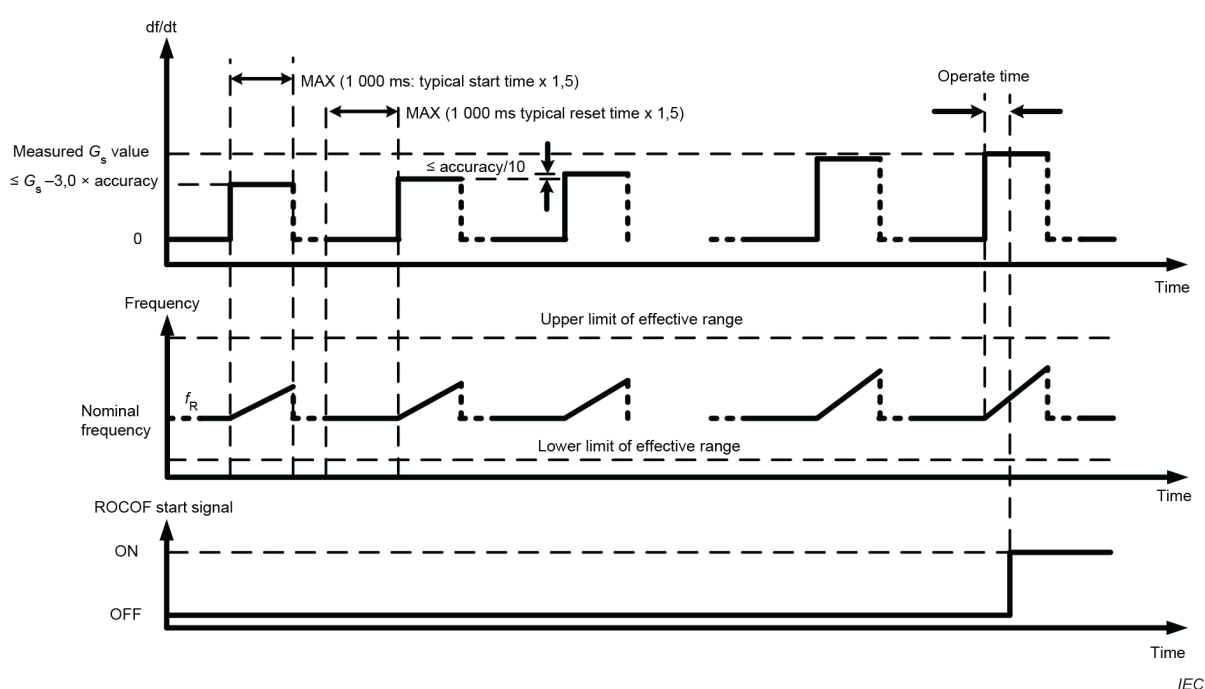
**Table 6 – Reporting of the frequency accuracy (alternative solution)**

| Overfrequency protection |                                                             |
|--------------------------|-------------------------------------------------------------|
| Frequency accuracy       | $\pm 10,0$ mHz or $\pm 0,01$ % $G_s$ , whichever is greater |

### 6.2.1.2 Rate of change of frequency

#### 6.2.1.2.1 Description of the generated frequency ramp

The accuracy of the ROCOF setting ( $G_s$ ) is assessed with a sequence of frequency ramps where the frequency increases or decreases from the nominal value depending on the sign of the frequency derivative ("+" or "-"). The test method is illustrated in Figure 8, applicable for a positive ROCOF function.

**Figure 8 – Example of test method for positive ROCOF function**

The ramp commences at the nominal frequency  $f_R$  and stops when the protection START signal operates or when the ramp terminates without the protection start being asserted. The ramp duration to assess if the protection has started or not during the injection is:

$$\text{MAX (1 000 ms; typical start time} \times 1,5)$$

The injected frequency shall always be within the effective range of the protection function, if an effective frequency range is declared for the ROCOF function. This condition may require a limited duration of the frequency ramp. If the duration of the frequency ramp needs to be shorter than the maximum start time for the ROCOF function, the function cannot be tested for that setting based on the standardized test conditions. In that case, the manufacturer shall declare this information and shall declare the appropriate test method to be used to check the accuracy of these start value settings.

The first ramp has a frequency derivative much lower than the absolute value of the protection setting  $G_s$ .

If the protection does not start within the ramp duration, the next ramp will be injected with a new frequency derivative value with a start point always equal to the nominal frequency value.

Before each ramp, frequency shall remain at its nominal value at least for the duration of:

$$\text{MAX (1 000 ms; typical disengaging time} \times 1,5)$$

Then, the frequency is changed in a linear way away from its nominal value. During this transition, the injected signal shall be continuous, with no step change in its phase angle or magnitude except its frequency.

At the end of each ramp, the frequency returns to its nominal value to get ready for the next ramp. During this transition, the injected signal is not defined in this document. Any start (pick-up) or operation during this period shall be ignored.

The next ramp has an increment (step) of frequency derivative equal to or smaller than:

$$(\text{frequency rate of change accuracy} / 10) \text{ Hz/s.}$$

When the protection start signal operates, the injection can be interrupted and the measured rate of change of frequency is the value of the frequency derivative for the last ramp.

The activation of the start signal shall be a "solid activation", this means no chattering of the signal with several transitions high–low–high during the injection of the ramp. The only chattering allowed in the signal is by the output contact, which has a reasonable bouncing time of less than 4 ms. If the start signal oscillates for more than 4 ms, the start activation shall not be considered and the ramp shall continue with the next step. For other output media, such as IEC 61850 GOOSE or static output, no chattering at all shall be present in the transition of the start signal, in order to be considered valid.

The normative Annex A defines the equation for test signals with a constant frequency slope.

To reduce the length of the test, the frequency increment can be higher at the beginning of the test, with the following rules:

- For the overfrequency function, this increment can be equal to  $G_s$  minus 3 times the "declared frequency accuracy".
- For the underfrequency function, this increment can be equal to  $G_s$  plus 3 times the "declared frequency accuracy".

The declared frequency rate of change accuracy is based on the requirements specified in 5.3.

Once the above value is reached the increment in the rate of change of frequency will be less than or equal to 10 % of the declared frequency rate of change accuracy until the end of the ramps caused by the operation of the start signal.

#### **6.2.1.2.2 Protection function settings**

Start ROCOF settings shall be varied in the setting range as shown in Table 7.

If some protection functions have a setting for the definition of the window length to measure the frequency rate of change, the setting value shall be the default value, unless the manufacturer has a special recommendation for the window length as a function of the rate of change setting ( $G_s$ ). In this case, the manufacturer's recommendation shall be followed.

#### **6.2.1.2.3 Test points and calculation of ROCOF accuracy**

The tests are repeated for each nominal power frequency value of the protection function (typically 50 Hz and 60 Hz).

The ROCOF accuracy is measured for the following test points (Table 7). Each test is repeated 5 times and the test results are reported as shown in Table 7.

All test points are carried out at nominal voltage. In addition, the first test (0 % – min. setting) and the last test (100% – max. setting) points are repeated at the maximum and the minimum voltage of the effective range. The results of the test points at minimum and maximum effective range of the voltage have to be documented in line with the other test points at nominal voltage.

When the function is based on an absolute  $df/dt$  value, each test line defined in Table 7 shall be performed with a positive and a negative ROCOF.

For each test, the measured rate of change of frequency shall be within the declared accuracy. The accepted values are calculated for each measured value as described below.

The start of the protection function shall occur within the error band around the expected start value ( $G_s$ ). The band has the following borders:

higher accepted value = ( $G_s$  + declared frequency rate of change accuracy);

lower accepted value = ( $G_s$  – declared frequency rate of change accuracy).

**Table 7 – Test points for ROCOF function**

| Test point value<br>$x^a$                                                                                                                              | ROCOF setting (start threshold, $G_s$ ) <sup>a</sup><br>Hz/s | Voltage magnitude<br>$U_b$ | Test 1<br>Hz/s | Test 2<br>Hz/s | Test 3<br>Hz/s | Test 4<br>Hz/s | Test 5<br>Hz/s | Acceptance criteria<br>Hz/s    |
|--------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|----------------------------|----------------|----------------|----------------|----------------|----------------|--------------------------------|
| Minimum (0 %)                                                                                                                                          |                                                              | Min. $U$                   |                |                |                |                |                | $G_s \pm f'_{\text{accuracy}}$ |
| 0 %                                                                                                                                                    |                                                              | Max. $U$                   |                |                |                |                |                | $G_s \pm f'_{\text{accuracy}}$ |
| 0 %                                                                                                                                                    |                                                              | $U_n$                      |                |                |                |                |                | $G_s \pm f'_{\text{accuracy}}$ |
| 5 %                                                                                                                                                    |                                                              | $U_n$                      |                |                |                |                |                | $G_s \pm f'_{\text{accuracy}}$ |
| 10 %                                                                                                                                                   |                                                              | $U_n$                      |                |                |                |                |                | $G_s \pm f'_{\text{accuracy}}$ |
| 30 %                                                                                                                                                   |                                                              | $U_n$                      |                |                |                |                |                | $G_s \pm f'_{\text{accuracy}}$ |
| 60 %                                                                                                                                                   |                                                              | $U_n$                      |                |                |                |                |                | $G_s \pm f'_{\text{accuracy}}$ |
| 100 %                                                                                                                                                  |                                                              | $U_n$                      |                |                |                |                |                | $G_s \pm f'_{\text{accuracy}}$ |
| 100 %                                                                                                                                                  |                                                              | Min. $U$                   |                |                |                |                |                | $G_s \pm f'_{\text{accuracy}}$ |
| Maximum (100 %)                                                                                                                                        |                                                              | Max. $U$                   |                |                |                |                |                | $G_s \pm f'_{\text{accuracy}}$ |
| <sup>a</sup> Test points are expressed in % to compute the ROCOF settings (threshold $G_s$ ) according to the common rules defined in 6.1.             |                                                              |                            |                |                |                |                |                |                                |
| <sup>b</sup> $U_n$ is the nominal voltage, and "Min. $U$ " and "Max. $U$ " are the minimum and maximum values of the declared voltage effective range. |                                                              |                            |                |                |                |                |                |                                |

#### 6.2.1.2.4 Reporting of the ROCOF accuracy

The accuracy of the ROCOF is reported as a measurement error, as per the example shown in Table 8.

**Table 8 – Reporting of ROCOF accuracy**

| ROCOF protection                     |                                                               |
|--------------------------------------|---------------------------------------------------------------|
| Rate of change of frequency accuracy | $\pm 5\%$ (of $G_s$ ) or $\pm 15$ mHz/s, whichever is greater |

## 6.2.2 Reset hysteresis or reset ratio determination

### 6.2.2.1 Under/over frequency

#### 6.2.2.1.1 Description of the test

The tests to assess the reset hysteresis for under/over frequency functions are based on two pseudo-continuous frequency ramps that are driven by the condition of the protection start signal which is monitored.

The first frequency ramp (increasing ramp for overfrequency functions and decreasing ramp for underfrequency functions) will start from the nominal power frequency value (or at any frequency where the protection function is stable in the non-starting condition to reduce the testing time); the START signal of the protection function is monitored. When the protection START signal operates:

- the value of the injected frequency is registered as "START frequency value", and
- the second ramp (decreasing ramp for overfrequency, increasing for underfrequency functions), will start.

The second ramp starts from the registered "START frequency value" and will stop when the START signal of the protection function resets. At that point, the injected frequency will be registered as "RESET frequency value".

The activation of the start signal shall be a "solid activation"; this means no chattering of the signal with several transitions high–low–high during the injection of the ramp. The only chattering allowed in the signal is by the output contact, which has a reasonable bouncing time of less than 4 ms. If the start signal oscillates for more than 4 ms, the start activation shall not be considered and the ramp shall continue with the next step. For other output media, such as IEC 61850 GOOSE or static output, no chattering at all shall be present in the transition of the start signal, in order to be considered valid.

For the reset transition high–low of the start signal, no matter which output media is considered, no chattering at all shall be present in the transition high–low of the signal, in order to be considered valid.

The reset hysteresis will be calculated from the "START frequency value" and "RESET frequency value" as indicated in the following paragraphs in 6.2.2.1.1.

Figures 9 and 10 show the principle of the two frequency ramps to determine the reset hysteresis.

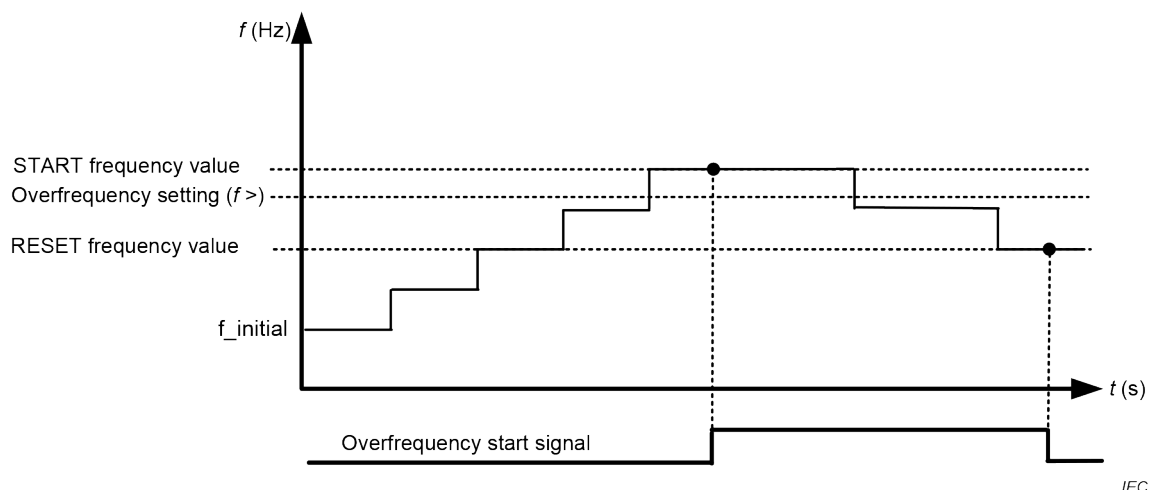


**Figure 9 – Frequency ramps for assessing the reset hysteresis for overfrequency functions**

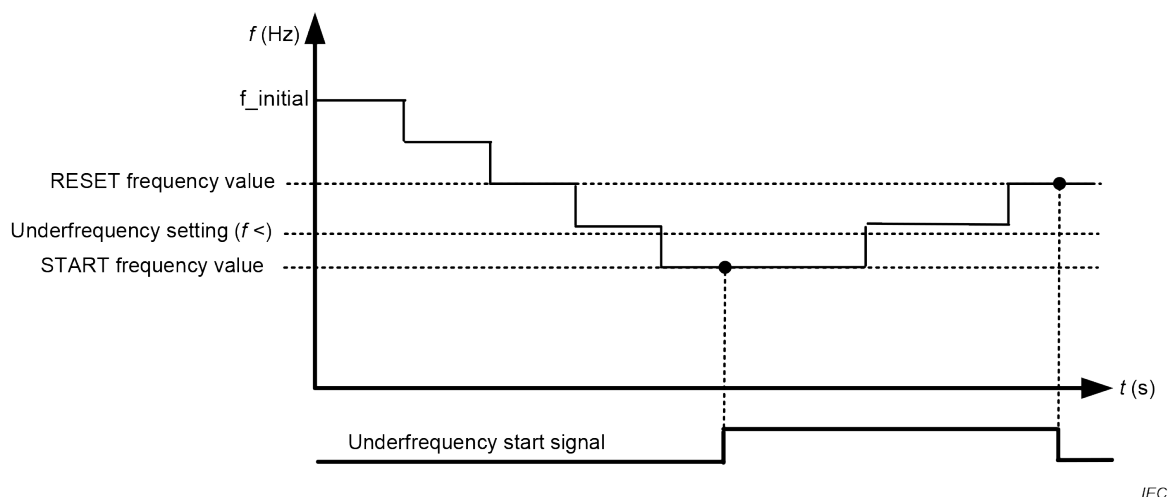


**Figure 10 – Frequency ramps for assessing the reset hysteresis for underfrequency functions**

Each step of the first ramp has a duration of: MAX (500 ms; 5 times the maximum start time).

If frequency tracking is performed, this time step is normally sufficient to process the frequency adjustment.

During the transition between successive frequency steps, the injected signal shall be continuous, with no step change in its phase angle or magnitude, except in its frequency.

To reduce the length of the test, the frequency increment can be higher at the beginning of the test, with the following rules:

- For the overfrequency function, this increment can be equal to  $G_s$  minus 3 times the "declared frequency accuracy".
- For the underfrequency function, this increment can be equal to  $G_s$  plus 3 times the "declared frequency accuracy".

$G_s$  is the frequency setting for the test, indicated as " $f >$ " in Figure 9 and " $f <$ " in Figure 10, and the declared frequency accuracy is based on the requirements specified in 5.3.

Once the above value is reached the frequency increment will be less than or equal to 10 % of the declared frequency accuracy until the operation of the start signal, which will cause the registration of the value "START frequency value" and the initiation of the second ramp.

Each step of the second ramp has a duration of:

MAX (500 ms; 5 times the expected disengaging time).

During the transition between successive frequency steps, the injected signal shall be continuous, with no step change in its phase angle or magnitude, except in its frequency.

The frequency variation will be equal to the variation of the last step of the first ramp (immediately prior to the protection START).

The second ramp will proceed until the START signal of the protection function resets, allowing the registration of the "RESET frequency value" and the final calculation of the reset hysteresis.

#### **6.2.2.1.2 Protection function settings**

Start frequency settings shall be varied in the setting range as shown in Table 9.

If some protection functions have a setting for the definition of the window length to measure the frequency, the setting value shall be the default value, unless the manufacturer has a special recommendation for the window length as a function of the frequency setting ( $G_s$ ) that is tested. In this case, the manufacturer's recommendation shall be followed.

#### **6.2.2.1.3 Test points and calculation of reset hysteresis**

The frequency hysteresis is measured for the test points indicated in Table 9 for under/over frequency functions.

All test points are carried out at nominal voltage. In addition, the first test (–100 % min. setting) and the last test (+100 % max. setting) points are repeated at the maximum and the minimum voltage of the effective range. The results of the test points at minimum and maximum effective range of the voltage have to be documented in line with the other test points at nominal voltage.

Each test is repeated 5 times and the test results are reported as shown in Table 9.

The measured reset hysteresis is calculated in the following way:

- reset hysteresis = "START frequency value" – "RESET frequency value", for overfrequency functions;
- reset hysteresis = "RESET frequency value" – "START frequency value", for underfrequency functions.

For all the tests, the measured reset hysteresis shall be below the declared reset hysteresis.

**Table 9 – Test points of reset hysteresis for under/over frequency function**

| Test point value<br>$x^a$                      | Frequency setting (start threshold, $G_s$ ) <sup>a</sup><br>Hz | Voltage magnitude <sup>c</sup> | Test 1<br>Hz | Test 2<br>Hz | Test 3<br>Hz | Test 4<br>Hz | Test 5<br>Hz | Acceptance criteria<br>Hz |
|------------------------------------------------|----------------------------------------------------------------|--------------------------------|--------------|--------------|--------------|--------------|--------------|---------------------------|
| -100 %<br>(min. setting)                       |                                                                | Min. $U$                       |              |              |              |              |              | ≤ Reset hysteresis        |
| -100 %                                         |                                                                | Max. $U$                       |              |              |              |              |              | ≤ Reset hysteresis        |
| -100 %                                         |                                                                | $U_n$                          |              |              |              |              |              | ≤ Reset hysteresis        |
| -10 %                                          |                                                                | $U_n$                          |              |              |              |              |              | ≤ Reset hysteresis        |
| -5 %                                           |                                                                | $U_n$                          |              |              |              |              |              | ≤ Reset hysteresis        |
| -2,5 %                                         |                                                                | $U_n$                          |              |              |              |              |              | ≤ Reset hysteresis        |
| -1 %                                           |                                                                | $U_n$                          |              |              |              |              |              | ≤ Reset hysteresis        |
| 0 %<br>( $f_R = 50$ Hz,<br>60 Hz) <sup>b</sup> |                                                                | $U_n$                          |              |              |              |              |              | ≤ Reset hysteresis        |
| +1 %                                           |                                                                | $U_n$                          |              |              |              |              |              | ≤ Reset hysteresis        |
| +2,5 %                                         |                                                                | $U_n$                          |              |              |              |              |              | ≤ Reset hysteresis        |
| +5 %                                           |                                                                | $U_n$                          |              |              |              |              |              | ≤ Reset hysteresis        |
| +10 %                                          |                                                                | $U_n$                          |              |              |              |              |              | ≤ Reset hysteresis        |
| +100 %                                         |                                                                | $U_n$                          |              |              |              |              |              | ≤ Reset hysteresis        |
| +100 %                                         |                                                                | Min. $U$                       |              |              |              |              |              | ≤ Reset hysteresis        |
| +100 %<br>(max. setting)                       |                                                                | Max. $U$                       |              |              |              |              |              | ≤ Reset hysteresis        |

<sup>a</sup> Test points are expressed in % to compute frequency settings (threshold  $G_s$ ) according to the common rules defined in 6.1.

<sup>b</sup> If the setting defined at the nominal power frequency is not available, this test point can be omitted.

<sup>c</sup>  $U_n$  is the nominal voltage, and "Min.  $U$ " and "Max.  $U$ " are the minimum and maximum values of the declared voltage effective range.

**6.2.2.1.4 Reporting of reset hysteresis**

The reset hysteresis for over/under frequency functions is reported in mHz as per the example shown in Table 10:

**Table 10 – Reporting of the reset hysteresis for over/under frequency functions**

| Over (or under) frequency protection<br>Reset hysteresis |         |
|----------------------------------------------------------|---------|
| Reset hysteresis                                         | 5,0 mHz |

### 6.2.2.2 Rate of change of frequency

#### 6.2.2.2.1 Description of the test

The tests to assess the reset value for ROCOF functions are based on sequences of frequency ramps that are driven by the condition of the protection start signal which is monitored.

The tests are carried out according to the following procedure.

- The start value for  $df/dt$  (associated to the protection function setting  $G_s$ , indicated also as  $df/dt\_setting$ ) is detected with a succession of frequency ramps with increasing value of the frequency slope for positive ROCOF (for negative ROCOF the ramps will have a decreasing frequency slope). The detected ROCOF start value is associated with the value  $df/dt\_start$ . See ramps  $S_1, S_2, \dots, S_{m-1}$  and  $S_m$  in Figure 11 (a), where the start operation is detected with the ramp  $S_m$  in the case of a positive error on start value.
- A frequency ramp with the value  $1,2 \times df/dt\_start$  is generated, causing a definite start operation.

At the end of this frequency ramp, a frequency ramp with a lower frequency slope is generated ( $df/dt_1$ , illustrated by ramp  $R_1$  in Figure 11 (b)). During this ramp, the protection function may or may not reset:

- if the function does not reset, then the initial ramp at  $1,2 \times df/dt\_start$  is generated again, following this, a ramp with an even lower frequency slope is generated ( $df/dt_2$ , illustrated by ramp  $R_2$  in Figure 11 (b));
- this process continues until the protection function resets, which occurs at the ramp with the frequency derivative value of  $df/dt\_reset$ . See ramps  $R_1, R_2, \dots, R_{n-1}$  and  $R_n$  in Figure 11 (b), where the reset operation is detected with ramp  $R_{n-1}$  in the case of positive error on reset value or with ramp  $R_n$  in the case of negative error on reset value. When the protection function resets, the reset value can be calculated.
- The reset value is calculated based on the values  $df/dt\_start$  and  $df/dt\_reset$ .

NOTE According to the declared accuracy of the start value, if the frequency ramp with value  $1,2 \times df/dt\_start$  is not sufficient to ensure a definite start operation, the frequency ramp can be fixed to  $(1 + 2 \times \varepsilon) \times df/dt\_start$ , where  $\varepsilon$  is the declared accuracy of the start value. This particular test condition can be used for lower threshold values, if the declared accuracy is close to or above 20 %.

Figure 11 shows the test method for a ROCOF function.

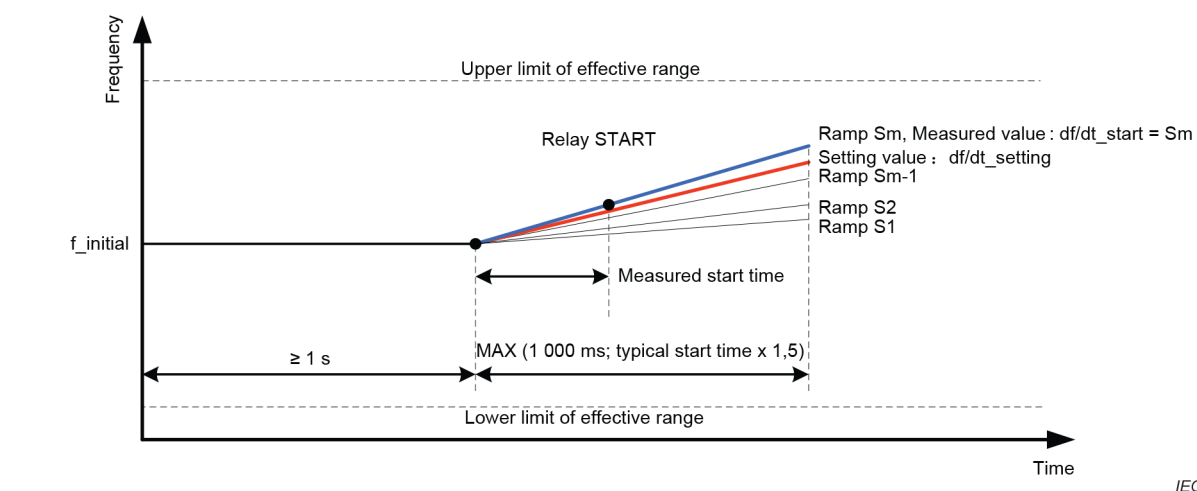
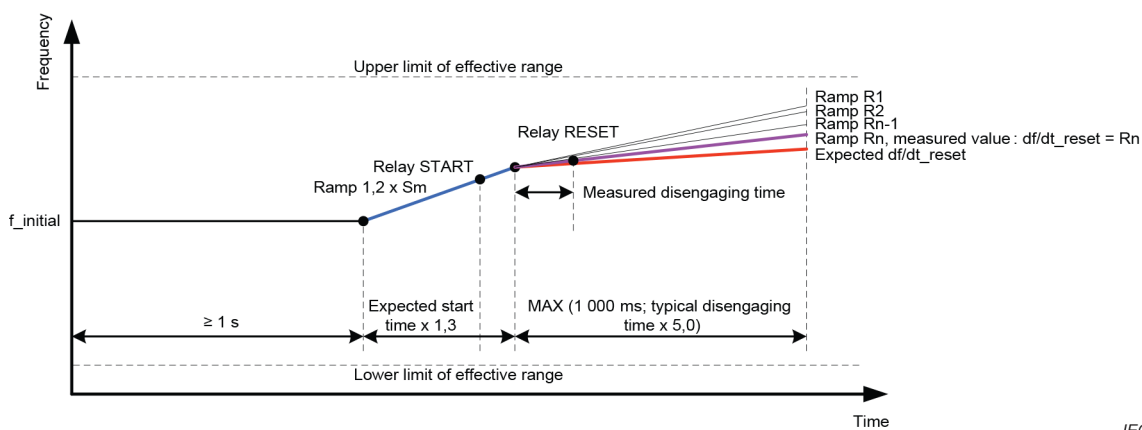
a) Test to determine  $df/dt_{start}$ b) Test to determine  $df/dt_{reset}$ 

**Figure 11 – Test method for measurement of reset value for ROCOF functions: example for positive ROCOF function**

Test to determine  $df/dt_{start}$  (see Figure 11 (a)).

The first sequence of frequency ramps (increasing ramp for positive ROCOF function and decreasing ramp negative ROCOF function) will start from the frequency value  $f_{initial}$  within the frequency effective range of the protection.

At the beginning of each ramp, the frequency shall be at  $f_{initial}$  at least for the duration of 1 s. If the duration of 1 s is not sufficient, the manufacturer shall declare in the type test report the time duration to be used for this test.

Then, the frequency is changed in a linear way, away from its initial value. During this transition, the injected signal shall be continuous, with no step change in its phase angle or magnitude, except in its frequency.

The frequency ramp will have a time duration of:

$$\text{MAX (1 000 ms; typical start time} \times 1,5).$$

The injected frequency shall always be within the effective range of the protection function, if a frequency effective range has been declared for the ROCOF function. This condition may require a limited duration for the frequency ramp.

The frequency value  $f_{\text{initial}}$  shall be equal to the nominal frequency. If during these tests, the frequency value exceeds the effective range, the frequency value  $f_{\text{initial}}$  can be chosen to the minimum or maximum value of the declared frequency effective range. The initial frequency value shall be declared in the type test report.

The START signal of the protection function is monitored and when the START signal operates, the value of the rate of change of the injected frequency is registered as " $df/dt_{\text{start}}$ " value.

The activation of the start signal shall be a "solid activation"; this means no chattering of the signal with several transitions high–low–high during the injection of the ramp. The only chattering allowed in the signal is by the output contact, which has a reasonable bouncing time of less than 4 ms. If the start signal oscillates for more than 4 ms, the start activation shall not be considered valid, and the ramp shall continue with the next step. For other output media, such as IEC 61850 GOOSE or static output, no chattering at all shall be present in the transition of the start signal, in order to be considered valid.

If the protection function does not start, the frequency ramp will continue until its end; the frequency value  $f_{\text{initial}}$  is applied for a minimum time duration of 1 s and a new ramp will be generated with a new frequency slope. The increment for the new frequency slope is:

$$(\text{Frequency rate of change accuracy} / 10) \text{ Hz/s.}$$

Annex A defines the equation for test signals with a constant frequency slope.

To reduce the length of the test, the frequency increment can be higher at the beginning of the test, with the following rules:

- For the overfrequency function, this increment can be equal to  $G_s$  minus 3 times the "declared frequency accuracy".
- For the underfrequency function, this increment can be equal to  $G_s$  plus 3 times the "declared frequency accuracy".

The declared frequency rate of change accuracy is based on the requirements specified in 5.3.

Once the above value is reached, the increment of the rate of change of frequency will be less than or equal to 10 % of the declared frequency rate of change accuracy until the end of the ramps caused by the operation of the start signal.

At this point, the start value of the protection function has been determined,  $df/dt_{\text{start}}$ , and the sequence of ramps for determining the reset value will initiate.

Test to determine  $df/dt_{\text{reset}}$  (see Figure 11 (b)).

Each ramp of the sequence of ramps is actually formed by two ramps: a first ramp with a frequency slope of  $1,2 \times df/dt_{\text{start}}$ , and a second ramp with a variable frequency slope. The first slope at  $1,2 \times df/dt_{\text{start}}$  has a duration of:

$$\text{Expected start time} \times 1,3.$$

The ramp starts at frequency  $f_{\text{initial}}$ , with the recommended value to be the minimum value of the frequency effective range for positive ROCOF and the maximum value of the frequency effective range for negative ROCOF.

At the beginning of each ramp, frequency shall be at  $f_{\text{initial}}$  at least for the duration of 1 s. If the duration of 1 s is not sufficient, the manufacturer shall declare in the type test report the time duration to be used for this test.

Then, the frequency is changed in a linear way, away from its initial value. During this transition, the injected signal shall be continuous, with no step change in its phase angle or magnitude, except in its frequency.

When this ramp ends, a new ramp begins. The transition between the first ramp and the second one shall be "smooth". This means that the injected signal shall be continuous, with no step change in its phase angle or magnitude, except in its frequency.

The second ramp has a duration of:

$$\text{MAX (1 000 ms; 5 times the expected disengaging time)}$$

and a frequency slope of:

$$df/dt = (df/dt_{\text{previous}}) - (\text{Frequency rate of change accuracy} / 10) \text{ Hz/s,}$$

where  $df/dt_{\text{previous}}$  is:

- $df/dt_{\text{start}}$ , if the ramp is the first shot of the sequence to determine the reset value  $df/dt_{\text{reset}}$  (ramp R1);
- the frequency derivative of the previous ramp, if the ramp is not the first shot of the sequence to determine the reset value  $df/dt_{\text{reset}}$  (ramp R2, R3, ...).

If, during this second ramp, the ROCOF function does not reset, at the end of the ramp a new set of frequency ramps is generated. The frequency value  $f_{\text{initial}}$  is applied for a minimum time duration of 1 s, followed by the first ramp to ensure a start and a second ramp with the new  $df/dt$  value. If the function resets instead, the frequency derivative of the generated ramp is recorded as  $df/dt_{\text{reset}}$ .

The reset of the start signal is considered valid if there is no chattering at all, regardless of whether the output media is a contact, IEC 61850 GOOSE or static output.

The reset ratio is calculated with the formula:

$$\text{Reset ratio} = (df/dt_{\text{reset}} / df/dt_{\text{start}}) \times 100 \%$$

If a minimum absolute reset hysteresis is declared, the reset hysteresis is calculated with the formula:

$$\text{Reset hysteresis} = df/dt_{\text{start}} - df/dt_{\text{reset}}$$

#### 6.2.2.2.2 Protection function settings

Start ROCOF settings shall be varied in the setting range as shown in Table 11.

If some protection functions have a setting for the definition of the window length to measure the frequency, the setting value shall be the default value, unless the manufacturer has a special recommendation for the window length as function of the ROCOF setting ( $G_s$ ) that is tested. In this case, the manufacturer's recommendation shall be followed.

#### 6.2.2.2.3 Test points and verification of reset value

The reset value is measured for the test points indicated in Table 11.

All test points are carried out at nominal voltage. In addition, the first test (0% – min. setting) and the last test (100 % – max. setting) points are repeated at the maximum and the minimum voltage of the effective range. The results of the test points at minimum and maximum effective range of the voltage have to be documented in line with the other test points at nominal voltage.

Each test is repeated 5 times, and for each of the five tests, the result shall be below the declared reset value.

**Table 11 – Test points of reset value for ROCOF function**

| Test point value<br>$x^a$                                                                                                                              | ROCOF setting<br>(start threshold, $G_s$ ) <sup>a</sup><br>Hz/s | Voltage magnitude <sup>b</sup> | Test 1 result | Test 2 result | Test 3 result | Test 4 result | Test 5 result | Acceptance criteria                   |
|--------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|--------------------------------|---------------|---------------|---------------|---------------|---------------|---------------------------------------|
| 0 %<br>(minimum)                                                                                                                                       |                                                                 | Min. $U$                       | % or Hz/s     | % or Hz/s     | % or Hz/s     | % or Hz/s     | % or Hz/s     | $\leq$ reset ratio<br>(or hysteresis) |
| 0 %                                                                                                                                                    |                                                                 | Max. $U$                       |               |               |               |               |               | $\leq$ reset ratio<br>(or hysteresis) |
| 0 %                                                                                                                                                    |                                                                 | $U_n$                          |               |               |               |               |               | $\leq$ reset ratio<br>(or hysteresis) |
| 5 %                                                                                                                                                    |                                                                 | $U_n$                          |               |               |               |               |               | $\leq$ reset ratio<br>(or hysteresis) |
| 10 %                                                                                                                                                   |                                                                 | $U_n$                          |               |               |               |               |               | $\leq$ reset ratio<br>(or hysteresis) |
| 30 %                                                                                                                                                   |                                                                 | $U_n$                          |               |               |               |               |               | $\leq$ reset ratio<br>(or hysteresis) |
| 60 %                                                                                                                                                   |                                                                 | $U_n$                          |               |               |               |               |               | $\leq$ reset ratio<br>(or hysteresis) |
| 100 %                                                                                                                                                  |                                                                 | $U_n$                          |               |               |               |               |               | $\leq$ reset ratio<br>(or hysteresis) |
| 100 %                                                                                                                                                  |                                                                 | Min. $U$                       |               |               |               |               |               | $\leq$ reset ratio<br>(or hysteresis) |
| 100 %<br>(maximum)                                                                                                                                     |                                                                 | Max. $U$                       |               |               |               |               |               | $\leq$ reset ratio<br>(or hysteresis) |
| <sup>a</sup> Test points are expressed in % to compute ROCOF settings (threshold $G_s$ ) according to the common rules defined in 6.1.                 |                                                                 |                                |               |               |               |               |               |                                       |
| <sup>b</sup> $U_n$ is the nominal voltage, and "Min. $U$ " and "Max. $U$ " are the minimum and maximum values of the declared voltage effective range. |                                                                 |                                |               |               |               |               |               |                                       |

#### 6.2.2.2.4 Reporting of the reset value

The reset value for ROCOF functions is reported by the manufacturer with a reset ratio expressed as a percentage, with or without a minimum reset hysteresis, as per the example shown in Table 12.

**Table 12 – Reporting of the reset value for ROCOF function**

| ROCOF protection<br>Reset value                                     |                  |
|---------------------------------------------------------------------|------------------|
| Reset ratio                                                         | 98 %             |
| (alternative solution)<br>Reset ratio with minimum reset hysteresis | 98 % or 40 mHz/s |

When the reset ratio is associated with a minimum reset hysteresis, the reset value is defined as the greater of the two values. The minimum reset hysteresis is mainly applicable to lower threshold values.

### **6.3 Determination of the start time**

#### **6.3.1 General**

The following tests describe the methods to assess the performance of the protection function in response to a frequency change in the voltage quantity of the power system.

The start time is determined by using the start signal of the protection function. If no specific output for the start signal is provided, the test is performed using the operate signal with a time delay set to zero (instantaneous tripping).

For over/under frequency protections, this performance is summarized in the start time diagrams of the protection function, where the start time is shown as a function of the velocity of the change of the power system frequency (rate of change of the power system frequency) when approaching and passing the protection setting ( $G_s = f >$  or  $G_s = f <$ ).

The tests shall be performed with constant slope frequency ramps from an initial nominal frequency value to the value above/below the setting. The frequency changes with different defined slopes. 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 out 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 for overfrequency and underfrequency functions, respectively.

For ROCOF functions, this performance is summarized in the typical start time for the protection function. The tests to assess the typical start time shall be performed with one test method based on different constant frequency slopes with a frequency derivative in the operate area of the ROCOF characteristic.

For characteristic accuracy tests (6.2), each test point is generally repeated 5 times. For type tests related to start time, each test point is repeated 10 times to obtain a more accurate time distribution, with minimum and maximum values.

#### **6.3.2 Under/over frequency**

##### **6.3.2.1 Description of the generated waveform**

The test method based on a sudden change in frequency is illustrated in Figure 12 (for overfrequency function).

During the transition of the sudden frequency change, the injected signal shall be managed without discontinuity in the voltage waveform, except in its frequency. This frequency change is illustrated in Annex E.

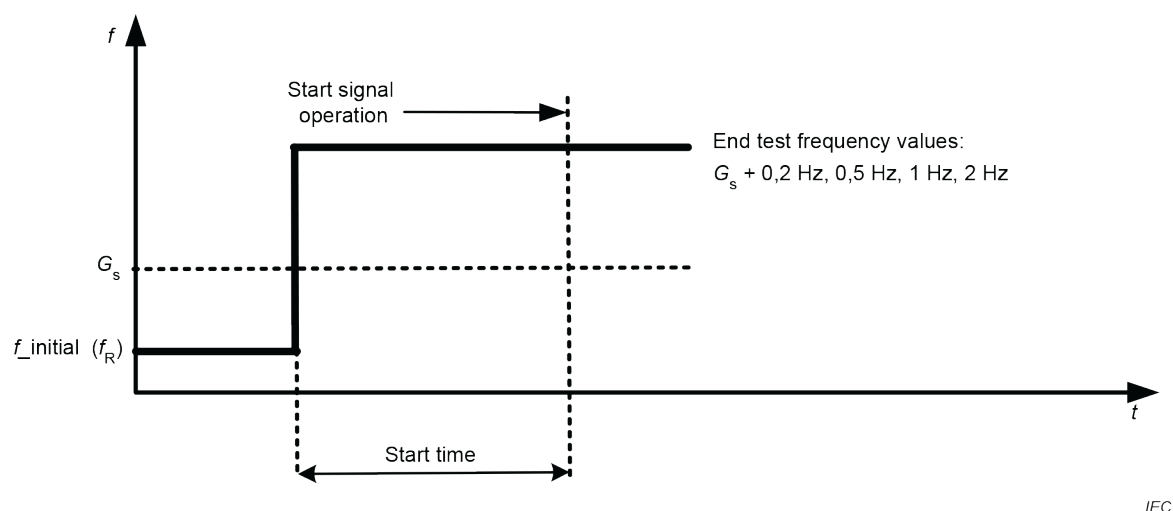


**Figure 12 – Start time measurement of overfrequency with sudden frequency change**

These tests are based on tests points defined in Tables 13 and 14. These tests points are identified with a frequency slope equal to "infinity" (sudden change).

- The initial test frequency value is always equal to the tested nominal power frequency.
- The end test point value is equal to the  $G_s$  setting plus (for overfrequency) or minus (for underfrequency) different frequency values (0,2 Hz, 0,5 Hz, 1 Hz and 2 Hz) to measure the start time with different ratios between the threshold and frequency signal.
- The start time is measured between the instant when the frequency changes and the instant when the start signal is asserted.

The injected frequency shall always be within the operating range of the protection function. For lower/higher settings of under/overfrequency functions, end test frequency value could be outside the operating range. In that case, the function cannot be tested with this method for that test point. The manufacturer shall declare this information in the type test report and the test shall be performed with the upper/lower limit of the declared operating range.

The test method based on a finite constant frequency slope is illustrated in Figure 13 (for overfrequency function).

During the transition in the frequency change, the injected signal shall be managed without discontinuity in the voltage waveform, except in its frequency. This frequency change is illustrated in Annex E.

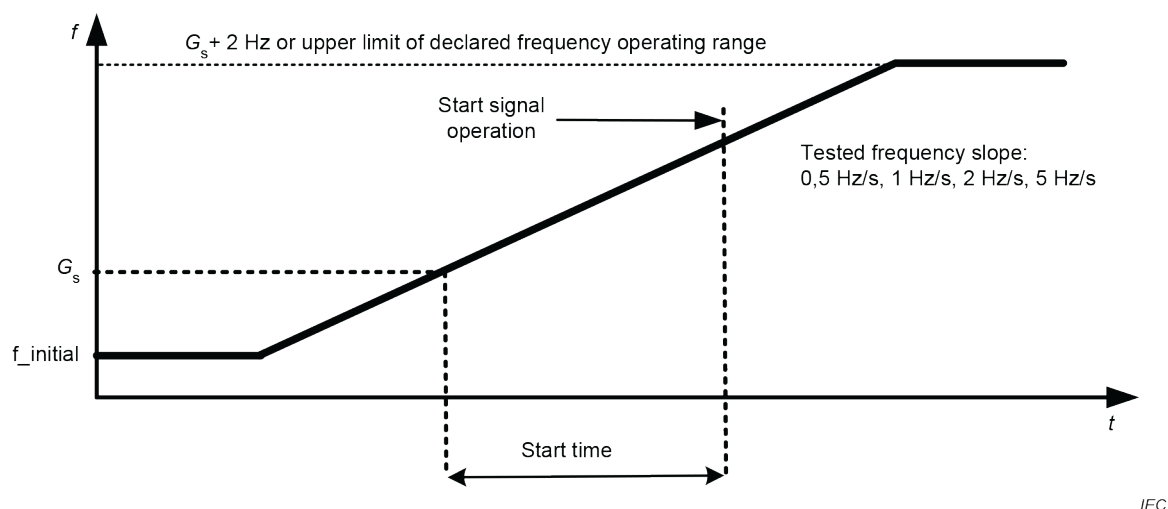


**Figure 13 – Start time measurement of overfrequency with constant slope frequency ramp**

These tests are based on tests points defined in Tables 13 and 14. These tests points are identified with finite frequency slope values.

- The initial test frequency value is equal to the tested nominal power frequency. When the setting range is wide, the initial value can be equal to  $G_s + 0,5 \text{ Hz}$  or  $G_s - 0,5 \text{ Hz}$ , to speed up the test of the under/over frequency functions.
- The frequency is increased (for overfrequency) or decreased (for underfrequency) with different values of frequency slope, to measure the start time with different test conditions.
- The injection can be interrupted after the operation of the protection start signal. In any case, the increasing or decreasing frequency is halted when the frequency is above  $G_s + 2 \text{ Hz}$  (for overfrequency) or under  $G_s - 2 \text{ Hz}$  (for underfrequency).
- The start time measurement is initiated when the frequency of the injected test signal crosses the start value setting (this point is defined as the frequency ramp given by the analytical formula described in Annex A) and stops when the protection start signal operates.

Annex A defines the equation for the test signals with a constant frequency slope.

The injected frequency shall always be within the operating range of the protection function, if an operating frequency range is declared. For lower/higher thresholds of under/over frequency functions, if the injected frequency is outside the declared operating range before the start signal operates, the function cannot be tested for that setting based on the standardized test conditions. In that case, the manufacturer shall declare this information and shall declare the appropriate test method to be used to measure the start time for these settings.

### 6.3.2.2 Protection function settings

Start frequency settings shall be varied in the setting range as shown in Tables 13 and 14.

If some protection functions provide a setting for the definition of the window length to measure the frequency, the setting value shall be the default value, unless the manufacturer has a special recommendation for the window length as a function of the frequency setting ( $G_s$ ). In this case, the manufacturer's recommendation shall be followed.

### 6.3.2.3 Test points and calculation of start time

The start time is measured for the following test points (Tables 13 and 14). Each test is repeated 10 times.

The tests are repeated for each nominal power frequency value of the protection function (typically 50 Hz and 60 Hz).

**Table 13 – Test points of start time for overfrequency function**

| Frequency slope                                                                                                                                     | Test point value<br>x <sup>a</sup> | Frequency setting<br>(start threshold,<br>G <sub>s</sub> ) <sup>a</sup><br>Hz | Initial test<br>frequency value                                              | End test frequency<br>value                                                                          |
|-----------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|-------------------------------------------------------------------------------|------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| Infinity<br>(sudden change)                                                                                                                         | 1 %                                |                                                                               | All declared rated<br>values (f <sub>R</sub> )                               | G <sub>s</sub> + 0,2 Hz<br>G <sub>s</sub> + 0,5 Hz<br>G <sub>s</sub> + 1 Hz<br>G <sub>s</sub> + 2 Hz |
|                                                                                                                                                     | 5 %                                |                                                                               |                                                                              | G <sub>s</sub> + 0,2 Hz<br>G <sub>s</sub> + 0,5 Hz<br>G <sub>s</sub> + 1 Hz<br>G <sub>s</sub> + 2 Hz |
|                                                                                                                                                     | 10 %                               |                                                                               |                                                                              | G <sub>s</sub> + 0,2 Hz<br>G <sub>s</sub> + 0,5 Hz<br>G <sub>s</sub> + 1 Hz<br>G <sub>s</sub> + 2 Hz |
|                                                                                                                                                     | 100 % (max.<br>setting)            |                                                                               |                                                                              | G <sub>s</sub> + 0,2 Hz<br>G <sub>s</sub> + 0,5 Hz<br>G <sub>s</sub> + 1 Hz<br>G <sub>s</sub> + 2 Hz |
| 0,5 Hz/s                                                                                                                                            | 1 %                                |                                                                               | All declared rated<br>values (f <sub>R</sub> )<br>or G <sub>s</sub> – 0,5 Hz | Not applicable<br>(G <sub>s</sub> + 2 Hz can be<br>used as final value<br>of the frequency<br>ramp)  |
|                                                                                                                                                     | 5 %                                |                                                                               |                                                                              |                                                                                                      |
|                                                                                                                                                     | 10 %                               |                                                                               |                                                                              |                                                                                                      |
|                                                                                                                                                     | 100 % (max.<br>setting)            |                                                                               |                                                                              |                                                                                                      |
| 1 Hz/s                                                                                                                                              | 1 %                                |                                                                               | All declared rated<br>values (f <sub>R</sub> )<br>or G <sub>s</sub> – 0,5 Hz | Not applicable<br>(G <sub>s</sub> + 2 Hz can be<br>used as final value<br>of the frequency<br>ramp)  |
|                                                                                                                                                     | 5 %                                |                                                                               |                                                                              |                                                                                                      |
|                                                                                                                                                     | 10 %                               |                                                                               |                                                                              |                                                                                                      |
|                                                                                                                                                     | 100 % (max.<br>setting)            |                                                                               |                                                                              |                                                                                                      |
| 2 Hz/s                                                                                                                                              | 1 %                                |                                                                               | All declared rated<br>values (f <sub>R</sub> )<br>or G <sub>s</sub> – 0,5 Hz | Not applicable<br>(G <sub>s</sub> + 2 Hz can be<br>used as final value<br>of the frequency<br>ramp)  |
|                                                                                                                                                     | 5 %                                |                                                                               |                                                                              |                                                                                                      |
|                                                                                                                                                     | 10 %                               |                                                                               |                                                                              |                                                                                                      |
|                                                                                                                                                     | 100 % (max.<br>setting)            |                                                                               |                                                                              |                                                                                                      |
| 5 Hz/s                                                                                                                                              | 1 %                                |                                                                               | All declared rated<br>values (f <sub>R</sub> )<br>or G <sub>s</sub> – 0,5 Hz | Not applicable<br>(G <sub>s</sub> + 2 Hz can be<br>used as final value<br>of the frequency<br>ramp)  |
|                                                                                                                                                     | 5 %                                |                                                                               |                                                                              |                                                                                                      |
|                                                                                                                                                     | 10 %                               |                                                                               |                                                                              |                                                                                                      |
|                                                                                                                                                     | 100 % (max.<br>setting)            |                                                                               |                                                                              |                                                                                                      |
| <sup>a</sup> Test points are expressed in % to compute frequency settings (threshold G <sub>s</sub> ) according to the common rules defined in 6.1. |                                    |                                                                               |                                                                              |                                                                                                      |

**Table 14 – Test points of start time for underfrequency function**

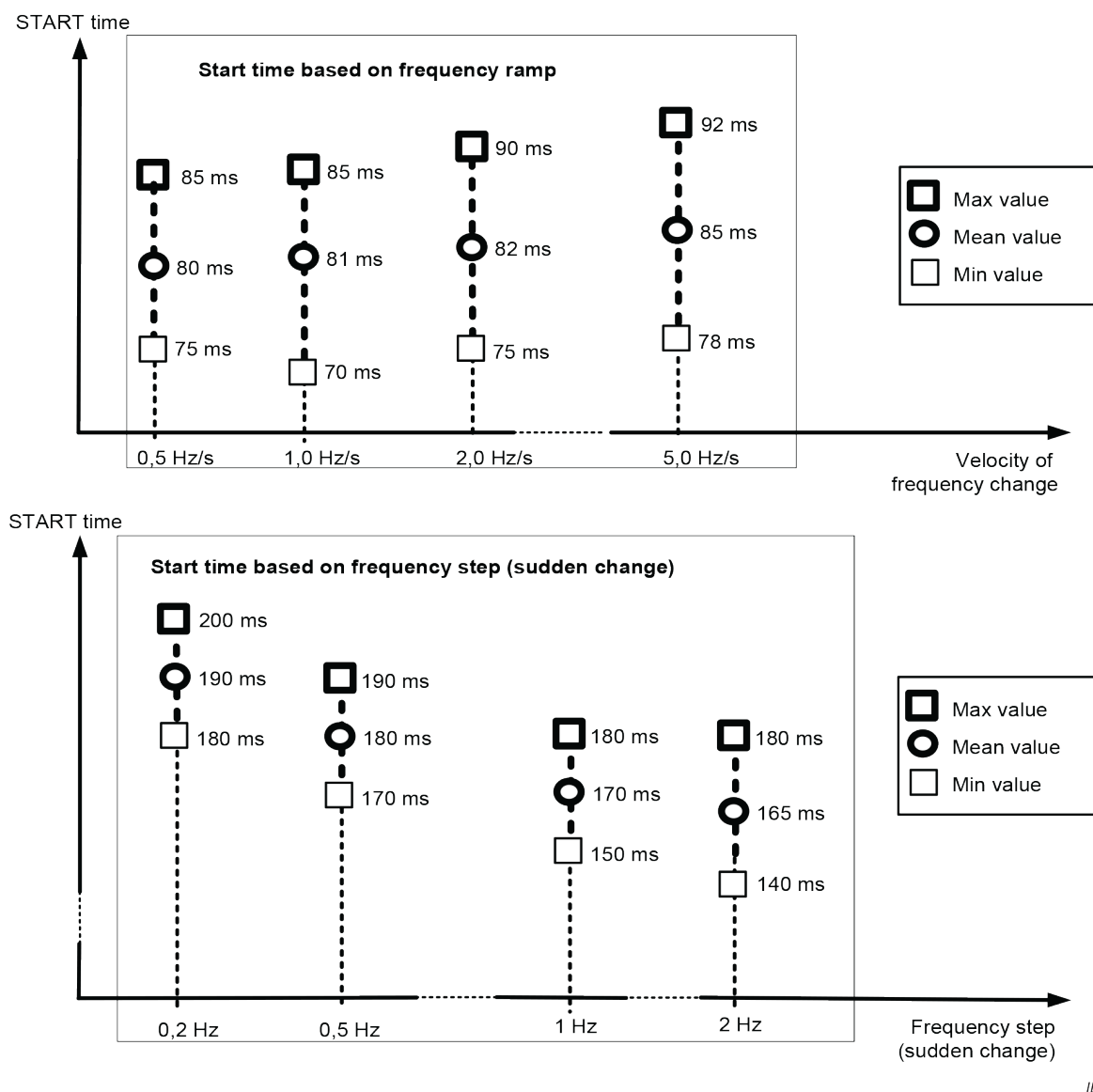
| Frequency slope                                                                                                                                     | Test point value<br>X <sup>a</sup> | Frequency setting<br>(start threshold,<br>G <sub>s</sub> ) <sup>a</sup><br>Hz | Initial test<br>frequency value                                              | End test frequency<br>value                                                                          |
|-----------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|-------------------------------------------------------------------------------|------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| Infinity<br>(sudden change)                                                                                                                         | -1 %                               |                                                                               | All declared rated<br>values (f <sub>R</sub> )                               | G <sub>s</sub> - 0,2 Hz<br>G <sub>s</sub> - 0,5 Hz<br>G <sub>s</sub> - 1 Hz<br>G <sub>s</sub> - 2 Hz |
|                                                                                                                                                     | -5 %                               |                                                                               |                                                                              | G <sub>s</sub> - 0,2 Hz<br>G <sub>s</sub> - 0,5 Hz<br>G <sub>s</sub> - 1 Hz<br>G <sub>s</sub> - 2 Hz |
|                                                                                                                                                     | -10 %                              |                                                                               |                                                                              | G <sub>s</sub> - 0,2 Hz<br>G <sub>s</sub> - 0,5 Hz<br>G <sub>s</sub> - 1 Hz<br>G <sub>s</sub> - 2 Hz |
|                                                                                                                                                     | -100 % (min.<br>setting)           |                                                                               |                                                                              | G <sub>s</sub> - 0,2 Hz<br>G <sub>s</sub> - 0,5 Hz<br>G <sub>s</sub> - 1 Hz<br>G <sub>s</sub> - 2 Hz |
| -0,5 Hz/s                                                                                                                                           | -1 %                               |                                                                               | All declared rated<br>values (f <sub>R</sub> )<br>or G <sub>s</sub> + 0,5 Hz | Not applicable<br>(G <sub>s</sub> - 2 Hz can be<br>used as final value<br>of the frequency<br>ramp)  |
|                                                                                                                                                     | -5 %                               |                                                                               |                                                                              |                                                                                                      |
|                                                                                                                                                     | -10 %                              |                                                                               |                                                                              |                                                                                                      |
|                                                                                                                                                     | -100 % (min.<br>setting)           |                                                                               |                                                                              |                                                                                                      |
| -1 Hz/s                                                                                                                                             | -1 %                               |                                                                               | All declared rated<br>values (f <sub>R</sub> )<br>or G <sub>s</sub> + 0,5 Hz | Not applicable<br>(G <sub>s</sub> - 2 Hz can be<br>used as final value<br>of the frequency<br>ramp)  |
|                                                                                                                                                     | -5 %                               |                                                                               |                                                                              |                                                                                                      |
|                                                                                                                                                     | -10 %                              |                                                                               |                                                                              |                                                                                                      |
|                                                                                                                                                     | -100 % (min.<br>setting)           |                                                                               |                                                                              |                                                                                                      |
| -2 Hz/s                                                                                                                                             | -1 %                               |                                                                               | All declared rated<br>values (f <sub>R</sub> )<br>or G <sub>s</sub> + 0,5 Hz | Not applicable<br>(G <sub>s</sub> - 2 Hz can be<br>used as final value<br>of the frequency<br>ramp)  |
|                                                                                                                                                     | -5 %                               |                                                                               |                                                                              |                                                                                                      |
|                                                                                                                                                     | -10 %                              |                                                                               |                                                                              |                                                                                                      |
|                                                                                                                                                     | -100 % (min.<br>setting)           |                                                                               |                                                                              |                                                                                                      |
| -5 Hz/s                                                                                                                                             | -1 %                               |                                                                               | All declared rated<br>values (f <sub>R</sub> )                               | Not applicable<br>(G <sub>s</sub> - 2 Hz can be<br>used as final value<br>of the frequency<br>ramp)  |
|                                                                                                                                                     | -5 %                               |                                                                               |                                                                              |                                                                                                      |
|                                                                                                                                                     | -10 %                              |                                                                               |                                                                              |                                                                                                      |
|                                                                                                                                                     | -100 % (min.<br>setting)           |                                                                               |                                                                              |                                                                                                      |
| <sup>a</sup> Test points are expressed in % to compute frequency settings (threshold G <sub>s</sub> ) according to the common rules defined in 6.1. |                                    |                                                                               |                                                                              |                                                                                                      |

### 6.3.2.4 Reporting of start time

The test results are reported in tabular form as shown in Table 15, where the minimum, average (mean) and maximum values are calculated. In addition, the test results are reported in graphical form, as shown in Figure 14. The results shown in Table 15 and in Figure 14 are provided by way of example.

**Table 15 – Reporting of start time for under/over frequency functions**

| Over (or under) frequency protection start times<br>50 Hz nominal frequency |                                |                    |                    |                    |
|-----------------------------------------------------------------------------|--------------------------------|--------------------|--------------------|--------------------|
| Velocity of frequency change                                                | Frequency jump (sudden change) | Minimum START time | Maximum START time | Average START time |
| 0,5 Hz/s                                                                    | NA                             | 75 ms              | 85 ms              | 80 ms              |
| 1,0 Hz/s                                                                    | NA                             | 70 ms              | 85 ms              | 81 ms              |
| 2,0 Hz/s                                                                    | NA                             | 75 ms              | 90 ms              | 82 ms              |
| 5,0 Hz/s                                                                    | NA                             | 78 ms              | 92 ms              | 85 ms              |
| Sudden change                                                               | 0,2 Hz                         | 180 ms             | 200 ms             | 190 ms             |
| Sudden change                                                               | 0,5 Hz                         | 170 ms             | 190 ms             | 180 ms             |
| Sudden change                                                               | 1 Hz                           | 150 ms             | 180 ms             | 170 ms             |
| Sudden change                                                               | 2 Hz                           | 140 ms             | 180 ms             | 165 ms             |



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**Figure 14 – Example of start time reporting for under/over frequency protection function**

### 6.3.3 Rate of change of frequency

#### 6.3.3.1 Description of the generated waveform

The start time measurement is assessed using a test method based upon a constant frequency slope. The method is illustrated in Figure 15 (for positive ROCOF function).

During the transition in the frequency change, the injected signal shall be managed without discontinuity in the voltage waveform, except in its frequency. This frequency change is illustrated in Annex E.

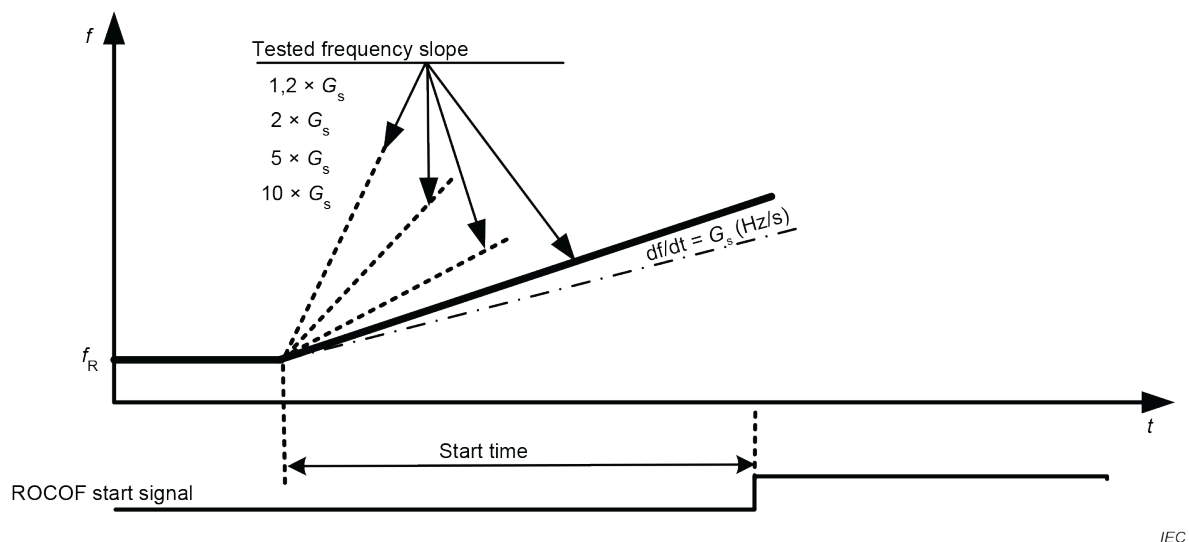


**Figure 15 – Start time measurement of positive ROCOF function**

Each test shot is determined by the tests points defined in Table 16.

- The initial test frequency value is always equal to the tested nominal power frequency.
- The frequency is increased with different values of frequency slope, to measure the start time with different test conditions.
- The injection can be interrupted when the protection start signal operates.
- The start time measurement is initiated when the frequency variation starts and stops when the protection start signal operates.

Annex A defines the equation for the test signals with a constant frequency slope.

The injected frequency shall always be within the operating range of the protection function, if an operating frequency range is declared for the ROCOF function. This condition may require a limited duration of the frequency ramp. For higher ROCOF settings, if the injected frequency is outside the declared operating range before the start signal operation, the function cannot be tested for that setting based on the standardized test conditions. In that case, the manufacturer shall declare this information and shall declare the appropriate test method to be used to measure the start time for these settings.

### 6.3.3.2 Protection function settings

Start ROCOF settings shall be varied in the setting range as shown in Table 16.

If some protection functions have a setting for the definition of the window length to measure the frequency or the frequency rate of change, the setting value shall be the default value, unless the manufacturer has a special recommendation for the window length as a function of the ROCOF setting ( $G_s$ ). In this case, the manufacturer's recommendation shall be followed.

### 6.3.3.3 Test points and calculation of typical start time

The start time is calculated for the test cases shown in Table 16. Each test is repeated 10 times.

The tests are repeated for each nominal power frequency value of the protection function (typically 50 Hz and 60 Hz).