FREQUENCY & ROCOF PROTECTIONS: TOWARD A BETTER EVALUATION OF THEIR RAPIDITY

Olivier ARGUENCE[1]
Grenoble INP SA – France
olivier.arguence@g2elab.grenoble-inp.fr

Florent CADOUX[1]
Fondation Grenoble INP – France
florent.cadoux@g2elab.grenoble-inp.fr

ABSTRACT

The new standard IEC 60255-181 [1] define several tests to evaluate characteristics of the frequency and ROCOF protections. We argue that the computational speed of the protection is an important characteristic to consider, which is currently not adequately covered by the above-mentioned standard. To overcome this issue, we propose a new test that could be introduced in the standard. This test is based on measuring the bandwidth of the protection.

INTRODUCTION

Frequency and ROCOF protections play a key role in the security of the grid. However many different algorithms may be used to compute these two values, sometimes with very different results; see for instance the prior CIRED article [2] where several ROCOF algorithms are compared. This leads to a wide range of characteristics from one protection manufacturer to the other in the market. The range is probably even wider for ROCOF protections, which are more recent, than for frequency protections.

To evaluate these characteristics, a novel standard, the IEC 60255-181 [1] was written and has been recently approved by all participating national committees (in the beginning of 2019). It describes several standard tests to evaluate several characteristics of the protection. These characteristics can be grouped within three different types: those concerning the precision of the protection, those concerning its rapidity and those concerning its robustness to perturbations.

The rapidity of the protection can be decomposed in two types: delays (intentional or not) and computational speed. In the paper, we argue in a first section why this computational speed is essential. However, it is not effectively evaluated by any test of the standard as seen in the second section. To evaluate the computation rapidity, the measure of the bandwidth is chosen. Then, a test is proposed to measure it as described in the third section.

I - RELEVANCE OF THE COMPUTATIONAL SPEED OF THE PROTECTION

Frequency and ROCOF computation

Many different algorithm exist to measure frequency. For the figure of this paper, the frequency is measured using a PLL algorithm tuned to be rather robust to perturbations (as algorithms used in protections should be).

The ROCOF can be derived from the frequency with different methods. In this paper, the ROCOF is computed by differentiating the frequency over a period T, like (1), the result is noted $ROCOF_T$.

$$ROCOF_T(t) = \frac{f(t) - f(t-T)}{T} \tag{1}$$

A high T leads to a slower and more robust ROCOF measurement. Two different periods T are considered in this section: 0.2 s and 0.5 s. They will be compared in order to catch the influence of computation rapidity on the protection operation.

Slowly changing frequency

Legacy continental power systems have rather high inertia, so the frequency evolution is rather slow, i.e. the ROCOF is low. As illustrated in Figure 1, in such conditions, the computation rapidity (here modified by changing the period T) does not have much influence. The frequency evolution is slow so any protection can follow it easily.

[1] O. Arguence and F. Cadoux are with the chair on Smartgrids of Enedis, within Univ. Grenoble Alpes, CNRS, Grenoble INP, G2Elab, 38000 Grenoble, France

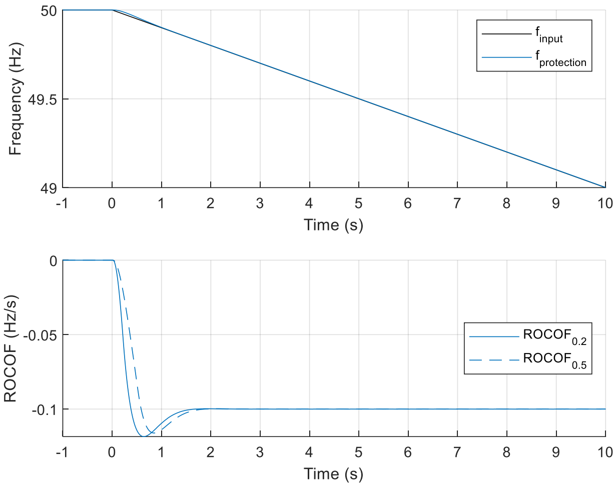

Figure 1 – Frequency and ROCOF measured with input ROCOF set to -0.1 Hz/s.

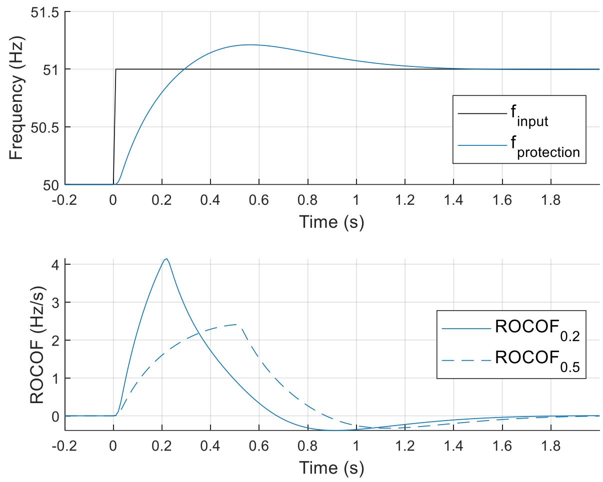

Figure 2 – Frequency and ROCOF measured with input frequency jump.

However, if the changes were faster, then the measured transient frequency and ROCOF would be different if measured by different devices. The following paragraphs show why it is important.

The protections need to be fast enough

ROCOF protections can be used to detect unintentional islanding. After opening the feeder, the islanded condition begins; and in some cases, frequency and voltage will change much faster than in a full continental power system. These fast changes can be close to a frequency jump. The measured frequency and ROCOF of such an event are plotted on Figure 2. It can be seen that for different periods T, the maximal ROCOF value reached is quite different: with a low value T = 0.2 s (i.e. a fast ROCOF computation), the ROCOF reaches higher values. So, with a lower period T = 0.2 s, the protection would trigger and detect unwanted islanding more easily (note that such conclusions were already obtained in a more detailed study in [3]).

Therefore, for islanding detection purpose, the computation of the frequency and ROCOF need to be as fast as possible (“fast” in terms of computation: intentional delays are irrelevant to know whether an island would be detected or not). Such needs for fast enough computation exist as well for other types of protections.

The protection needs to be robust to perturbations

Perturbations might occur on the grid, leading to false detection and unwanted opening of the protection. Examples of perturbations are harmonics, and voltage jumps or phase jumps following the connection or disconnection of a large load. The protections need to be robust to such kind of perturbations. This is why IEC 60255-181 proposes to evaluate the performances of protections when they face these types of disturbances.

However, improving the robustness with respect to perturbations generally comes at the price of slowing down computations. This is illustrated by Figure 3: after a phase jump, the measured frequency jumps, leading to high ROCOF values. Observe that for the higher period T = 0.5 s (i.e. a computation with slow dynamics), the ROCOF reaches a lower value. This illustrates the fact that the protection is less likely to trigger unduly when its computation is slower.

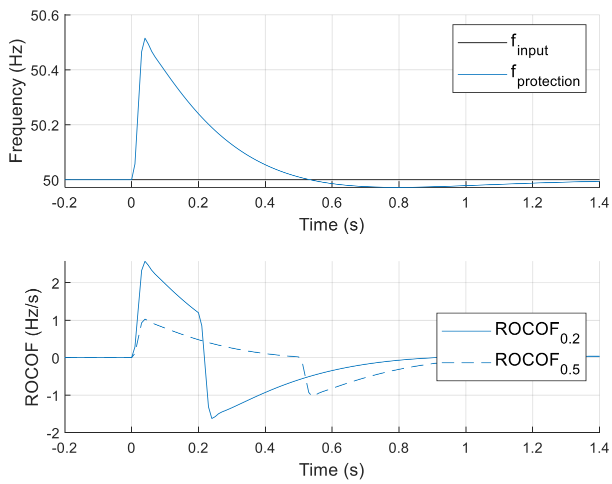

Figure 3 - Frequency and ROCOF measured with input phase jump of 30°.

Thus, when designing the algorithm of a frequency and ROCOF protection, there is a trade-off to reach between the robustness of the protection to perturbations and its ability to detect abnormal conditions of the grid. Therefore, to make a well-informed choice, someone choosing a protection device needs to be well informed of the computation rapidity of the protection.

II - TOWARD EVALUATING THE BANDWIDTH OF PROTECTIONS

In the IEC 60255-181, several tests evaluate the time response of the protection. More precisely, they measure:

1) The start time, which is the time interval between the instant the input go beyond the protection threshold and the instant the start signal is activated.
2) The disengaging time, which is the time interval between the instant the input go below the protection threshold and the instant the start signal is deactivated.

However, the start time and disengaging time are the consequence of two different and indistinguishable characteristics of the protection: the delay (which can be intentional or not) and the computation time. So knowing the start time and the disengaging time does not enable to know the computation rapidity. Yet, as seen in the previous section, it is an important characteristic to evaluate.

To evaluate it, we propose in this paper to measure the bandwidths of the protection with an additional test. Note that the bandwidth is a characteristic that is usual to evaluate for grid frequency measurement devices. For example, IEC/IEEE 60255-118-1 [4], which is a standard on synchrophasor for power systems, describes a test to measure the bandwidth.

The bandwidth that needs to be measured is the bandwidth of the system that measures the frequency (or ROCOF). Its input is the frequency (or ROCOF) used to generate the alternative voltage feeding the protection and its output is the frequency (or ROCOF) measured by the protection. Such a system behaves as a low-pass filter. Therefore, the bandwidth is equal to the cut-off frequency.

The higher the bandwidth, the faster the computation rapidity. So if one needs a fast protection, e.g. to detect islanding, a rather high bandwidth would be needed. At the opposite, if one needs a protection to be robust to perturbations, they should be aware that the protection would be slower, with a lower bandwidth.

III - TEST PROPOSITION TO MEASURE THE BANDWIDTH

The frequency and ROCOF are not available as an output of the protection. The protection is seen as a black box with an AC voltage as an input and with two outputs: the start signal and the operate signal. Therefore, the tests of protection may only rely on these two outputs to measure characteristics of the protection.

The core idea of the proposed test is to modulate the input frequency and to check whether the start signal is activated or not. To simplify, only the test to measure the bandwidth of frequency protection (and not ROCOF protection) will be detailed and studied in the paper.

Frequency modulation

For the test, the input frequency is modulated as described in:

$$\begin{cases} V_a = V\sin(\theta(t)) \\ V_b = V\sin(\theta(t) - 2\pi/3) \\ V_c = V\sin(\theta(t) - 4\pi/3) \end{cases}$$
$$with \begin{cases} \theta(t) = 2\pi \int f(t)\,dt \\ f(t) = f_{threshold} - k_a/2 + k_a \sin(2\pi f_m t) \end{cases} \tag{2}$$

Where θ is the phase angle, f the input frequency, $f_{threshold}$ the upper threshold of the protection, f_m the modulation frequency and k_a the frequency modulation factor.

The average value of f(t) is $f_{threshold}$-k_a/2 which is below $f_{threshold}$ and the maximal value of f(t) is $f_{threshold}$+k_a/2 which is above $f_{threshold}$. As the frequency measurement algorithm behave as a low-pass filter, for high value of f_m, the measured frequency would be close to its average and remain below $f_{threshold}$ and the protection would remain close. While for low value of f_m, the measured frequency would exceed $f_{threshold}$ and protection would open. These observations are illustrated on Figure 4.

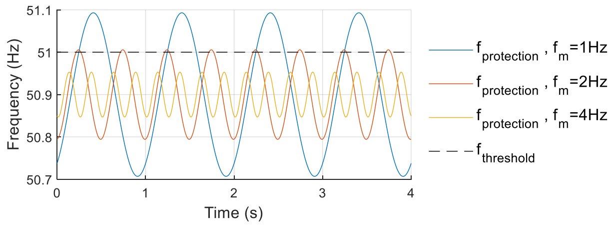

Figure 4 - Frequency measured by the protection for different modulation frequencies of input.
Parameters: $f_{threshold}$ = 51 Hz, k_a = 0.2 Hz.

Test proposition to measure the bandwidth of protection

The core idea of the proposed test is to start with a high modulation frequency and to decrease f_m until the protection opens. The modulation frequency reached when the protection opens is the cut-off frequency (and bandwidth).

Said otherwise, the protection opens when the measured frequency reaches $f_{threshold}$, which happens when the measured modulation amplitude reaches k_a/2, i.e. half the input modulation amplitude, which is the very definition of cut-off frequency. Of course, the equation $f(t) = f_{threshold} - k_a/2 + k_a \sin(2\pi f_m t)$ was designed to get such a result.

Test illustration

Using our measurement algorithm with the modulated frequency input, we computed the gain (i.e. ratio) between the output frequency amplitude and the input frequency amplitude (= k_a) for different modulation frequencies f_m to get Figure 5 a). Meanwhile Figure 5 b) display whether the protection would open or not. With the bandwidth test, the measured bandwidth of the algorithm used for Figure 5 would be 2 Hz.

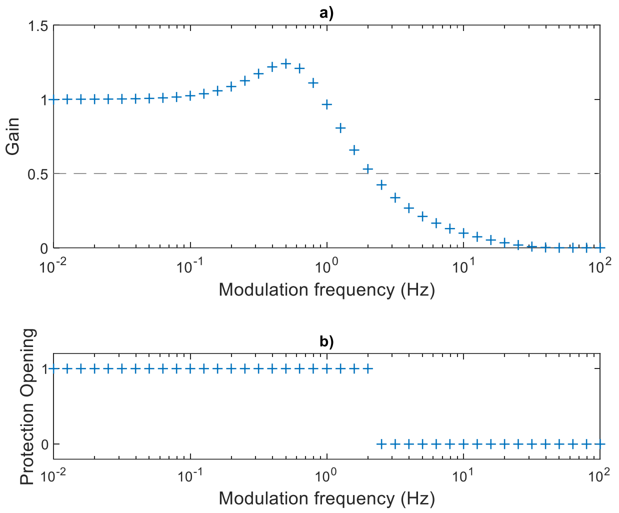

Figure 5 – a) Gain between frequency variation of protection and frequency variation of the input, b) Protection Opening as a function of modulation frequency.

CONCLUSION

The rapidity of computation of frequency and ROCOF is an important characteristic to consider when choosing a protection. To improve the evaluation of this rapidity, a novel test is proposed to measure the bandwidth of protection which is a good indicator of such rapidity.

The proposed test still needs more detailed descriptions and parameters before considering to add it in a future version of IEC 60255-181. Several parameters need to be defined, one important is the frequency modulation factor, and others are the initial modulation frequency and the modulation frequency step between each measure. The test also needs to be applied in practice to several existing industrial protections in order to verify that it does provide a repeatable and precise measurement of their bandwidth.

REFERENCES

[1] ‘Measuring relays and protection equipment – Part 181: Functional requirements for frequency protection’. IEC/IEEE 60255-181 ED1, 2018.

[2] M. Kleemann and V. Piskarov, ‘Rate of change of frequency protection: towards a viable algorithm for a protective relay’, in *CIRED 2017 - 24th International Conference on Electricity Distribution*, Glascow, United Kingdom, 2017, vol. 2017, pp. 1393–1397.

[3] O. Arguence, F. Cadoux, B. Raison, and L. De Alvaro Garcia, ‘NDZ of an anti-islanding protection with ROCOF threshold’, in *CIRED 2017 - 24th International Conference on Electricity Distribution*, Glascow, United Kingdom, 2017.

[4] ‘IEEE/IEC Draft International Standard - Measuring relays and protection equipment - Part 118-1: Synchrophasor for power system - Measurements’, pp. 1–75, Jan. 2018.