IMPACT OF NEW EUROPEAN GRID CODES REQUIREMENTS ON ANTI-ISLANDING PROTECTIONS: A CASE STUDY

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ABSTRACT

As more and more new small- to medium-scale generators connect to distribution networks, network operators have to adapt to new situations, in particular by adjusting their protection plan. This paper deals with one of the main issues that such generators may cause, namely, unintentional islanding. The motivation for this work is the fact that future European Grid codes will require these generators to contribute to power system stability by implementing some additional control features. The aim of the paper is thus to study how the non-detection zones of a standard test case (parallel RLC oscillating circuit) will be modified when these new requirements are implemented. The methodology used for this work is to perform a static study to compute the steady state values of frequency and voltage in the oscillating circuit, when a typical reactive power regulation and/or the required over-frequency droop are applied, and to compare these values with the thresholds of standard interface protections used by generators.

INTRODUCTION

By definition, unintentional islanding occurs when a part of the grid gets disconnected from the main network but remains energized by local generators. This abnormal situation creates risks for people and equipment (see for instance [1]) that distribution system operators (DSOs) obviously want to avoid. Another motivation relates to power quality, as follows. In France, overhead medium-voltage feeders are usually equipped with automatic reclosers associated with voltage presence detectors. When a distributed generator (DG) is connected to these feeders, a voltage presence detector is used in the reclosing scheme in order to avoid reclosing on an energized feeder, possibly out-of-phase. Therefore the presence of an (even very short) islanded situation would inhibit the recloser whenever downstream voltage is sensed. Slow disconnection of DG can thus impact the quality of service by delaying or even preventing reclosing operations. For all these reasons, it is important to protect distribution systems against the occurrence of islanding; however, it may be challenging in practice to prevent or even merely detect its occurrence.

Protection against unintentional islanding is currently ensured by relays installed at generator-level, usually called “interface protections”; these devices constantly monitor the values of RMS voltage (direct and zero sequences) and frequency, and trip the associated generator whenever these values exceed some thresholds around the normal (nominal) values of voltage and frequency. These protections thus suffer from a “blind zone”, called the non-detection zone (NDZ): when the values of voltage and frequency in the island remain too close to nominal values, the relays cannot distinguish whether an islanding is occurring.

To ensure proper operation of interface protections, it is thus important to evaluate whether voltage and frequency in the island are likely to remain close to nominal values. A first important observation is that maintaining closely the nominal value of voltage and frequency in an island requires to also provide the nominal active power consumed by loads, which may only occur when local generators are sufficiently numerous and/or powerful to balance local load. As a consequence, the likelihood of islanding was clearly very low in the past [2], when most generation was centralized. Conversely, the increasing development of distributed generation, e.g. photovoltaic, is likely to enlarge this risk in the future.

A second important observation is that voltage and frequency in an island depend, among other things, on the controls implemented by generators. As a consequence, automatic control actions at generator-level (that are designed to support system stability and/or local voltage control), may have an impact on the operation of interface protections. An example of this situation is provided by the new European Grid code “Requirements for generators” (RfG) [3] that requires all generators with

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nominal power higher than 800W to implement a so-called “over-frequency droop”. The latter aims at reducing the active power injection of the generation installation when frequency becomes too high. This new control action is motivated by the needs of transmission system operators (TSOs) and aims at stabilizing system frequency; but it also raises some questions about its impact on unintentional islanding. Other regulation features, such as controlling the reactive power injection of generators as a function of local voltage, may also be useful in the future, raising similar questions. In this paper, we study how such generator-level control actions affect the NDZ.

**CONTEXT**

In France, photovoltaic inverters connected to the LV network must comply with the pre-standard DIN VDE 0126-1-1/A1. The latter requires power generating modules to pass the standard oscillating circuit test-bed, which consists in testing whether their anti-islanding protection is able to detect an islanded situation (and thus trip the generator) when the generator feeds a parallel RLC load that is tuned in such a way that its active and reactive power consumption balances the (constant) active and reactive power injected by the generator. Motivated by this standard test-bed, for which calculations are relatively easy, we decided to use in this paper such a parallel RLC load as the main case study.

**Oscillating circuit test from the DIN VDE 0126-1-1/A1**

![Oscillating circuit test](image)

The R, L and C parameters are tuned so that no current (in practice, “a very small current”) flows from the grid to the load. When the balance between both active and reactive power consumed and produced is obtained, the breaker is intentionally tripped to leave the inverter alone with the parallel RLC load. The system consisting of both the inverter and the load is thus made to be very close to equilibrium (in active and reactive power): note that, by construction, the steady state frequency of the islanded system is thus 50 Hz (or more generally, the nominal frequency of the considered grid) and similarly, the steady state voltage of the islanded system is set to the nominal voltage of the grid. The test is considered to be passed if the anti-islanding protection trips within five seconds. This test is then replayed with new values of L or C (± 1% with a maximum of ± 5%) and a new power input in the inverter (25%, 50%, 75% and 100% of the maximum power input). The test of oscillating circuit is passed if the anti-islanding protection trips in less than 5 seconds for each test. Note that this test was designed for inverters without any regulation of the kind discussed in the introduction (over-frequency droop, control of reactive power as a function of voltage, etc.); the active and reactive power injected by the inverter is implicitly assumed to be constant.

The steady state of such a system (constant power generator and parallel RLC load) is easily computable in closed form. An easy way to calculate the steady state frequency and voltage is to separate active power and reactive power: the resistor does not consume any reactive power, the inductor and the capacitor do not consume any active power, and there holds:

\[
P_0 = \frac{|U|^2}{R} \quad (1)
\]

\[
Q_0 = \left(\frac{1}{\omega C} - \omega L\right) |U|^2. \quad (2)
\]

Solving these equations for \(|U|\) and \(f\), we obtain:

\[
|U| = \sqrt{P_0 R}. \quad (3)
\]

\[
f = \frac{-\frac{Q_0}{|U|^2} + \left(\frac{Q_0}{|U|^2}\right)^2 + 4\omega^2 C}{4\pi^2 C}. \quad (4)
\]

In particular, if the generator does not produce or consume any reactive power, then the steady state frequency of the system is the resonance frequency of the parallel RLC load.

**New regulation functions**

Two new regulation functions are studied in this paper. The first one, required by the new RIG European Grid code is the over-frequency droop.

**Over-frequency droop P(f)**

![Over-frequency droop P(f)](image)
The behaviour of the over-frequency droop required by the new RIG European Grid code for all installations over 800W is shown in Figure 2. The active power P injected by the inverter is a function of frequency: when the latter exceeds some threshold, the active power injection is reduced linearly according to a slope that may be set from 2%/Hz to 12%/Hz. The frequency threshold may be chosen from 50.2 Hz to 50.5 Hz. The exact value of these settings within the given range will be decided at national level by national TSOs.

Reactive power regulation Q(U)

For the purpose of this study, we considered a typical “Q(U)-type” regulation [4], in which the voltage thresholds on the x-axis were chosen somewhat arbitrarily.

\[
\frac{Q}{P_{\text{max}}} = f(U)
\]

Figure 3 – Reactive power regulation \( Q = f(U) \) with deadband

The logic of this regulation is the following: the reactive power Q injected by the inverter at the connection node is a function of the measured grid voltage U. When voltage exceeds \( U_{\text{DB, max}} \), reactive power is consumed by the inverter (the rationale being to decrease the voltage and bring it back closer to its nominal value). Similarly, when voltage decreases under \( U_{\text{DB, min}} \), reactive power is produced by the inverter. The maximum reactive power consumed is reached at \( U_{\text{max}} \) and is then held constant.

NON-DETECTION ZONES IN RLC SPACE

In this paper, we fix the nominal power of the generator, and define the NDZ as the values of R, L and C for which islanding remains undetected according to our steady state calculations (and thus ignoring the dynamics of the islanded system, as well as the various methods that are typically implemented by manufacturers to pass the oscillating circuit test, and that are not captured in the steady-state calculations). Note that this is in conformance with [5], but contrary to standard practice, which consists in fixing the values of the R, L and C parameters of the load, and then defining the NDZ as the variations \( \Delta P \) and \( \Delta Q \) of the injected power (around the values that perfectly balance the load) that lead to undetected islanding [6] [7].

Our approach simply consists in measuring the volume of the NDZ in the RLC space, when various kinds of regulations are used. When no regulation feature is implemented by the generator, which simply injects constant active and reactive power, this space is \textit{a priori} defined only by the following inequalities (5) and (6):

\[
\left(\frac{1}{2} \frac{2\pi f_{\text{up}}^Q}{f_{\text{up}}} \right) \leq 4 \pi^2 C \leq \left(\frac{1}{2} \frac{2\pi f_{\text{low}}^Q}{f_{\text{low}}} \right),
\]

\[
\frac{U_{\text{low}}}{p} \leq R \leq \frac{U_{\text{up}}}{p}.
\]

Unfortunately, computing the volume of this area makes little sense: it can be shown that the volume is infinite, essentially because it is always possible to enlarge the size of the capacitor as long as the inductor is also reduced to balance the excess of reactive power (and conversely). As defined above, the NDZ thus contains loads with extreme values of the quality factor, which seem of little practical interest since such values are unlikely to represent any realistic situation. Motivated again by the pre-standard DIN VDE 0126-1-1/A1, which imposes a lower bound requires for the oscillating circuit test as follows,

\[
Q_f = R \cdot \sqrt{\frac{C}{L}} \geq 2,
\]

we decided to bound the NDZ by imposing an additional upper bound (whose will be set later in the paper, see for instance Figure 6) on the quality factor \( Q_f \).

Figure 4 – Example of an area in (LC) plan at fixed R

Figure 4 shows an example of a cross-section, for fixed R, of a NDZ. This area is defined by five inequalities obtained from (5), (6), (7) and using the voltage and frequency thresholds of the interface protections.

METHODS

We considered different ways to compute volumes in the RLC space. Two methods were used and cross-validated: one numerical, general and approximate, and the other theoretical, less general but exact.

Only the numerical one is explained below. We used it both for cross-validation (when no regulation is used, the
theoretical method applies and the results of both methods may be compared) and to measure the volume of the NDZ when “complex” regulations were used (in this case, closed-form calculations appear much more challenging). We simply enclosed the area whose volume needs to be evaluated into a larger 3-dimensional box; we discretize this box along the R-axis, the L-axis and the C-axis; and for all (R,L,C) triplets in the discretized volume, we compute the corresponding steady-state and check whether the triplet lies in the NDZ or not. After this rather brutal computation, the area of the NDZ is assessed using the following formula:

\[ A = \frac{N_{in}}{N_{tot}} \cdot A_{box}, \]  

(8)

where:

- \( A \): the area of the NDZ at R fixed;
- \( N_{in} \): the number of RLC triplets in the NDZ at R fixed;
- \( N_{tot} \): the number of RLC triplets tested;
- \( V_{box} \): the area of one box at R fixed.

The volume of the NDZ is computed by the sum of all the areas at discretized R.

**RESULTS**

The results are shown for the regulations shown in Figure 2 and Figure 3. The active power produced by the inverter is 36 kW. By default, no reactive power is produced. The thresholds of anti-islanding protections chosen for this study are \( U = [0.85 \text{ pu}; 1.15 \text{ pu}] \) and \( f = [47.5 \text{ Hz}; 51.5 \text{ Hz}] \).

The numerical results are shown for a sliding window on the quality factor, up to some values. The sliding window starts with \( Qf = [2; 2.2] \). A step of +0.2 is then applied to obtain the next window: \( Qf = [2.2; 2.4] \) and so on up to \( Qf = [9.8; 10] \).

Input parameters for the chosen regulations are the following:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_{thres} )</td>
<td>50.2 Hz</td>
</tr>
<tr>
<td>( U_{\min} - U_{\max} )</td>
<td>0.95 – 1.05 p.u.</td>
</tr>
<tr>
<td>( U_{\min_{\Delta U}} - U_{\max_{\Delta U}} )</td>
<td>0.9625 – 1.0375 p.u.</td>
</tr>
</tbody>
</table>

The results are displayed in the three following figures. Figure 6, where the black, green and dark blue curves are almost superimposed, shows the volume of the NDZ. Figure 7 displays the same information, relatively to the base-case (no regulation) and Figure 8 shows the volume of the intersection of the NDZ.

**Table 1 - Input parameters**

![Figure 6 – NDZ volume (in Ω.H.F), as a function of the quality factor Qf](image)

What stands out in Figure 6 and Figure 7, is that adding...
either a “Q(U)-type” regulation or a “P(f)-type” regulation seems to have very little impact on the volume of the NDZ (it increases slightly, by less than 1%); this volume is essentially the same as in the base case, without any regulation. However, when both regulations are used at the same time, the volume of the NDZ increases significantly, especially for low values of the quality factor Qf; the maximum increase is about +40% for Qf in [2, 2.2]. Our main finding is thus that these two types of regulations seem to interact in such a way that their combined effect is much stronger that the sum of their individual effects. A secondary finding is that the difference decreases when the quality factor increases. A final observation, depicted on Figure 8, is the following: while the volume of the NDZ is not changed much (by comparison with the base case) when only one of the two types of regulation is used, the location of the NDZ in the RLC space does significantly change for the “Q(U)-type” regulation, whereas the NDZ almost does not move when the “P(f)-type” regulation is used. (Of course, when both regulations are used, the volume of the NDZ itself changes as explained above and as a consequence the “location” changes as well).

![Figure 8 - Volume of the intersection of the NDZ with the base-case NDZ, as a function of the quality factor](image)

CONCLUSION

In this paper, we showed that the (newly required) over-frequency droop and the (future?) reactive power regulation alone do not significantly increase the NDZ; we interpret this as an indication that the likelihood of islanding may not increase too much if only one of these two regulations is deployed. On the contrary, when both regulations are used, we showed that the volume of the NDZ increases significantly, especially for low values of the quality factor; we deduce that the risk of islanding may increase if both types of regulation were to be deployed in practice. These results seem counter-intuitive, as the combined effect of these two types of regulations is apparently much stronger than their individual effects.

This study is subject to several limits. First, it consists merely of static calculations: the dynamics of the system were not considered. Moreover, the stability of the static solutions was not studied. Finally, the load model used in our study (parallel RLC load) is arguably not representative of real-world distribution systems. Our findings thus need to be refined and confirmed by further studies, which will be the subject of future research.

REFERENCES