

FIELD TESTS OF A NEW SMART ISLANDING DETECTOR (SMARTID)

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ABSTRACT

The present paper focuses on the validation of an innovative islanding detector, named SmartID, to be included into anti-islanding protection systems for LV distribution networks. The SmartID is designed to guarantee a reliable islanding detection when the classical voltage and frequency relays at the distributed generation premises fail, due to their limited sensitivity. On-field tests have been performed by ENEL Distribuzione S.p.a. installing 20 SmartIDs in the smart grid located at Isernia (Italy). The analysis of the results shows the ability of the SmartID to detect islanding in real operation when generation and load are balanced.

INTRODUCTION

Islanded operation occurs when part of a distribution network loses connection with the main supplying system of the grid and remains in operation as an independent entity thanks to the presence of Distributed Generation (DG). In the utility practice, islanding is not permitted because it severely affects the safe and secure operation of distribution systems.

To detect islanding, common industrial practice is to adopt protections based on over/under frequency, over/under voltage, rate of change of frequency (ROCOF), vector shift or surge (VS) relays. These are local passive protections integrated into the DG interface [1].

The continuous increase of DG penetration in distribution systems is amplifying the problem of a reliable islanding detection. The Transmission System Operators (TSOs) are requiring the DG to contribute to the stable operation of the power system by remaining connected to the network when frequency and voltage perturbations occur at the transmission level. Consequently the threshold settings of the classical protections are being revised to enlarge their non detection zone.

Moreover, the DG growth is increasing the probability that in islanded operation DG may balance the loads. In this conditions, the frequency and voltage variations in the island may be so limited that cannot be detected by the classical protection systems. Then, additional anti-islanding protection systems must be introduced to guarantee high enough sensitivity [2].

Different anti-islanding communication-based protection systems are being proposed; these are effective solutions

but their high costs can be afforded only in MV distribution systems, which are characterized by a limited number of DG devices and are already equipped with automation systems [3]. On the contrary, in LV networks such an approach is not economically viable and, then, alternative solutions have to be identified.

Recently, a new patent-pending islanding detection method has been proposed for LV distribution systems [4]. The method has been implemented in a device, named SmartID, by Ambra Energy Systems S.r.l. [5]. It is a cheap passive relay to be added to the classical anti-islanding protections and it is conceived to guarantee a reliable detection of islands characterized by the balance between generation and load.

This paper presents and analyses the results of some field tests performed by ENEL Distribuzione S.p.a. in the smart grid located at Isernia (Italy). Real islands have been created in LV networks and the behaviour of some SmartIDs installed in different nodes has been recorded.

LV ANTI-ISLANDING PROTECTION SYSTEM

The proposed SmartID enriches the classical anti-islanding protection system adopted in LV distribution systems, which is based on voltage and frequency relays.

Classical voltage and frequency relays

The voltage and frequency relays are integrated into the interface protection system of each DG. The classical relays are designed to detect voltage and frequency variations subsequent to power imbalances in the islanded system. Commonly, they assume different tripping thresholds and delays, according to different standards. Table 1 shows the minimum requirements for the voltage and frequency relays imposed by the Italian standard CEI 0-21. In general, these relays present large non detection zones and small detection times, so as to avoid islanding conditions characterized by a significant power mismatch and to permit a successful fast reclosure in MV distribution systems.

The SmartID

A SmartID is installed in one or more points of the LV distribution network. It is designed to detect the islanding events when the variations of the electrical quantities are too small to be detected by the classical relays. The passive method adopted by the SmartID is described by the block scheme in Figure 1. On the basis of local

Voltage relays		Frequency relays		
V (%) ¹	t_c ¹ (s)	DG type	f (Hz)	t_c ¹ (s)
≥ 110	≤ 3.00	Rotating	> 50.5	0.10
≥ 115	0.20		< 49.5	0.10
< 85	0.40	Static	> 51.5	0.10 or 4.00 ³
< 40	0.20		< 47.5	0.10 or 4.00 ¹

Table 1. Voltage and frequency requirements for LV distribution system in the Italian standard CEI 0-21.

voltage $v(t)$ and current $i(t)$ measurements, the corresponding phasors \bar{V} and \bar{I} at the fundamental frequency are evaluated to estimate the parameters \bar{a} and \bar{b} of the Thevenin-like model, representing the LV distribution system upstream the SmartID installation point. The dimensions of the parameters \bar{a} and \bar{b} are, respectively, a voltage and an impedance. The detection method is based on the different absolute values assumed by \bar{a} and \bar{b} in grid-connected and islanded operation. Comparing a and b with their respective thresholds ref_a and ref_b , if

$$a \geq ref_a \quad \text{and} \quad b \leq ref_b \quad (1)$$

an output signal OS is generated which is representative of the grid-connected operation; on the other hand, if

$$a < ref_a \quad \text{and} \quad b > ref_b \quad (2)$$

a different output signal OS is generated which is representative of the islanded operation. Details about the islanding detection method and its implementation in the SmartID prototype can be found in [4,5]. Table 2 shows the thresholds adopted by the SmartIDs under validation. The thresholds values are set according to the procedure described in [6] and guarantee the detection of islands in which generation and load closely match. The presence of two different limits in dependence of the transition type (from grid connected to islanded operation and viceversa) introduces a hysteresis that improves the SmartID stability. The detection time¹ is not a stringent requirement. In fact, the SmartID detects islands occurring in the LV network caused, for instance, by failures of the MV fast reclosure or joint disconnections along LV feeders. These events last for long time (from several seconds to hours) because of the low level of automation of the LV distribution system. Then, a detection time equal to 10 s is a suitable requirement.

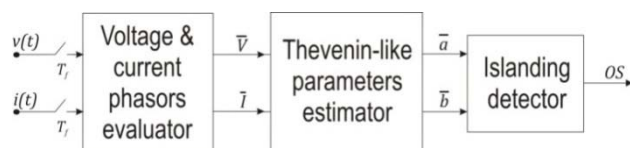


Figure 1. Block diagram of the SmartID.

¹ The detection time represents the time elapsing between the occurrence of the island and the change of the relay output.

SmartID relays		
<i>transition operation</i>	ref_a (V)	ref_b (Ω)
grid connected \rightarrow islanded ($g \rightarrow i$)	120	2.0
islanded \rightarrow grid connected ($i \rightarrow g$)	200	1.0

Table 2. Voltage and frequency requirements for LV distribution system in the Italian standard CEI 0-21.

ON-FIELD EXPERIMENTAL RESULTS

The aim of the on-field experimental tests is to validate the ability of the SmartID to detect islands characterized by the balance between generation and load. The tests have been performed by ENEL Distribuzione S.p.a. in the smart grid located in Isernia (Italy), which has been set-up for the Isernia Pilot Project [7]. The validation has involved 20 SmartIDs which have been installed in different LV networks of the smart grid in the frame of the EU FP7 project named IGREENGrid [8]. The SmartID preproduction series has been realized by Ambra Energy Systems S.r.l.. To generate balanced islands, a 75 kVA Diesel generator has been used; it has a power factor equal to 0.8 and it is protected by a breaker with a breaking capacity equal to 115 A. ENEL Distribuzione S.p.a. has rearranged the DG control system by adding an active and a reactive control loop which can be activated during the operation of the Diesel generator in parallel with the LV network. In the following, details about tests and experimental results are reported with reference to two LV networks, respectively fed by the Cupello MV/LV substation and the Castelromano MV/LV substation.

Cupello LV network

The 20/0,415 kV-630 kVA transformer at the Cupello substation supplies different LV lines. The tests have been performed on the line D shown in Figure 2, whose length is 2.489 km. Line D is protected by an utility breaker and supplies 145 customers with an installed power equal to 464 kW. To perform the tests, the Diesel generator has been connected to the head of the line D, downstream the utility breaker, and three SmartIDs have been installed along the feeder; in particular, the SmartID S1 at the head of the feeder and the SmartIDs S2 and S3 along the feeder, as shown in Figure 2.

To create an island, after the start-up, the Diesel generator is synchronized and closed in parallel with the grid. Then, the active and reactive control loops are activated and the generated powers regulated to catch up with the powers absorbed by the Line D. Once the balanced conditions have been reached, the utility breaker is manually opened and the islanded operation of Line D starts. Then, the islanded operation is kept lasting until the voltage and/or the frequency variations cause the intervention of the interface protection system and, then, the tripping of the generator.

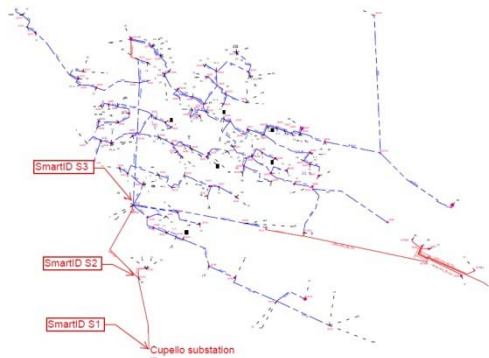


Figure 2. Cupello LV network.

Figure 3 shows the time evolutions of the rms voltage V and the frequency f measured at the head of the Line D, and of the active and reactive powers, P_{DG} and Q_{DG} , injected by the generator. The island starts at 11h 37' 22" and lasts for 4' 4". For all the island duration, V remains in the range 227-239 V, that is within the acceptable limits. On the contrary, f remains in the range 49.5-50.0 Hz for the first 3' 10" and, then, slowly decays, reaching 48.0 Hz at 11h 41' 26", when the generator tripped off for under frequency. In principle P_{DG} and Q_{DG} should remain constant. Indeed, as evidenced by the third plot in Figure 3, there are transient variations of the powers injected by the generator in response to load variations due to the way the generator control system works. For example, at 11h 39' 49" an increase of the load (evidenced by a drop of f in the third plot of Figure 3) causes at first an increase of P_{DG} , which is due to the action of the existing speed governor, and, then, a decrease of P_{DG} , which is due to the action of the additional active power control loop.

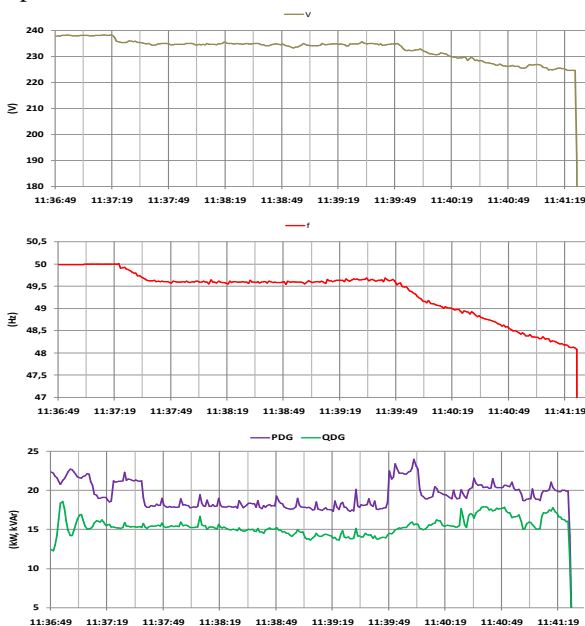


Figure 3. Time history of the rms voltage V and the frequency f measured at the head of the Line D, and of the active and reactive powers, P_{DG} and Q_{DG} , injected by the Diesel generator.

Figures 4-6 report the plots of the output signal OS and of the estimated parameters a and b for three SmartIDs S1, S2 and S3, respectively. The two operating conditions detected by S1 are evidenced by the time evolution of OS , which changes from 0 to 1 in the transition from grid-connected to islanded operation, as shown in the first plot of Figure 4. The detection time of S1 is around 4"; then, S1 detects the island 4' before the generator tripping by the under frequency protection. The permanence of OS in the status 1 for all the duration of the island demonstrates the stability of the SmartID. The time histories of a and b of S1 are shown in the second and the third plot of Figure 4. For the sake of comparison, also the values of the respective thresholds ref_a and ref_b in Table 2 are reported. When the island occurs, the parameter a changes its value from 241 V to values well below 50 V and the parameter b increases its value from 0.2Ω to around 5.0Ω . During islanded operation, while the parameter a reaches values higher than $ref_a=120$ V at the time 11h 41' 00" for 2", the parameter b is always significantly higher than its thresholds. However, the OS does not change because the SmartID detection requires that both the inequalities in (1) were satisfied. From the first plot in Figure 5, it is apparent that also S2 correctly detects the transition from the grid-connected to islanded operation. The detection time of S2 is equal to 3". Observing the time evolutions of a and b in the second and third plot of Figure 5, considerations similar to the ones for S1 can be derived. In fact, as in the previous case a and b significantly change their order of magnitude in the transition; differently from the previous case, both the parameters a and b are less stable. Even if the parameter a overcomes both its thresholds, the parameter b is

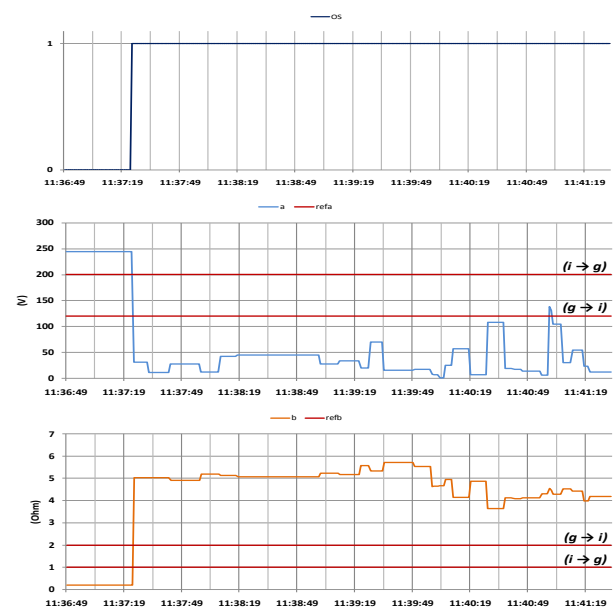


Figure 4. Time history of the output signal OS and of the estimated parameters a and b of the SmartID S1.

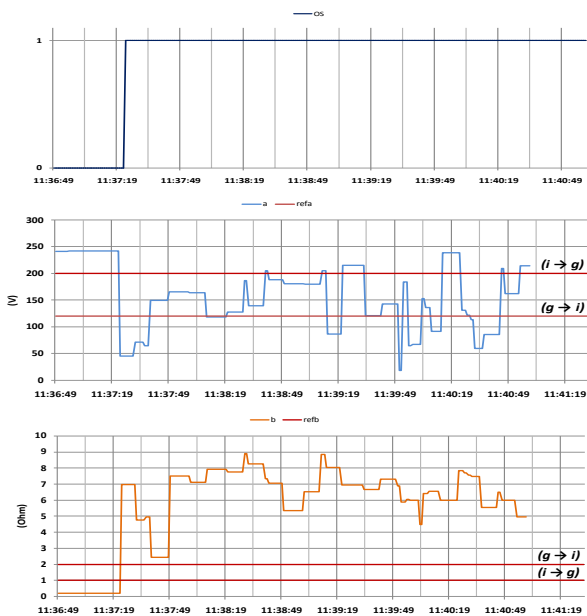


Figure 5. Time history of the output signal OS and of the estimated parameters a and b of the SmartID S2.

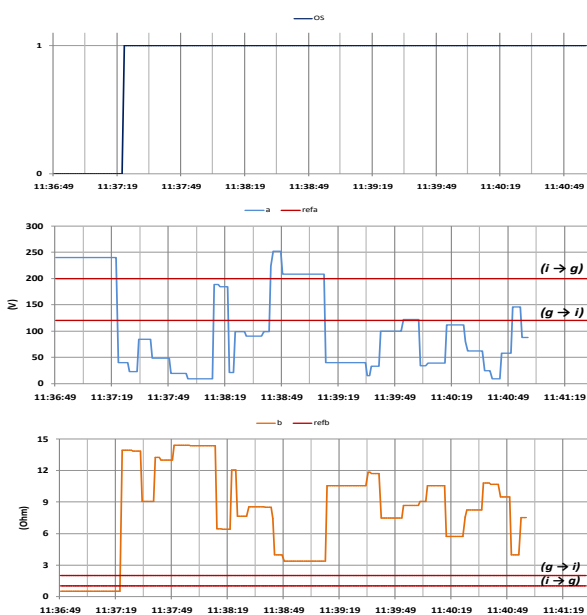


Figure 6. Time history of the output signal OS and of the estimated parameters a and b of the SmartID S3.

always significantly higher than the thresholds and S2 can continue to successfully detect the island. Similar considerations can be made for S3 in Figure 6; in this case the detection time is equal to 2".

As a general consideration, it can be stated that the oscillations of parameters a and b during islanded operation worsen when the SmartID is located far from the DG. Furthermore, it can be expected that with actual DG devices, that keep the active and reactive powers at constant values, such oscillations would reduce.

Castelromano LV network

The 20/0,400 kV-250 kVA transformer at the Cupello substation supplies different LV lines. The tests have been performed on the line D shown in Figure 7, whose length is 1.924 km. Line D is protected by an utility breaker and supplies 112 customers with an installed power equal to 361 kW. The tests have been performed by connecting the Diesel generator and the SmartID S1 to the head of the line D and the SmartIDs S2 and S3 along the feeder.

The island occurs at 11h 11' 48" and lasts for 1' 34". During the island, the rms voltage V measured at the head of the Line D increases and remains within the admissible limits, reaching the final value of 254 V, as shown in the first plot of Figure 8. Eventually, the DG trips off for over frequency (51.6 Hz), as shown in the second plot of Figure 8. The third plot in Figure 8 shows the time evolutions of the active and reactive powers injected by the generator. Considerations similar to the ones in the previous case can be made.

All the SmartIDs correctly detect the islanded operation, as illustrated by the time evolutions of OS s in the first plot of Figure 9, which change from 0 to 1. The detection times of S1, S2 and S3 are equal to 3", 3", and 4", respectively, and the OS s remain constant to 1 for all the island duration. Also in this case it is evident that there is a wide variation of the estimated parameters a and b in the transition from the grid-connected to islanded operation, as evidenced by the second and third plots in Figure 9. Even if during the power island the oscillations of a overcome the thresholds assuming values that characterize the grid-connected operation, the SmartIDs continue to correctly detect the island, thanks to the high values assumed by b . The robustness of the method is to be attributed to the adoption of two parameters rather than a single one for the detection of the islanding conditions. The general considerations reported at the end of the previous section for Cupello test, referring to the origin of such oscillations, are still standing.

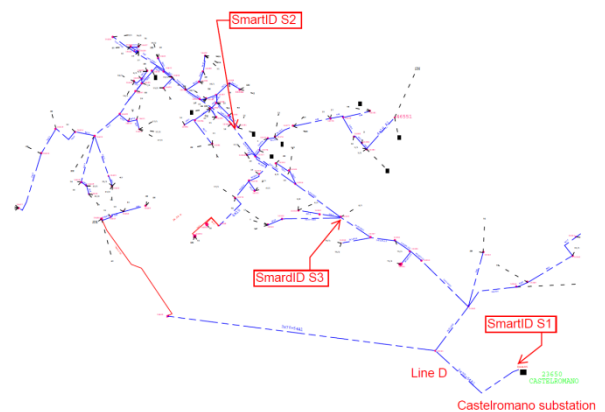


Figure 7. Castelromano LV network.

CONCLUSIONS

The paper has presented the results of on-field tests of an innovative islanding detector, named SmartID, to be included into anti-islanding protection systems for LV distribution networks. The tests have been performed by realizing actual islanded operations of feeders in different LV networks of the smart grid of Enel Distribuzione S.p.a in Isernia (Italy). During the islanded operation, the balancing between generation and load has been realized by the active and reactive control system of a Diesel generator so as to guarantee limited variations of voltage and frequency for long time (minutes). In this conditions the classical frequency and voltage relays adopted in the DG interface do not detect the island. On the contrary, all the SmartIDs installed in different points of the feeder have successfully detected the island with a detection time of few seconds. The stability of the output signal of the SmartIDs during the islanded operation allows to foresee the possible use of this innovative device in the smart grids of the future, in which such an operation will be permitted.

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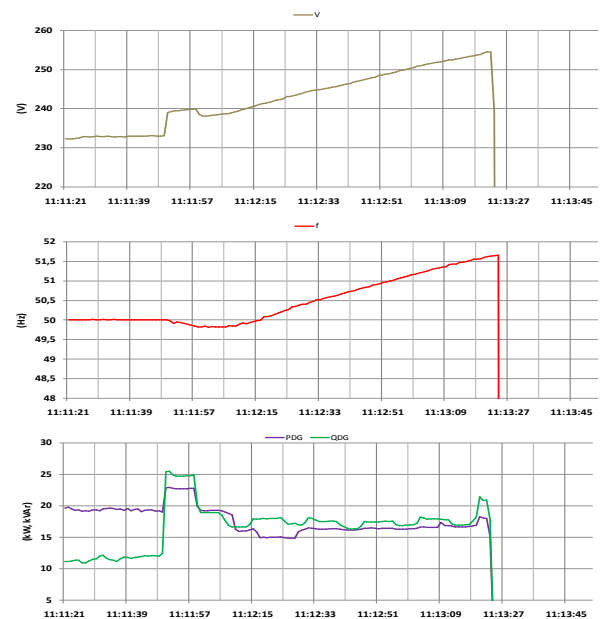


Figure 8. Time history of the rms voltage V and the frequency f measured at the head of the Line D, and of the active and reactive powers, P_{DG} and Q_{DG} , injected by the generator.

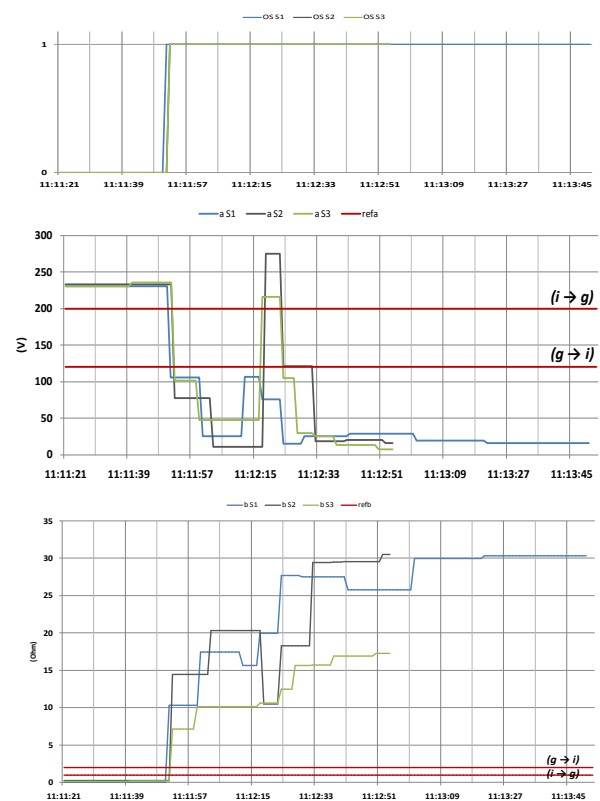


Figure 9. Time history of the output signal OS and of the estimated parameters a and b for S1, S2 and S3.