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A smart device for islanding detection in distribution system operation

Anna Rita Di Fazio[a,*], Giuseppe Fusco[a], Mario Russo[a], Sara Valeri[a], Christian Noce[b], Giuseppe Amura[c]

[a] DIEI, Università degli Studi di Cassino e del Lazio Meridionale, Cassino, Italy
[b] Enel Distribuzione SpA, Roma, Italy
[c] Ambra Energy Systems S.r.l., Pomezia, Italy

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ABSTRACT

The present paper focuses on the design, realization and validation of the prototype of an innovative relay, named SmartID, for islanding detection in LV distribution systems. The SmartID adopts a patent-pending detection method: it uses local measurements to estimate the parameters of a linear model of the distribution system, which can be used to distinguish grid-connected from islanded operation. The hardware of the SmartID prototype is composed of a voltage transducer, some conditioning stages, a commercial μcontroller and an output stage. The software implements the A/D conversion of the measurements, the phasors evaluation by Kalman Filters, the model parameters estimation by a constrained recursive least-squares algorithm, and the detection criteria. The validation of the SmartID is performed on a test site in a smart grid located in Isernia (Molise, Italy). Experimental results show the good performance of the SmartID in the detection of both grid-connected and islanded operation; transitions from one condition to the other is only partially analyzed, due to the limitations introduced by the use of a commercial DG. The anti-islanding relay is the result of a joint research project among the University of Cassino and Southern Lazio, Ambra Energy System S.r.l. and Enel Distribuzione S.p.a.

1. Introduction

A reliable detection of islanding events is one of the most challenging aspects in the operation of both actual and future electrical distribution systems.

Islanding occurs when part of the distribution network, including distributed generators (DGs), loses connection with the main supplying system of the grid [1]. The main benefit of allowing the islanding operation is the improvement of the distribution system reliability, because DGs can continue to supply loads during system emergencies, avoiding customer interruptions [2–4].

In the present distribution grids the absence of adequate control systems for DGs and of a secure coordination among the feeder protection systems makes islanded operation not viable. In fact, DGs are P/Q regulated and, then, unable to maintain frequency and voltage within the admissible limits. Furthermore, the feeder automatic reclosers can attempt to reconnect two networks when they are out of synchronism. Then, to guarantee the security of the system, the prolonged operation of a power island fed from DGs is considered to be unacceptable: DGs are required to detect islanding and immediately disconnect themselves from the distribution networks [1,5,6].

In the future smart grids the introduction of advanced monitoring, control and communication systems will enable the distribution network to operate in intentional islanding, so as to exploit the potential benefits introduced by the DGs and the other distributed energy resources. In particular, while DGs can operate in P/Q mode when connected to the main supplying system, they have to be switched from P/Q mode to P/V or f/V control mode during islanding to balance generated and absorbed active and reactive powers [7,8]. Also protection systems must re-tuned to account for the different operating conditions of the smart grid. Then, in the future distribution systems, islanding detection will still be necessary to switch the control mode of the DGs and the tuning of

* Corresponding author.
E-mail addresses: a.difazio@unicas.it (A.R. Di Fazio), fusco@unicas.it (G. Fusco), russo@unicas.it (M. Russo), s.valeri@unicas.it (S. Valeri), christian.noce@enel.com (C. Noce), giuseppe.amura@alice.it (G. Amura).

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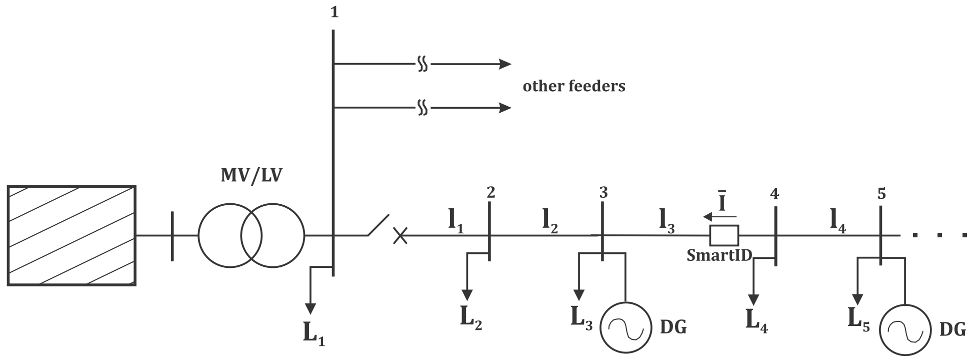

Fig. 1. Simple distribution system with DGs and the SmartID.

the protection systems [5,6]. In a nutshell, a reliable anti-islanding detection today guarantees a successful islanded operation in the future [9].

Extensive research has been carried out to develop islanding relays. However, the problems related to islanding detection and operation are not solved and a single world-wide accepted solution does not exist yet [10].

The methods used for the detection of islanding are usually classified into passive, active and communication-based. The passive methods use local measurements, do not affect the power quality of the distribution system, are inexpensive, but usually present a large non detection zone (NDZ) [5]. The active methods have a good performance in islanding detection but, since they are based on the injection of disturbances into the distribution system, present the disadvantage of worsening the power quality [11]. The communication-based methods require communication infrastructures among the DGs and the utility grid control system; these methods are very effective, being characterized by the absence of the NDZ, but present a high cost of implementation [6,5,12].

The present paper focuses on the design, realization and validation of the prototype of an innovative relay, named SmartID, for islanding detection in LV distribution systems, which is reliable and economically viable. The SmartID adopts a new patent-pending passive method based on a linear representation of the distribution system as seen from the point of installation of the SmartID: on the basis of current and voltage measurements, the parameters of the distribution system model are estimated and, then, used to distinguish islanded from grid-connected operation. The prototype of the SmartID has been developed by the University of Cassino and Southern Lazio (Uniclam) in the context of a research project promoted by Ambra Energy System S.r.l. (AES). Firstly, the functional requirements have been defined in terms of accuracy of the input measurements, of computational capability of the μcontroller and of output signal characteristics; then, the hardware and software architectures have been developed. The hardware of the SmartID prototype is composed of a voltage transducer, some conditioning stages, a commercial μcontroller and an output stage. The software implements the A/D conversion of the measurements, the phasors evaluation by Kalman Filters, the model parameters estimation by a constrained recursive least-squares algorithm, and the detection criteria. The validation of the SmartID has been performed on a test site in a smart grid located in Isernia (Molise, Italy) by ENEL Distribuzione S.p.a. [13]. The results of the on-field tests show the ability of the SmartID to detect the grid-connected and islanded operating conditions. The SmartID performance in the transitions from one condition to the other is only partially analyzed, due to the limitations introduced by the use of a commercial DG equipped with a standard control system.

The paper is organized as follows. After describing in Section 2 the basic principle and implementation of the detection method, Section 3 presents the functional requirements together with the hardware and software architectures of the SmartID prototype. The experimental results are finally reported and discussed in Section 4.

2. The islanding detection method

2.1. The principle

To illustrate the new patent-pending detection method, reference is made to the generic distribution system shown in Fig. 1. A supplying system, composed of the MV network and the MV/LV substation, supplies multiple feeders that can include DGs. In the distribution system the DGs are P/Q regulated and the MV busbar operates as slack node. The SmartID is installed along a single phase feeder that can operate in connection to the main supply or in islanding, according to the status of the breaker located at its head.

The model of the distribution system as seen from the point of installation of the SmartID is shown in Fig. 2. The part of the grid located downstream the SmartID is modeled by a time-varying current injection $\bar{I}$, whereas the upstream network is represented by a linear model according to

$$\bar{V} = \bar{a} + \bar{b}\bar{I} \tag{1}$$

where $\bar{V}$ is the voltage at the SmartID installation point. The parameter $\bar{a}$ represents the share of $\bar{V}$ invariant to $\bar{I}$, whereas the term $\bar{b}\bar{I}$ is a linear representation of the share of the voltage $\bar{V}$ that depends on $\bar{I}$. The dimensions of the parameters $\bar{a}$ and $\bar{b}$ are, respectively, a voltage and an impedance.

Indeed, the behavior of the distribution system upstream the SmartID is not linear, because of the presence of DG. In fact, the DG current injection is dependent on the voltage at its terminal and, then, on the distribution system operating conditions. Consequently, model (1) represents a linear approximation of the distribution system non-linear behavior. It can be considered as a Thevenin-like model.

The parameters $\bar{a}$ and $\bar{b}$ can be used to detect grid-connected from islanded operation.

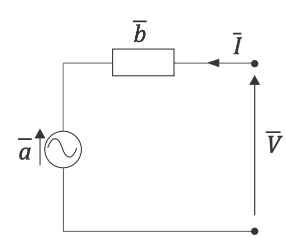

Fig. 2. Circuit model of the distribution system upstream the point of installation of the SmartID.