PLC-Based Anti-Islanding and Fault Locating System Concept

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Abstract

In this paper, loss-of-mains (LoM) concept implemented using software-defined radios (SDR) and based on power line communication (PLC) is presented. The LoM protection scheme is described in detail including its operation principles and system topology. Applicable frequency band is determined based on the grid topology, channel characteristics, and the functionalities implemented, which set requirements for certain bandwidth. Installation and power supply of signal transmitters and receivers are considered.

Index Terms

Anti-islanding; grid protection; loss-of-mains (LoM); power line communication (PLC); software-defined radio (SDR); smart grid (SG).

I. INTRODUCTION

RECENTLY, smart grids (SG) including distributed generation (DG) units have become ubiquitous around the world. Nevertheless, DGs pose safety-related challenges in implementation, loss of mains (LoM) protection being one of them. Islanding condition is present when a switch between a customer and the main electricity utility grid opens, for instance at transformer substation or remote switch in the medium voltage (MV) grid, and the client becomes energized exclusively by a DG unit. The islanded part of the grid can contain transformers and other grid equipment depending on the faulted grid domain. Under islanding condition grid personnel are at risk, as they can be unaware that parts of the grid are still energized by DGs [1], [2]. At the same time, islanding condition interferes power balance of the grid, and can cause over voltages and currents, that is, overloads, which can be harmful for electrical equipment. The task of an anti-islanding system is to detect the LoM condition in a shortest period of time (less, than 1 s) and prevent islanding, or to transit micro grid into controlled island mode. A number of approaches have been developed for designing an anti-islanding system; active, passive and communication-based methods can be named [1], [2]. Nevertheless, these methods propose different implementation complexity, speed of operation and accuracy under various conditions. In this paper, a new LoM protection concept based on power line communication (PLC) is designed for islanding detection and monitoring in MV/LV power distribution grids. Proposed concept is designed against environmental constraints and tested in the lab.

II. CONCEPT DESIGN

The main target of an anti-islanding system is to detect the loss of mains condition and disconnect a DG from the power network, protecting both personnel and electrical equipment. Besides fault detection functionality, moving to controlled island mode is needed, which requires control system in MV and also in LV grids between customers and DGs. Moreover, grid-monitoring solutions are challenging, as distribution MV grid can consist of a high number of branches comprising both overhead lines and underground cables. Therefore, combining fault detection and location functionalities in one system is a technically and economically feasible solution.

At first, evaluation criteria for a LoM concept is introduced. The system should be relatively simple in implementation, obtain economic feasibility, have a small no detection zone (NDZ), which means a low risk of false alarm and high accuracy in the case of a fault, and be scalable. To design such composite concept, available technologies and physical constraints are considered. Available LoM solutions can be divided into three groups – active, passive and communication-based. Taking into account the evaluation criteria proposed here, communication-based approach was chosen as the most feasible one. The proposed concept is based on continuous signaling through power lines by PLC means. Talking about physical constraints, grid topology and signaling range are considered first. A concept of continuous signaling over the power lines and cables arises the question of signaling range throughout the distribution grid under an electricity substation, including signal propagation through the main MV feeder, grid branches and through distribution MV/LV transformers to the customers and DGs in LV grids. A PLC system should cover the MV part of the grid and all LV networks. The MV grid part presents less challenging conditions for signal propagation comparing to the LV side. It can be explained by a less branched structure, and different insulation materials used in power lines or cables [3], [5]. However, the line/cable lengths of the MV grid feeders as well as part of the grid branches are significantly longer compared with the ones of LV grid under each MV/LV transformer [6]. Distribution transformers are also crucial elements; each one represents a major attenuator to signal. Signal propagation through a transformer has been studied previously by the authors and obtained results from [3], [4] are used in the current work.

Another constraint is signaling frequency band. Based on previous research, evaluation criteria and available data regarding grid noise scenario and signal propagation over the grid, CENELEC band (3–148.5 kHz) was chosen. This frequency band can provide a signal transmission with a relatively high signal to noise ratio (SNR) and a higher data transmission rate, comparing to lower frequencies. Certain data rate, and thus bandwidth required is a crucial criteria, as a concept is intended to combine fault detection and location functionalities by data transmission means. The drawbacks however, are the limited signaling power in the considered band. As a comparison, the allowed signaling powers applied in ripple control signals and in the band under 10 kHz, according to EN 50160 standard [7] are higher than in the band around 100 kHz considered in this concept. With higher signaling power and lower signal attenuation in frequencies under 10 kHz, longer signaling ranges and better MV/LV transformer pass through ability are provided [4], [5]. Thus, the most suitable frequency band for continuous signaling based LoM concept is a trade off between grid noise scenario, signal propagation, data transmission rate and signaling power.

By summarizing the results gathered and by derived analysis, a final concept topology can be introduced (Fig. 1). The main transmitter is installed at the main substation, signal repeaters should be installed in the MV/LV transformers, and receivers are installed at the customers' sites. This way, loss of signal will be interpreted as a loss of mains and protection mechanism will trigger. Fault location can be estimated by analyzing which parts of the grid receive the LoM signal. As a grid can cover a large area, intermediate signal transceivers can also be used, which can increase fault locating accuracy. It will be beneficial to install a radio device at the transformer and power it from the LV side, as powering it from the MV grid can be technically complicated and expensive. Moreover, the devices are coupled both to the MV and LV sides with capacitive or inductive coupler interfaces. By this way, the transformers are bypassed.

III. LABORATORY TESTS

Signal detection method analyzing signal level fluctuation was designed for laboratory tests. Laboratory test bench included two software-defined radios (SDRs), a host PC, and a 20/0.4 kV distribution transformer. SDRs are used as a flexible platform in implementing LoM functionalities and in testing the signaling performance on different frequency bands. One SDR unit was set as a transmitter, the second one as a receiver. Performed radio transmission consisted of a random data signal, modulated using PSK (phase-shift keying) and was performed in the frequency band of 80-400 kHz, which is a combination of CENELEC and FCC (14–480 kHz) bands [8]. This frequency range was chosen to compare detection speeds in CENELEC and FCC bands. Signaling was performed over the distribution transformer, which was not connected to the mains. Therefore, no noise scenario was present during the tests. An average time of signal loss detection performed by this algorithm with a 80 kHz carrier frequency was 30 ms, while with a carrier frequency of 400 kHz it was around 20 ms. According to IEC 61727, total operational time of an anti-islanding system should be under 2 seconds, including signal loss detection and protection triggering (island disconnection) [9]. Proposed signal-level-based algorithm can be supplemented with sensitivity adjustments that can influence NDZ and detection speed. Permitted signal level fluctuation should be chosen taking into account the balance between accuracy and speed. In fact, signal level analysis can be performed with a sinusoidal signal and no data modulation is needed. Another approach for LoM detection is signal data decoding. In this case the transmitted LoM signal includes modulated data, which is then analyzed in the radio receiver. Transmitted data can include operational or control information. This method is more complicated in implementation, though it can increase the concept accuracy and widen system functionality.

Signal modulation techniques are crucial part of the concept, if we consider LoM detection mechanism featuring data demodulation. Wide spectrum modulation approaches provide better signal propagation and a lower data error rate, comparing to single carrier modulation [3]. A direct sequence spread spectrum (DSSS) technique is tested in the lab. DSSS modulation tool is designed base on BPSK (binary phase-shift keying) modulation technique. After laboratory tests with two SDRs and a transformer a designed solution can be applied in a powered grid segment or a powered test bench. Designed solution with an error-correction algorithm can support a lower BER level, comparing to conventional modulation techniques. Moreover, the LoM concept can be expanded with multiuser communication based on the same DSSS software. In multiuser communication, each MV/LV substation is transmitting a unique signal, which can be decoded in every secondary substation and at the primary substation. This way simple grid monitoring functionality can be performed. Channel access options considered in this application are time division and code division multiple access

(TDMA and CDMA) techniques. First one proposes dividing transmitted signals in the time domain, and the second one is based on unique spreading codes and a multistage decoder to separate signals [10].

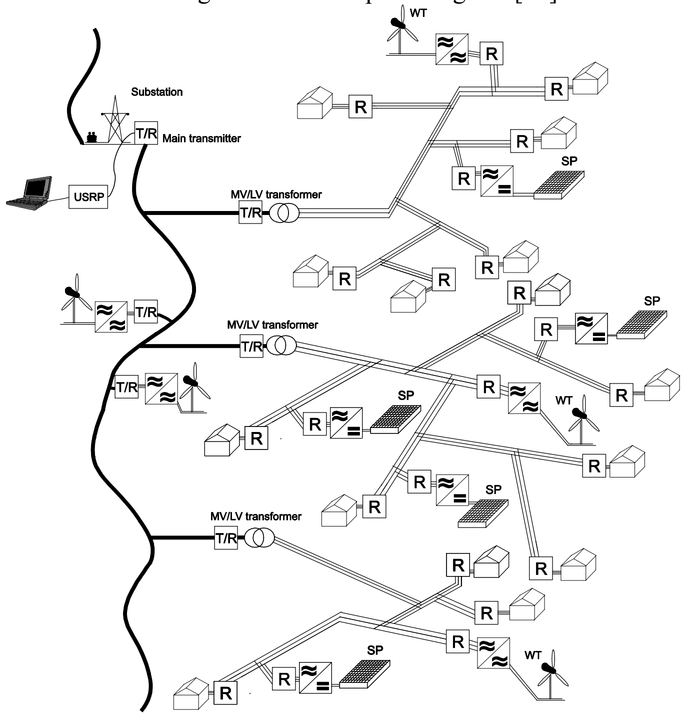

Fig. 1 Typical distribution network from the electrical substation to the customers with DGs; solar panels (SP) and small-scale wind turbines (WT), and the proposed anti-islanding protection system with a transmitter (T) and receivers (R) in an MV-LV grid.

IV. CONCLUSION

In this paper, an anti-islanding concept design for a MV/LV power distribution grid using a PLC technique is introduced. Applicable concept technologies and related physical constraints are analyzed. Initial laboratory tests examining LoM detection algorithms are discussed. Additional concept modifications and new functionalities are proposed.

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