IEC 61850 GOOSE MESSAGING APPLICATIONS IN DISTRIBUTION NETWORK PROTECTION AND AUTOMATION

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ABSTRACT

Introducing distributed generators into distribution networks creates problems for protection systems like electric island formations or protection blinding. Possible solutions utilizing communication aided automation in IEC 61850 standard are presented in following paper. A hybrid adaptive islanding detection method and advanced network automation features in form of adaptive protection and distribution management system (DMS) are demonstrated. The results obtained through hardware-in-the-loop simulations using OPAL-RT simulator and SEL 421 relays show that presented functionalities can augment overall microgrid reliability.

INTRODUCTION

An uprising global trend towards shifting production of electric energy from conventional sources like coal, fossil fuels or nuclear energy to renewable sources like wind, solar or other non-conventional sources is evident from the recent development and this leads to a paradigm shift in basic power system operational principles. Traditional power system requires higher costs in transmission line expansion, fuel costs and time-consuming construction [1]. The concept of microgrid is introduced to counteract the above mentioned problems. A microgrid is an amalgamation of different equipment, which includes Distributed Energy Resources (DERs), smart meters, current/voltage transformers, and intelligent electronic device (IED) used for protection and communication/network routers [1] [2].

One of the major advantage of a microgrid the possibility to operate in both grid connected and islanded mode. Islanding is a phenomenon of separating a section of the grid for the benefits of operation, stability and/or economic aspects [3]. Communication assisted islanding detection has been proposed in references [4-7], these discuss use of IEC 61850 based communication topology for islanding detection and implementation of different islanding detection schemes using commercially available IEDs.

The IEC-61850 standard has been introduced in 2003 and it has been constantly improving to cover more aspects of the future energy systems. The standard initial goal is to provide an interoperable substation automation system and over the years the developments has lead the standard to implement the changes in recent developments such as integrating electric vehicle (EV), DERs, synchrophasor, and control centers through various technical reports IEC 61850-7-420, 90-1,2 and 5 [8].

This paper proposes an adaptive islanding detection algorithm with the use of IEC61850 based Generic Object Oriented Substation Event (GOOSE) messaging and to optimize the non-detection zone for local passive method. The proposed method is realized using Opal-RT real-time simulator and SEL 421 relay. Secondly, it demonstrates potential applications of GOOSE messaging in distribution networks' protection and automation.

The rest of the paper is organized as follow, section II provides background of power system protection and automation, section III gives details about network modeling, section IV outlines simulation cases and associated results to support the proposed algorithm and finally conclusions are provided in section V.

POWER SYSTEM PROTECTION AND AUTOMATION

IEC 61850 is a standard defining a set of communication protocols and abstract data models for IEDs. It provides interoperability and simple architecture. IEC 61850-8-1

GOOSE service available in commercial relays (in this paper example of SEL 421) is capable of carrying both binary and analog data. Message can be broadcasted in both event driven and periodic manner providing flexibility in different communication traffic circumstances. Next subsections shortly introduce possible power systems protection and automation applications, which can be executed utilizing GOOSE messaging.

Grid codes compliant islanding detection

Islanding detection scheme consists of two steps:

- remote circuit breaker (CB) status update with GOOSE
- local passive method in form of frequency relay using auxiliary set of more sensitive settings.

In Europe, grid codes prohibit the sole utilization of remote CB status for island detection [9]. Here in this paper, a hybrid island detection method is proposed. In this method, the remote CB status is sent from the bay relay to the local generator relay. If this information is received, it will assist the local over/under frequency function and allow highly sensitive settings in order to confirm island formation locally. Among the advantages of the proposed method are:

- grid codes compliance
- significant reduction of local detection method's non-detection zone
- double confirmation (remote+local) provides reliability and immunity for external events causing nuisance trips

Adaptive protection after islanding

Subsequent to islanding detection by generator relay, it broadcasts a GOOSE message to the other relays within formed island (i.e. line relay in Fig. 1) to change their setting groups adapting protection to new network conditions maintaining protection sensitivity and selectivity.

Distribution management system (DMS)

Communication in the IEC 61850-8-1 (GOOSE) standard also supports broadcasting analog values within GOOSE message. This enables an implementation of DMS service supporting islanding detection. The bay relay broadcasts measured power flowing through the main feeder breaker (CB_{1a} in Fig. 1). By subscribing to these measurements, a generator relay, is able to supervise a power transfer between network and a possible island. In case of detecting a power transfer within a non-detection zone of local passive method, the generator relay can force, for instance a generator exciter to change reactive power set point.

NETWORK DESCRIPTION

The CIGRE benchmark model of an European medium voltage distribution system [10] is used as a test case for case studies. The network shown in Fig. 1 represents two MV feeders connected to 110 kV transmission system through two separate HV/MV transformers. Feeder 1 is dominated by underground cables, while feeder 2 is purely overhead lines. The model has been slightly modified to meet requirements of this study. A synchronous distributed generator has been connected through a step-up transformer at bus 7. The generator dynamics are represented by fifth order machine model with both exciter and hydro turbine governor included. The generator parameters reflect an existing machine, small hydro generator typical in Norway. Also, in order to be able to simulate perfect power match in a potential island in feeder 1 the loads in that feeder has been reduced to 20% of their nominal powers.

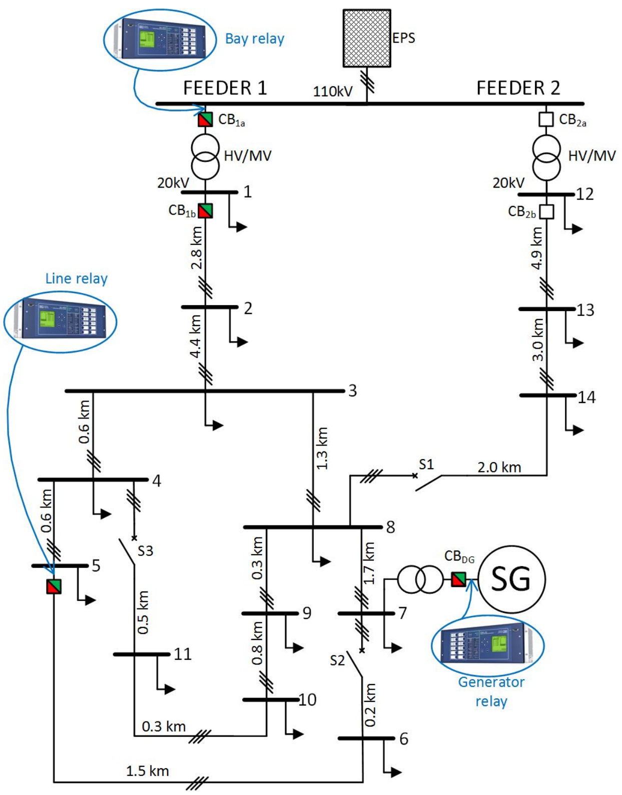

Figure 1 - European medium voltage distribution network by CIGRE working group [10]

SIMULATIONS AND RESULTS

The section presents results obtained from hardware-in-the-loop simulations using OPAL-RT and SEL 421 relays. The real time simulator, while running the network model from Fig.1, publishes Sampled Values to SEL 421 relays. The relays then close a loop by publishing GOOSE frames with their Trip signal status, active setting group status and/or other auxiliary control signals like in a case of DMS example.

Islanding detection

Fig. 2a and Fig. 2b present performance of discussed islanding detection method, respectively for power imbalance of $\Delta Q = 0.01\ pu$, $\Delta P = 0\ pu$ and $\Delta Q = 0.005\ pu$, $\Delta P = 0\ pu$. The main feeder breaker opens at $t = 5s$.

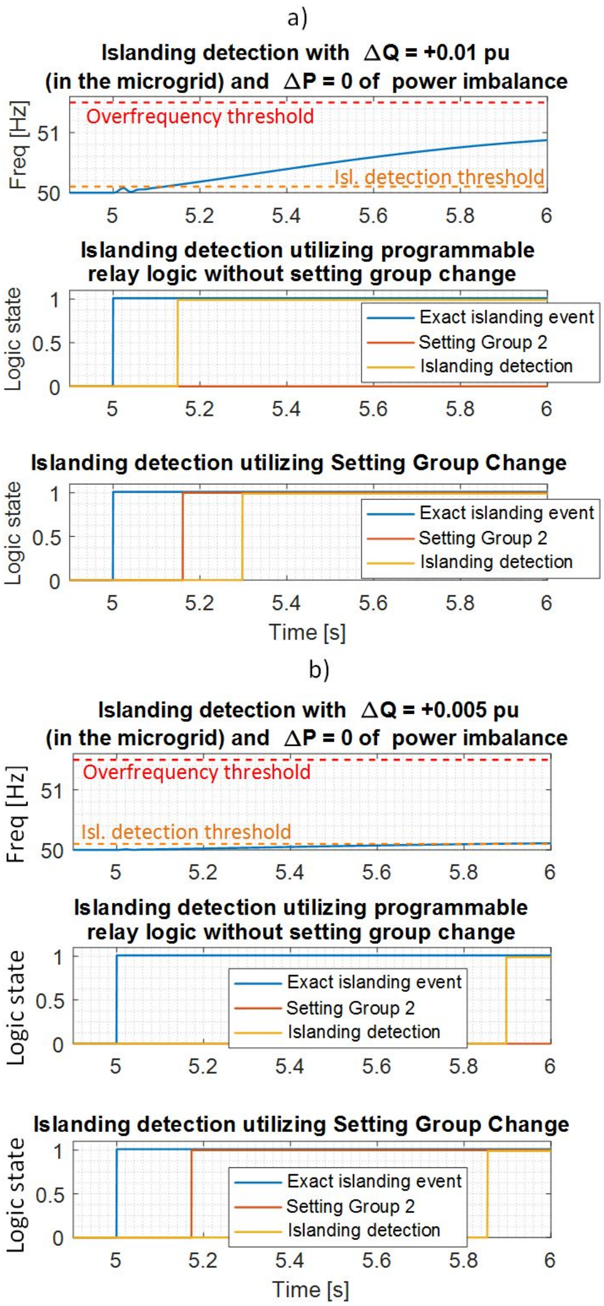

Figure 2 - Comparison of timelines of operation for proposed islanding detection method for a) bigger unbalance and b) smaller unbalance

One can observe that utilizing auxiliary frequency protection thresholds (marked with dashed light brown color line in both top Fig. 2a and Fig. 2b), activated by remote part of the method, reduces the local detection method time of operation compared to primary frequency protection thresholds (marked with dashed red color line in both top Fig. 2a and Fig. 2b).

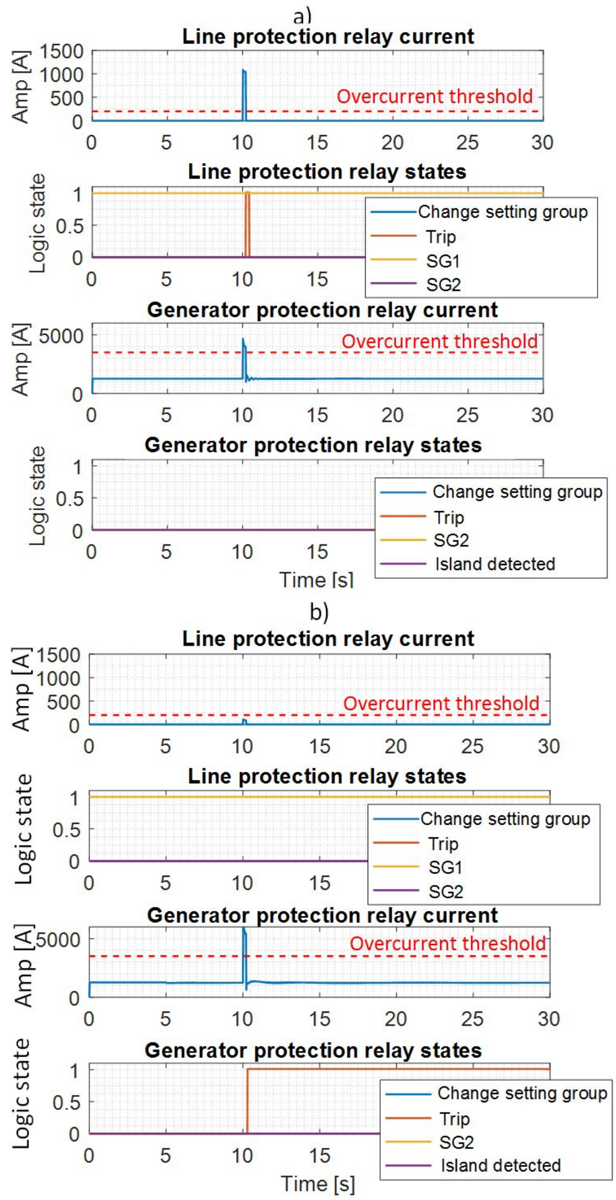

Figure 3 - Timelines for the cases of the same fault during: a) grid connected mode; and b) islanded mode.

Adaptive protection

Subsequent to a successful islanding it is necessary to adjust settings of relays being included in a newly formed island. Fig. 3a and Fig. 3b present the same fault event, i.e. two phase short circuit at bus 6 (Fig. 1). The graphs in Fig. 3a show a case of grid connected mode, where both line protection and generator relay pick up and line protection relay trips due to time coordination, maintaining protection selectivity. However, the same fault in islanded mode, Fig. 3b, is fed only by distributed generator, thus having significantly lower fault current. In such case, relays may loose coordination resulting in worsening reliability. Comparing the cases in Fig. 3a and Fig. 3b it becomes clear that a lack of setting adaptation can jeopardize protection coordination.

With a developed communication between relays within a distribution network an adaptive protection scheme, based on IEC 61850 messaging, can be realized and additionally integrated with already discussed islanding detection.

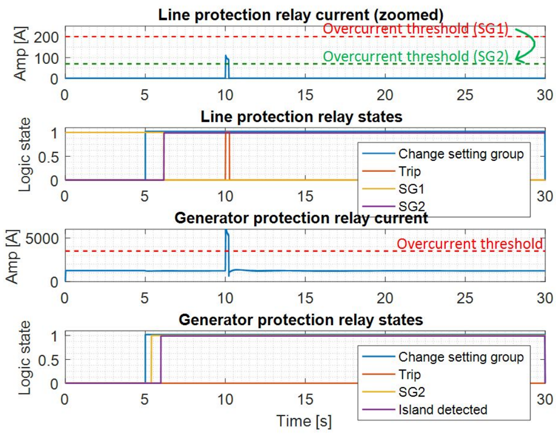

Figure 4 - Timeline for islanding and subsequent fault during islanded mode.

Complete scenario is pictured in timeline (Fig. 4). The main breaker opens and generator goes islanded at $t = 5s$. Further, under islanded mode a fault occurs at $t = 10s$. For the first event a generator relay is supposed to detect islanding condition, what happens approx. after 1s and follows setting group change (approx. 150ms). After detecting an island a generator relay broadcasts a GOOSE message to all relays inside an island to change a setting group. Thus, line protection relay changes its setting group and is ready for islanded operation after about 1.2s after islanding happened. At $t = 10s$ a fault at bus 6 occurs and line protection relay commands tripping signal and clears a fault before generator relay does. Hence, maintaining protection coordination and selectivity.

Distribution management system

In this example, a DMS service based on analog GOOSE is used to exchange information about power flowing between main grid and an island. Too small power transfer can result in islanding detection blinding, so by subscribing to power measurements published by a bay relay, a generator relay can supervise power flow. Whether it is within non-detection zone, and if so, slightly modify exciter control, escaping blinding zone.

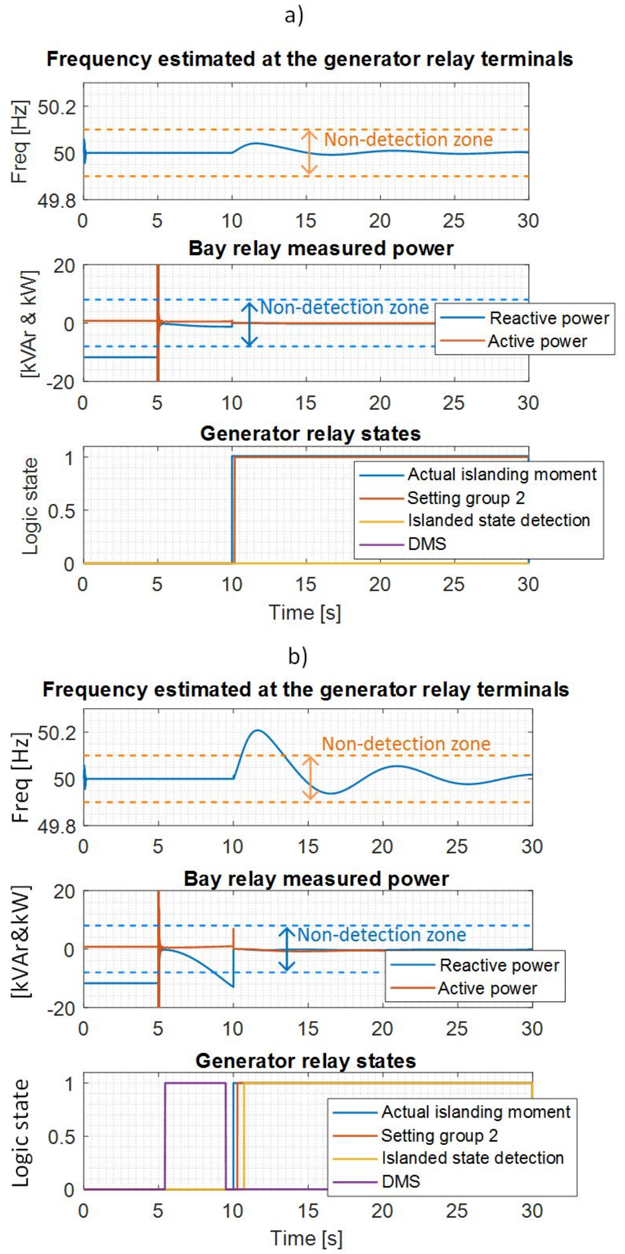

Figure 5 - Timelines for islanding detection blinding after capacitor bank connection: a) without DMS; and b) with DMS implemented

In a scenario without DMS (Fig. 5a), when a capacitor bank is connected at $t = 5s$ and islanding occurs at $t = 10s$ it goes undetected, since a power imbalance was to small prior to breaker opening to cause a detectable frequency change. However, in a case of DMS (Fig. 5b), once a capacitor bank is connected ($t = 5s$) and power flow enters non-detection zone, a generator relay takes an action and gives a signal to exciter controller, in this case to reduce reactive power generation. Hence, when an islanding occurs at $t = 10s$, a frequency perturbation is big enough to be detected.

CONCLUSIONS

The IEC 61850 standard together with its Sampled Values and GOOSE messaging can play an important role in realization of future distribution networks. Providing an interoperability and flexibility, the standard can be a base of protection and automation features like islanding detection, adaptive protection and distribution management systems. As presented in this paper, these features can be combined to realize grid codes compliant islanding detection and mitigating of non-detection zone by DMS functionality. Additionally, when operating in islanded mode, enhance microgrid reliability by application of adaptive protection.

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