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Microgrid Islanding via GOOSE Messaging

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SUMMARY

Microgrids(MG) are becoming popular worldwide due to the benefits they bring to the electric grid. MG can be utilized to enhance local reliability, reduce emissions, improve power quality, and potentially lower costs of energy supply. Dominion Energy values these characteristics in order to keep customers online during abnormal conditions. Many of Dominion Energy's assets are protected using SEL relays, which also provide control and data acquisition capabilities. It is the objective of this paper to use IEC 61850-8-1 GOOSE messaging to perform MG islanding with the existing SEL relay settings to smoothly and quickly transition from grid connected to islanded mode. Modeling and analysis of the MG network is done with RSCAD, RTDS, and SEL relays. Hardware-in-the-loop (HIL) simulation results are presented to show the validation of the islanding procedure.

KEYWORDS

Microgrid (MG), Distributed Generation (DG), Islanding, Relays, GOOSE, Hardware-in-the-loop (HIL)

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1. INTRODUCTION

The importance of having electrical power cannot be understated. This is especially true to those who have spent large amounts of time without it. In 2013, the state of Connecticut announced that it would build nine MG to deliver power to critical loads, such as hospitals, a naval base, and university campuses. This $18 million investment comes as a response to when Hurricane Sandy left 625,000 homes and businesses without power [1]. Businesses all over the country are coming to the same realization; they need stable power in times of crisis. Researchers and engineers have proposed the idea of MG as a practical solution to this problem.

MG are already a growing trend around the world. It is estimated by 2020 that MG revenue will be almost $20 billion [2]. Utility companies, such as ComEd and Southern Cal Edison, have begun planning MG and distributed generation (DG) resources interconnection to aid the grids they supply [3][4]. ComEd will develop six MG in the Chicago area, totaling near $300 Million [3]. Southern Cal Edison has picked six companies to develop 125 MW of distributed energy storage [4].

In the presence of unplanned events like faults, MG separation from the medium voltage (MV) network must occur as fast as possible [5]. Multiple islanding strategies have been studied. Slave Master Operation(SMO) uses a singular inverter as a voltage and frequency reference. In SMO mode a single inverter can be used as a voltage reference when the main power supply is lost and the other power sources can operate in PQ mode [5]. Load shedding is another widely studied MG islanding strategy. In a scenario in which the islanded MG does not have enough generation to power the entire load the non-critical loads are disconnected [6]. Another recently developed strategy is power sharing within a network of MG. In this strategy, grid connected MG export power to other MG in islanded mode to balance the load [7].

This paper will use a MG strategy most resembling SMO. The MG will have (photovoltaic) PV generation that partially powers the load in grid-connected mode. Once islanded additional generation will be brought online to supply the necessary power to satisfy the load. This paper will go beyond Simulink simulations and will use RTDS to implement relays to send trip signals in order to get an extremely accurate islanding time measurement.

SEL relays, RTDS Hardware-in-the-loop (HIL) technology, and RSCAD software will be utilized to simulate a MG islanding from the main grid when a fault occurs on the distribution network. Dominion Energy's current DG tripping scheme will be utilized to island the MG. The SEL-451's overcurrent protection will recognize the fault and send a signal to a SEL-651. The SEL-651R will island the MG and send the trip signal to a SEL-3530. The SEL-3530 will then send a signal to a SEL-651R to start additional generation. The communication between the relays will be done via GOOSE messaging to minimize latency [8].

The rest of this paper is organized as follows: In Section 2, the MG model and formulation is discussed. In Section 3, HIL simulation results is presented. Section 4 concludes the paper.

2. MODEL OUTLINE AND FORMULATION

Dominion Energy has relay logic and communication protocols for tripping DG offline in the event of a grid disturbance. Figure 1 displays how the relay communication protocol is set up. The relays use SEL's communication protocol, mirrored bits, to send open and closed signals. Within substations that are connected to DG sites, there are panels equipped with a SEL-451 and a SEL-735. The SEL-735 is used primarily to monitor total demand distortion (TDD) and the total harmonic distortion (THD). In the event that one of these changes by more than a set percent, it will send a trip signal to the SEL-451 via mirrored bit. The SEL-451 then sends a signal to the SEL-651R at the DG site via fiber optic cables to disconnect the DG.

This paper uses similar protocol for MG islanding. When disconnected, the MG will not cease to generate but instead it will work to balance generation and load. The SEL-651R will send the trip signal to a SEL-3530, in addition to disconnecting the MG. The SEL-3530 will then send a signal to a SEL-651R to bring more generation online. GOOSE messaging will be used as the primary form of communication instead of mirrored bits in order to decrease latency [8][9].

A model was developed using the RSCAD software. A oneline of the model can be seen in figure 2. A 115kV infinite source is stepped down to 34.5kV then to 480V. A circuit breaker (CB) is placed after this transformer, which is the point of common coupling (PCC) CB. PV, natural gas, and diesel generation are all connected to the 480V bus. A load is attached to the 480V bus via a 480/208.2 transformer. The PV generation is set to 200 kW and the load of the MG is 400 kW. To test the islanding procedure, a 2 phase L-G fault is placed at the 34.5 kV level, creating an overcurrent. The SEL-451 monitoring the current will send a trip signal to a SEL-651R when the fault occurs. The SEL-651R then sends the signal to the RTDS, to island the MG. The SEL-651 also sends a signal to the SEL-3530, which sends a signal to another SEL-651R. The SEL-651R then sends a signal to the RTDS to connect the natural gas generator. The natural gas supplies the remaining 200 kW in order to balance load demand and generation. The HIL set up can be seen in figure 3.

To determine the effectiveness of the islanding scheme four variables were overserved. The status of the circuits breakers at the PCC and additional MG generation and the MG's load voltage and frequency were observed. A Parks transformation of the load's p.u. voltage was performed in order to monitor the MG's voltage. The D and Q outputs were then used to compute the p.u. value of the voltage by the equation $\sqrt{(D^2 + Q^2)} = LoadVPU$. BRKX is the circuit breaker that connects the MG to the main grid and BRK8 is the circuit breaker that connects the natural gas generator to the 480V bus. The frequency of the load voltage, MGFREQUENCY, is determined by a PLL.

Figure 1. DG trip procedure

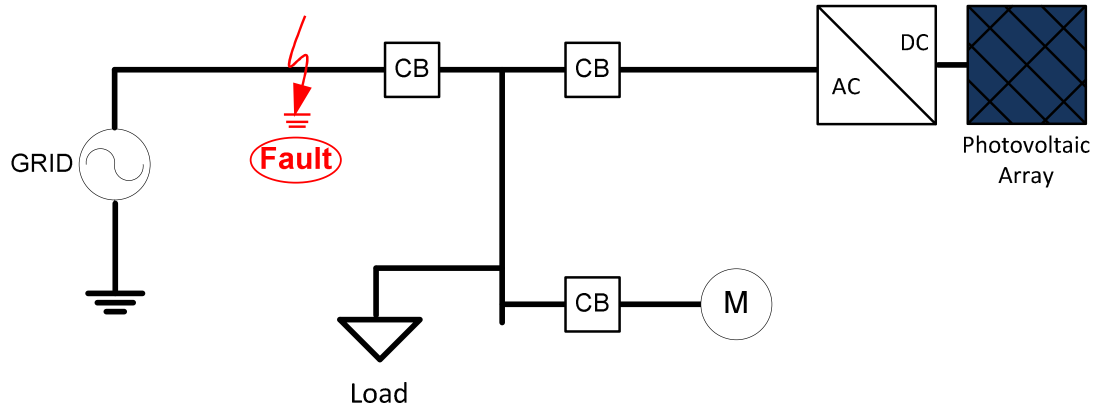

Figure 2. Model oneline

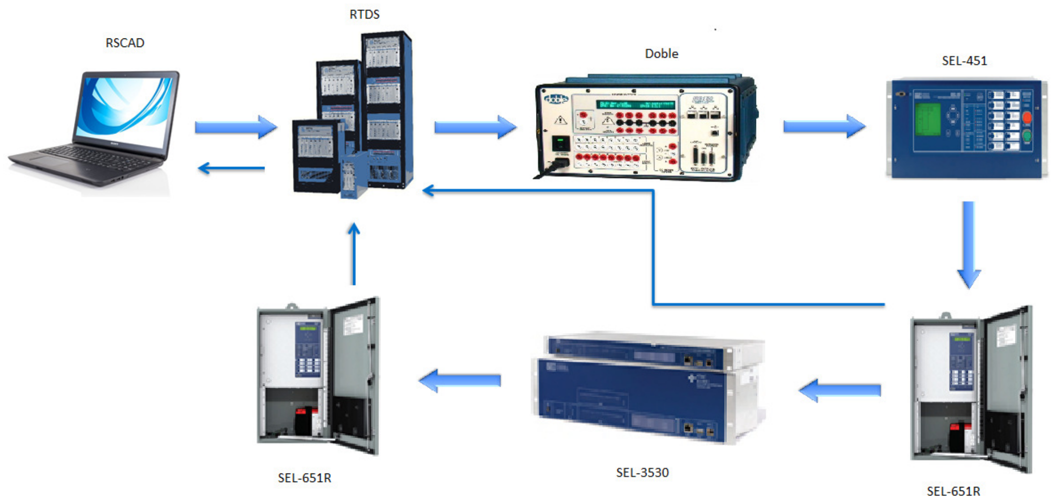

Figure 3. HIL set up

3. SIMULATION RESULTS

Here, HIL simulation results is presented to demonstrate the effectiveness of the islanding procedure. A fault was triggered. The effects of this fault can be observed at 0.19992 s, as shown in figure 4a. The MG is islanded, via BRKX, at 0.22536 s, as seen in Figure 4b. The delay of 25.92 ms can be attributed to the time the SEL relay takes to recognize the overcurrent and send a signal back to the RTDS. Figure 4c shows that the natural gas generator is brought online at 0.23712 s, 37.2 ms after the fault occurs. The time delay is caused by the relay fault detection, as specified above, and the time needed for the relays to communicate via GOOSE messaging. It takes 12 ms for the fault signal to be sent from the islanding SEL-651R to the MG generation relay (SEL-651R). This latency duration is 6 ms (for each relay to relay communication). Figure 5 shows the equivalent voltage of the MG before and after the fault. The voltage recovers to 1 p.u. at 0.26184 s, which is 61.92 ms or four cycles after the fault occurs. Figure 6 shows the frequency before and after the fault. The frequency recovers to nominal conditions, 60 Hz, at 0.27336 s, which is 73.44 ms or four cycles after the fault occurs.

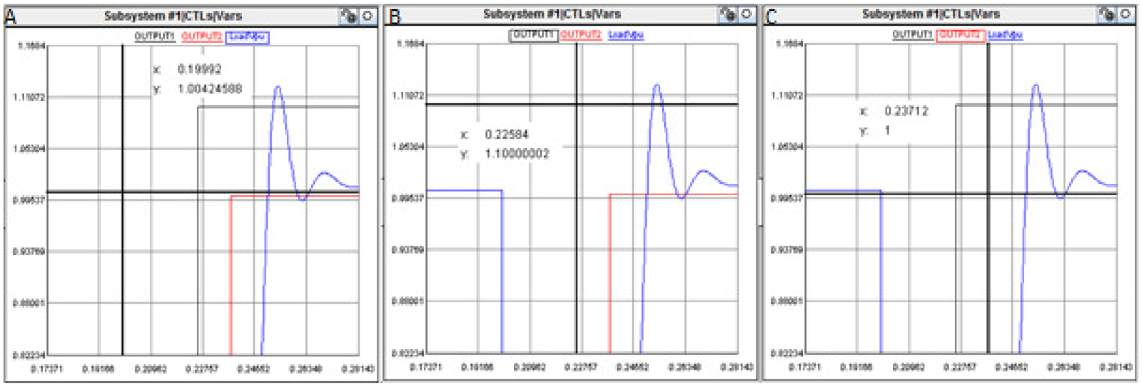

Figure. 4. a) Measured time of fault occurrence b) Measured time of MG islanding c) Measured time of natural gas generator start up

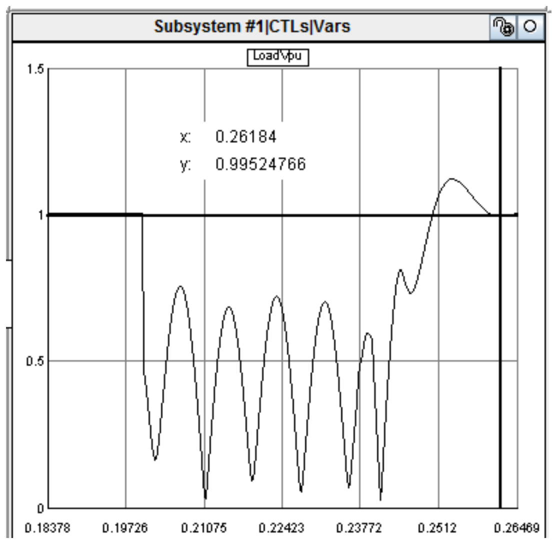

Figure 5. Voltage p.u. islanding results

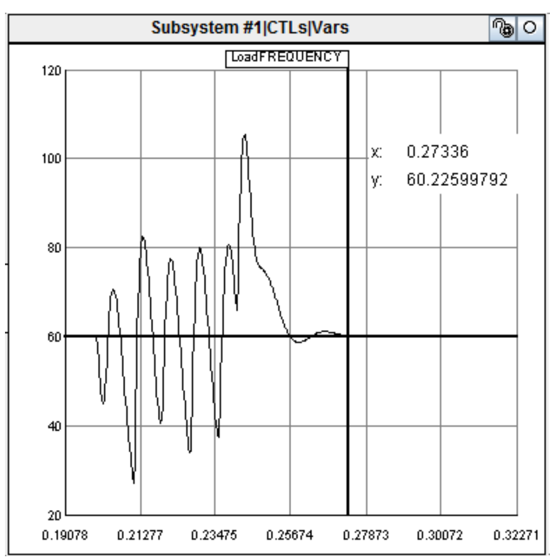

Figure 6. Frequency islanding results

4. CONCLUSIONS

Dominion Energy's DG tripping scheme was successfully applied to a MG islanding scenario. Almost half the four cycles needed to correct voltage and frequency came from the generator's ability to stabilize voltage. Tuning the PI controller of the generator could produce even faster stabilization. The SEL relays and GOOSE messaging accounted for the other two cycles. The small delay of 37.2 ms, is adequate for MG islanding, proving the procedure's ability to recognize fault conditions, island a MG, and bring generation online.

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