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Simulated Islanding Test for a Practical Utility-Scale Microgrid

M. BAZRAFSHAN, A. MAJZOOBI, A. KHODAEI
University of Denver
USA

N. GURUNG, H. CHEN, L. ZHANG, M. LELIC, A. VALBUENA GUERRA
ComEd
USA

SUMMARY

The Bronzeville Community Microgrid (BCM) was recently launched by ComEd as an exemplary technology that addresses the innate variability of solar photovoltaic (PV) by leveraging a utility-scale battery energy storage system (BESS) and control functions of smart inverters. A salient feature of microgrids, however, is their islanding capability in that it allows disconnection from the main utility grid during maintenance or emergencies. Although an electrical separation from the main grid currently raises concerns for frequency stabilization, it is feasible to control the power flow through the point of interconnection (POI). This paper presents analyses pertaining to a novel series of tests developed by ComEd, termed simulated islanding tests. The simulated islanding tests ensure that the installed PV and BESS, their smart inverters, the diesel generator, along with communication units installed on the BCM are capable of controlling the power flow through the POI.

KEYWORDS

Energy Storage, Solar Photovoltaic, Microgrid, Simulated Islanding

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amin.khodaei@du.edu

1. INTRODUCTION

Microgrids allow for the decentralization of electricity, incorporation of clean energy, and enhancement of power system reliability and resilience [1]. Microgrids host a variety of components including distributed energy resources such as solar photovoltaic (PV) and battery systems, master controllers, and smart inverters [2] which can be used in concert to simulate a flexible demand for the utility grid and disconnect from the utility grid during disturbances [3].

One of the primary goals of the Bronzeville Community Microgrid (BCM) launched by ComEd [4] is addressing the inherent fluctuation in power injections of solar PV systems by incorporating BESS and advanced control features of smart inverters. However, as mentioned above, one of the defining characteristics of microgrids is their ability to operate autonomously as an island during disturbances [5]. This paper introduces the *simulated islanding test* designed by ComEd that examines the potential of BCM to switch to an island mode. The term *simulated* emphasizes the fact that the microgrid is not electrically disconnected, but the components of BCM -- the PV and BESS, their inverters, and the existing diesel generator -- are managed to zero out the power flow through the point of interconnection (POI), effectively turning the BCM into a controllable aggregate load.

The one-line diagram of the BCM is depicted in Figure 1. The SW1 switch indicates the POI of BCM to the main utility grid. BCM features a 587 kW DC/484 kW AC, PV system which is an aggregate of 17 rooftop PV installations that are communicated via a single point through the SW3 switch. The BESS is a utility-scale front-of-meter 500 kW DC/600 kVA AC system. A mobile 2 MW diesel generator is additionally attached to BCM to provide assistance in maintaining the power exchange through the POI within a specified threshold of the desired setpoint.

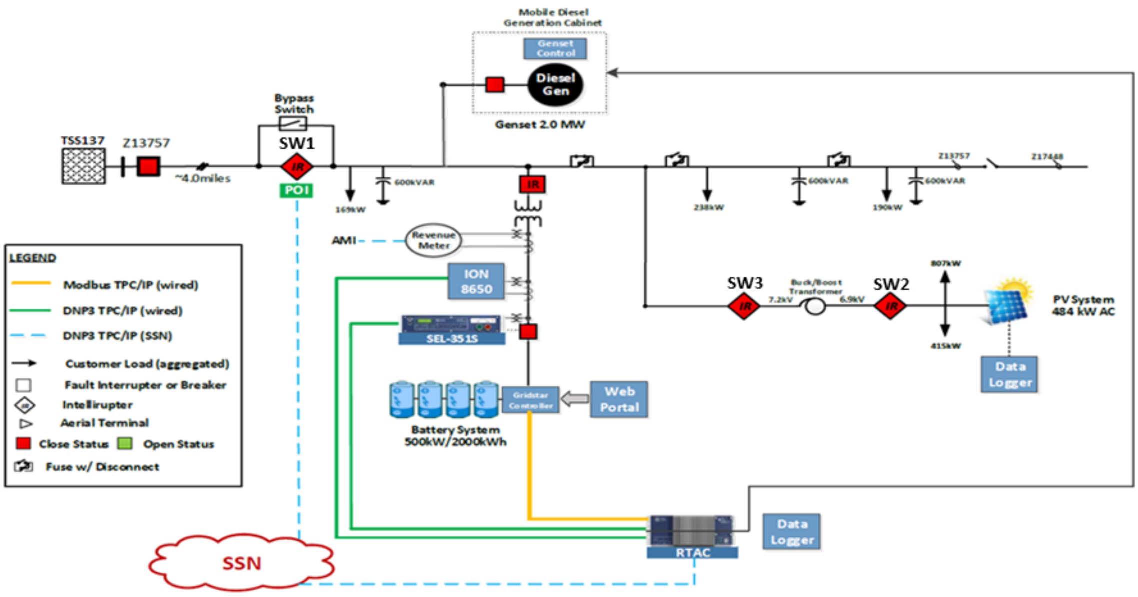

Figure 1. One-line diagram of BCM.

This paper is organized as follows. Section 2 describes the procedure for the simulated islanding test and presents the specific analyses for controlling the BCM with unity, lagging, and leading power factor loads. The paper is concluded in Section 3.

2. SIMULATED ISLANDING SETUP

In real-time, two phenomena are inherently uncontrollable in a microgrid. First, load demand variations according to customer behavior and second, the PV output variations based on the available solar irradiance. To avoid unnecessary service disruptions to subscribed electricity consumers, the following precautions were taken for the islanding test:

- The testing time was selected to be within the hours of 10:00 a.m.to 02:00 p.m. During this time period, most residential consumers are expected to not be at home. The real power injection from the PV system is also typically at its maximum.
- A controllable, mobile 2 megawatt (MW) diesel generator is connected to the BCM. The purpose of the diesel generator is to offset the load while the BESS is controlled to zero out the power exchange with the main electricity grid.

2.1. Unity Power Factor Load

The load is set to have a unity power factor. The diesel generator is used to offset most of the load. The corresponding plots of real and reactive power are illustrated in Figures 2 and 3, respectively. The solid black pulse-like line demonstrates the islanding command recorded by the data logger. A command of 1 implies that the BCM is controlled in a simulated island mode.

In Figure 2, the blue plot portrays the PV real power output, which is initially at about 150 kW. The green plot portrays the POI real power which is initially at about 250 kW. After start of the test at 14:01:38 the battery controls are adjusted according to the islanding command. A battery discharge follows and ultimately brings the POI real power close to 0 kW by 14:02:38. This setup is consistent until 14:13:38 where an abrupt rise from 150 kW to about 250 kW occurs in PV output. This event causes the POI to briefly exchange power back to the grid. However, the BESS immediately reduces its discharge from about 230 kW to about 130 kW to counteract the PV output rise. This action brings the power exchange with the grid close to 0 kW.

The attempt to zero out the reactive power simultaneously with real power is portrayed in Figure 3. In this setup, a reactive power of about 200 kvar is supplied by the PV inverter to maintain power factor close to zero before initiating the islanding command. After islanding command is initiated, the reactive power is fluctuating around zero but lies within 200 kvar. This phenomenon is observed in the green plot of Figure 3. Notice that in Figures 2 and 3, the negative sign for BESS implies active power discharge and reactive power injection.

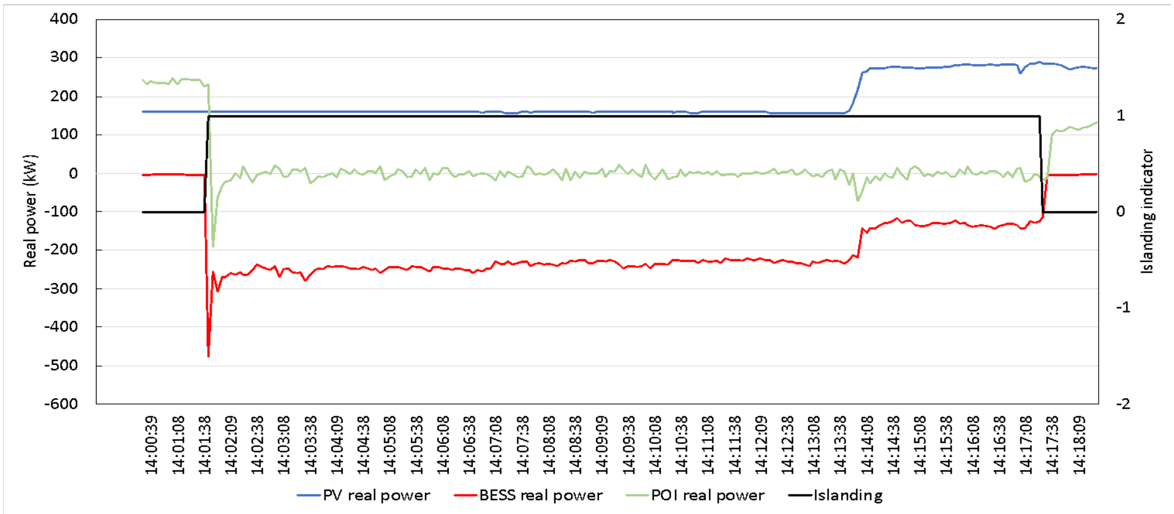

Figure 2. Zeroing out real power exchange at POI with unity power factor load at BCM

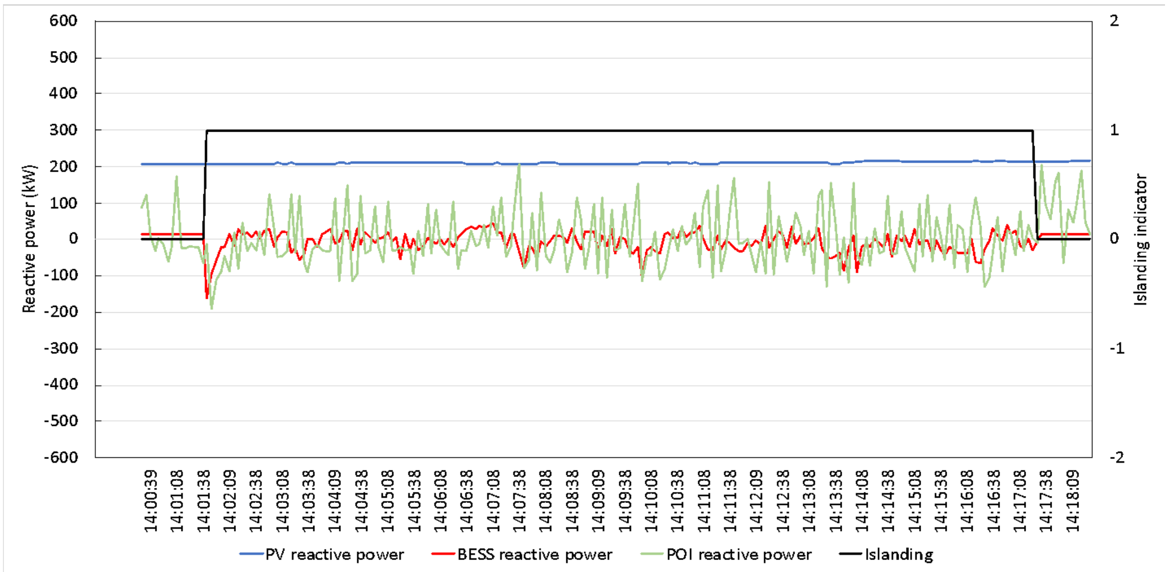

Figure 3. Zeroing out reactive power exchange at POI with unity power factor load at BCM

2.2. Lagging Load

The microgrid load is at a lagging power factor in this case. The diesel generator is again used to offset most of the load. The corresponding plots of real and reactive power are given in Figures 4 and 5, respectively. The solid black pulse-like line demonstrates the islanding command where a value -1 implies that the BCM is in a simulated island mode.

In Figure 4, the blue plot portrays the PV real power output which is initially at about 350 kW. The green plot portrays the POI real power, which initially is above 200 kW. After the test starts at 12:53:28 the battery controls are adjusted according to the islanding command. As the islanding mode starts, the BESS has a surge charge from the grid causing an increase in power exchange from the grid to BCM as demonstrated at 12:53:58. As the BESS starts discharging, the POI real power decreases to be closer to 0 kW by 12:54:28. This setup is consistent throughout the test, although occasional variations of PV output are observed, for instance, at 13:06:03 or 13:09:03.

These variations are immediately counteracted by the BESS to maintain the real power at POI close to 0 kW.

A similar trend is observed in Figure 5. To elaborate, at the start of the test, that is, at 12:53:28 the BESS controls are adjusted according to the islanding command. As the islanding mode starts, the BESS initially has a surge reactive power consumption from the grid. As the BESS returns (produces) reactive power back to the BCM the reactive power exchange at POI approaches 0 kvar. The PV reactive power output was set to 0 kvar in this test.

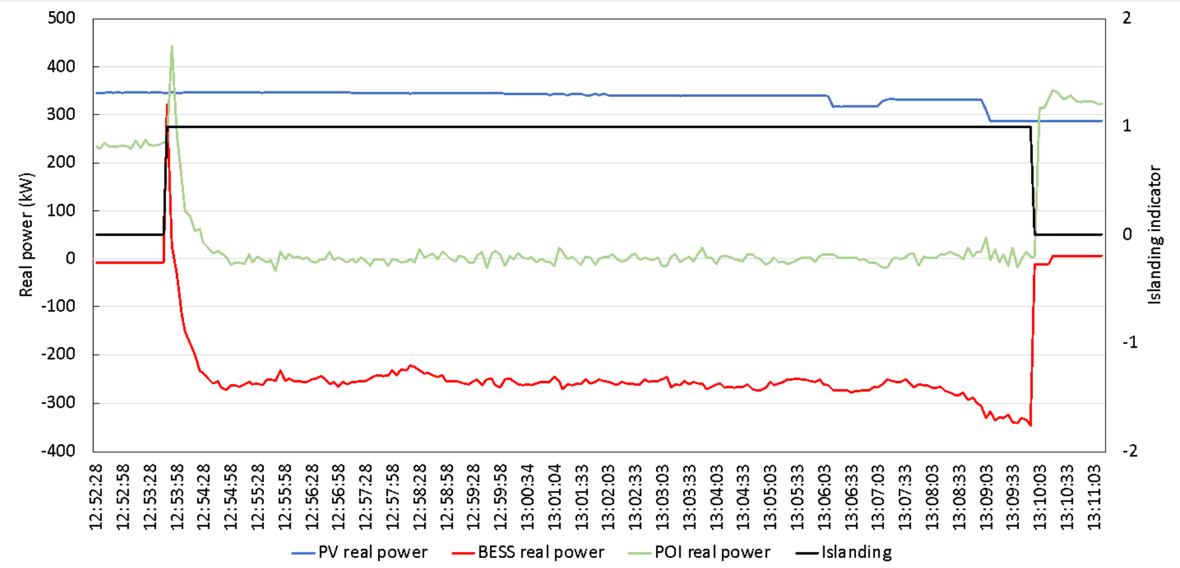

Figure 4. Zeroing out real power exchange at POI with lagging power factor load at BCM

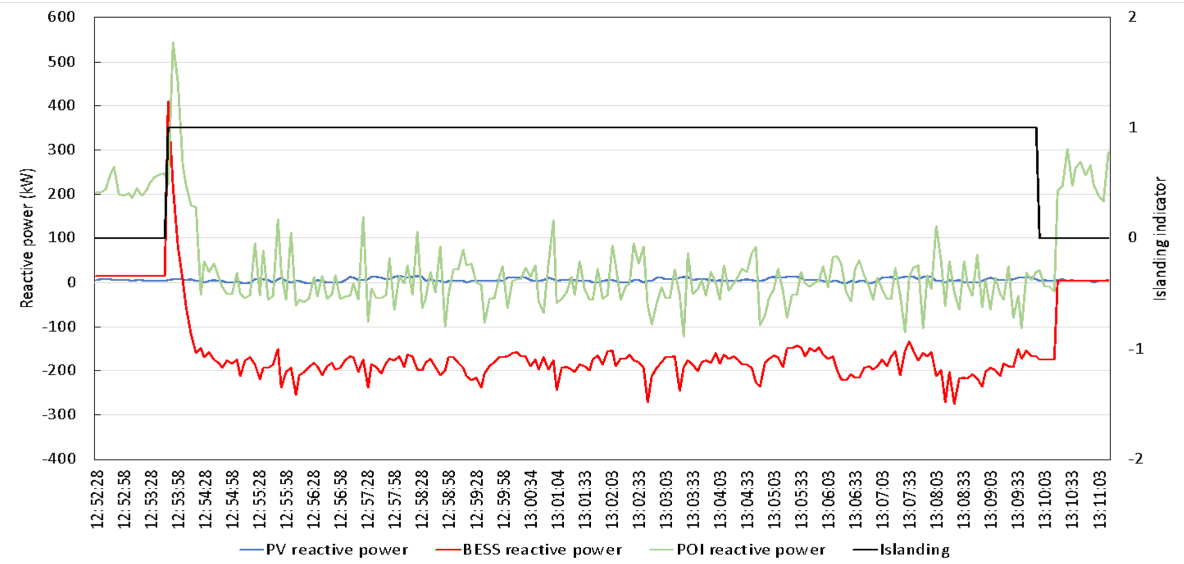

Figure 5. Zeroing out reactive power exchange at POI with lagging power factor load at BCM

2.3. Leading Load

Islanding the BCM while hosting a leading power factor load is considered in this test. In this test, the diesel generator is not used to offset the load, and the leading power factor of load is simulated by incorporating capacitor banks near the POI. The goal in this test is to use the BESS system to maintain the power exchange at POI at a setpoint of 1700 kW and 1100 kvar leading instead of zeroing out the power exchange. The corresponding plots of real and reactive power are given in Figures 5 and 6, respectively. In Figures 6 and 7, real power discharge and reactive power consumption are depicted by negative values. The black pulse-like line demonstrates the islanding command.

In Figure 6, the green plot portrays the POI real power and its values correspond to the left axis. It is observed that initially the real power exchange is above the desired 1700 kW prior to start of the test. After start of the test at 12:05:42 the battery controls are adjusted according to the desired setpoint command. The BESS real power output is portrayed by the red plot and its values correspond to the right axis. Upon start of the islanding mode, the BESS starts discharging to bring the POI power exchange close the desired setpoint of 1700 kW.

In Figure 7, the green plot portrays the POI reactive power corresponding to the left axis. The initial reactive power exchange at POI is higher than 1100 from BCM to the main grid. After start of the test at 12:05:42 the battery controls are adjusted according to the desired reactive power setpoint command. This triggers a sudden drop of reactive power exchange at the POI. As the islanding continues, the BESS starts consuming reactive power, portrayed by the red plot and corresponding to the right axis, and brings the POI reactive power exchange closer the desired setpoint of -1100 kvar.

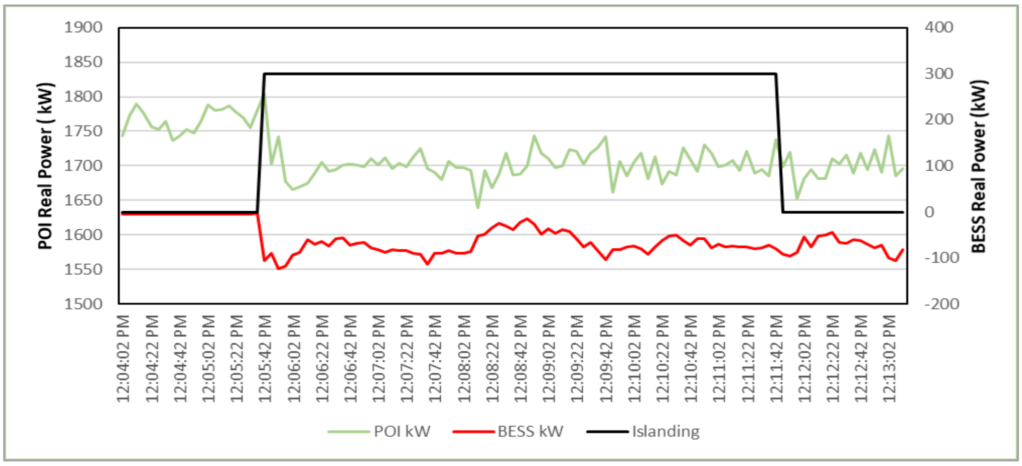

Figure 6. Maintaining real power exchange at POI with leading power factor load at BCM

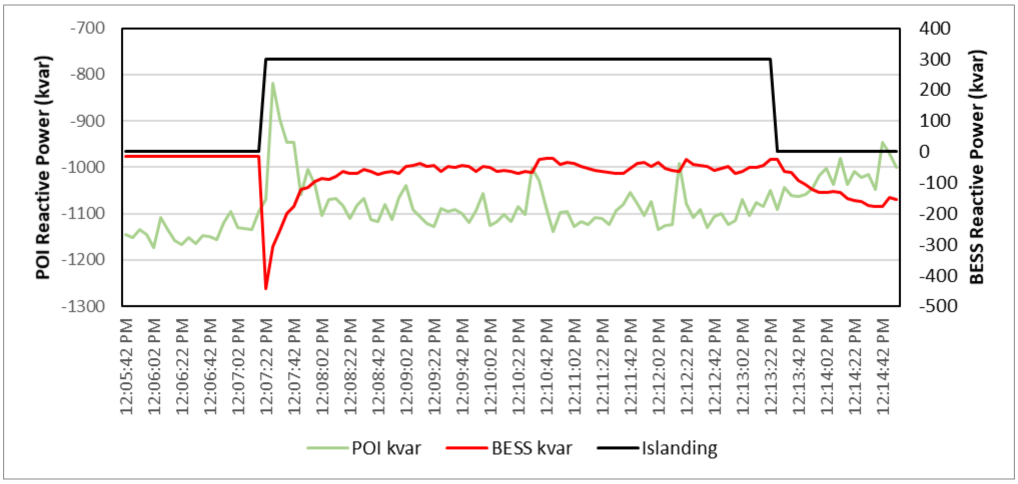

Figure 7. Maintaining reactive power exchange at POI with leading power factor load at BCM

3. CONCLUSION

The goal of this paper was to present the setup and analysis of conducting a novel islanding test, termed *simulated* islanding, on the newly-developed BCM of ComEd. The term simulated refers to the fact that BCM is not electrically separated from the main grid. Rather, when the islanding is enabled, BCM controls the power exchange at POI at specific values. It was demonstrated that microgrid distributed energy resources, specifically PV, BESS, and the mobile diesel generator, can be used efficiently and synergistically to achieve zero power exchange at POI when BCM load is of unity or lagging power factor. During leading power factor, the tests demonstrated that the BESS can be programmatically used to maintain the power exchange at POI at desired setpoints with a desired power factor level.

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