Microgrid Islanding and Grid Restoration With Off-the-Shelf Utility Protection Equipment

William C. Edwards Jr., Scott Manson, and Jakov Vico
Schweitzer Engineering Laboratories, Inc.

This paper was presented at the IEEE International Humanitarian Technology Conference and can be accessed at: https://doi.org/10.1109/IHTC.2017.8058185.

For the complete history of this paper, refer to the next page.

Published in
Wide-Area Protection and Control Systems: A Collection of Technical Papers Representing Modern Solutions, 2017

Originally presented at the
IEEE International Humanitarian Technology Conference, July 2017

Microgrid Islanding and Grid Restoration With Off-the-Shelf Utility Protection Equipment

William C. Edwards Jr., Scott Manson, and Jakov Vico
Schweitzer Engineering Laboratories, Inc.
Pullman, USA

***Abstract*—Automatic islanding and reconnection are commonly required at the point of common coupling between microgrids and macrogrids. Islanding systems open the point of common coupling during short circuits, open circuits, and dangerous backfeed conditions in the macrogrid. Automatic synchronizing systems provide reconnection by dispatching multiple distributed energy resources to reduce slip and voltage differences at the point of common coupling.**

This paper explains how commercial, off-the-shelf protective relays can be used to automatically island microgrids from and reconnect microgrids to the macrogrid.

Keywords—synchronization, decoupling, islanding, grid forming, grid-connected, point of common coupling, microgrid

I. Introduction

Microgrid owners want to avoid power outages when transitioning from grid-connected to islanded operation. This is called seamless islanding. The same electronics used to provide seamless islanding can also be used to provide a seamless transition back from islanded to grid-connected operation. This is called seamless reconnection.

Seamless islanding and reconnection systems have many benefits. For example, industrial users can avoid costly process outages, utility generation sites can reduce powerhouse restarts, universities can avoid losing academic research, and critical military operations can avoid interruption.

This paper provides an overview of seamless islanding and reconnection techniques. It includes explanations of common challenges users face when implementing these systems and how commercial, off-the-shelf (COTS) protection equipment can be used to provide these functionalities [1].

The COTS systems described in this paper are a combination of microprocessor-based protective relays and customized relay configurations. These configurations provide sophisticated functionality that simultaneously protects and controls the microgrid. Because multifunction protective relays are required at the point of common coupling (PCC), the added intelligence of an automatic islanding and reconnection system can be added with minimal cost and complexity. Fig. 1 shows a typical implementation.

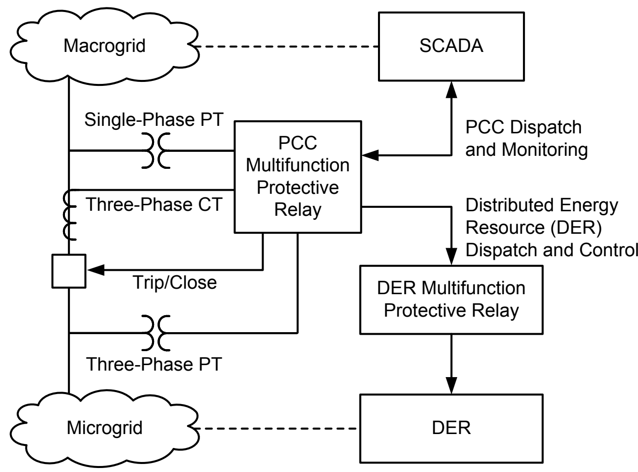

Fig. 1. Multifunction Relays Already at the PCC

II. Background

Many microgrid designers, specifiers, and owners are not aware of the low cost and advanced control capabilities of modern, multifunction protective relays. As such, many microgrid systems put into operation require manual islanding and reconnection. In addition, a great deal of government, academic, and industrial funds are unnecessarily spent on research and development when automatic islanding and reconnection functionality has been available in COTS relays for over 15 years.

IEEE 1547-2003 provides recommendations for how microgrids can island and reconnect with macrogrids [2]. IEEE 1547-2003 defines strict guidelines for the allowable voltage disturbances caused by synchronization at the PCC. These in turn require that microgrids use a synchronism-check mechanism to secure reconnection. Most microgrids can be easily retrofitted with the seamless islanding and reconnection functionality provided by COTS systems [3].

By using the capabilities of the multifunction relays that often already exist at the PCC, microgrid blackouts can be prevented and grid resynchronization can be automated. This saves microgrid owners significant time and money. Modern PCC relays can provide the functionality needed to meet upcoming IEEE 1547-2003, IEEE 2030.7, and IEEE 2030.8 specifications.

III. Grid Reconnection

Grid reconnection is called PCC autosynchronization by electrical power engineers. The ANSI symbol for manual synchronism-check functionality is 25, and it is A25 when the functionality includes automatic dispatch. Because of the complexity of the function, A25 systems are commonly referred to as advanced automatic synchronizers (A25A) [4].

A25A systems reduce cost, speed up the reconnection process, and improve operator safety. They do not require synchroscopes, meters, or costly panels and wiring. These systems also eliminate the need for operators to travel to remote locations to perform the synchronizing process [5].

This paper focuses on PCC A25A systems with multiple DERs. A25A systems autosynchronize the PCC and simultaneously dispatch multiple DERs. For clarity, Table I shows the four types of synchronizing systems. A25A systems are significantly more sophisticated than other synchronizing systems.

TABLE I
FOUR TYPES OF SYNCHRONIZING SYSTEMS

	Single DER	**Multiple DERs**
25	Single-function relay that confirms safe synchronizing **Not discussed in this paper**	Single-function relay that confirms safe synchronizing **Not discussed in this paper**
A25A	Multifunction relay that dispatches and synchronizes a single DER **Not discussed in this paper**	Multifunction relay that dispatches and synchronizes multiple DERs **Focus of this paper**

The PCC A25A relay shown in Fig. 2 has both a synchronism check and a dispatch function. The A25A process is always human-initiated for safety. Once the process is initiated, the A25A system operates autonomously to close the breaker and dispatch the DERs.

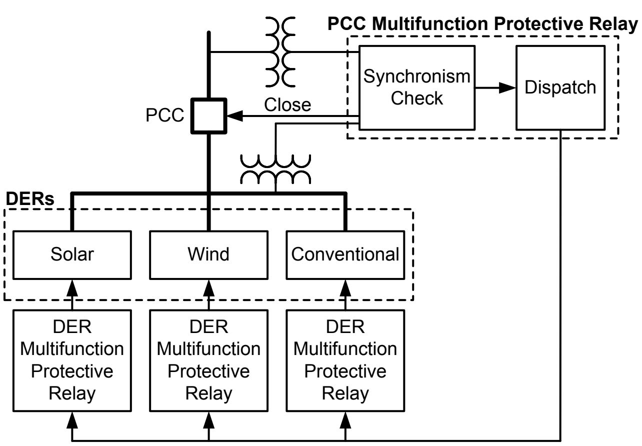

Fig. 2. Multifunction Relays Performing PCC A25A Function

The dispatch functionality sends time-varying reference corrections to DERs to bring the frequency, voltage, and angle difference across the PCC to within synchronizing acceptance limits. The synchronization functionality monitors the frequency, voltage, and angle difference across the PCC in real time. Once acceptance criteria are met, the relay sends a close command to the PCC breaker.

A. *Automatic Synchronizing*

This subsection explains how the PCC synchronism check and breaker close logic works.

Once the A25A process is initiated, the PCC A25A relay attempts to close the PCC breaker when the slip, voltage difference, and angle on both sides of the breaker are within the synchronizing acceptance criteria [4] [6] [7]. Fig. 3 shows what the angle (Δδ), voltage (ΔV), and slip (δ) signals look like for typical ac waveforms at the PCC.

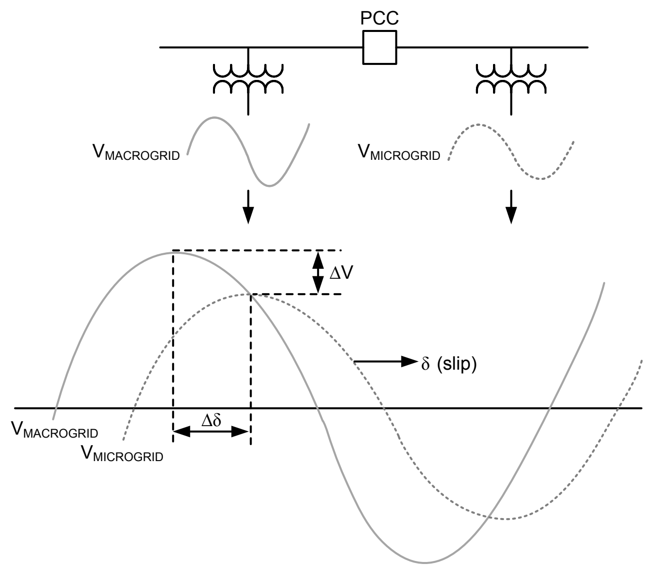

Fig. 3. Relay Performing Synchronism Check

If the PCC breaker is closed at the wrong angle, the current can surge at the PCC, potentially damaging DERs. A proven way to prevent such damage is breaker close delay logic. This logic compensates for the breaker mechanism close delay times by sending an anticipatory PCC breaker close command at the precise moment that ensures a zero-angle close [8].

Table II compares the default PCC A25A synchronization settings of two IEEE standards governing synchronous generators. IEEE 1547-2003 has similar requirements.

TABLE II
SUPERVISION SETTINGS FOR A25A PCC BREAKER CLOSE

Setting	**IEEE C50.12 and IEEE C50.13 [9] [10]**	**Typical A25A Acceptance Criteria**
Angle	±10°	Target 0°
Voltage	+5%	±5%
Breaker close time	n/a	3 cycles
Slip	±0.067 Hz	±0.04 Hz

B. Automatic Dispatch

This subsection describes the automatic DER dispatch function. This function dispatches DERs to bring slip, voltage difference, and angle on both sides of the PCC to within synchronizing acceptance criteria.

In many cases, the PCC A25A relay is remote from the DER. As shown in Fig. 2, relays are placed at each DER that communicate to the PCC A25A device. The DER relays control the individual DER output while the PCC A25A relay provides the dispatch and synchronization functionality. The DER relays control the active and reactive output of the individual DERs to meet PCC A25A relay dispatch requests.

When the complexity of the dispatch schemes becomes too complex for a single PCC A25A relay to manage, the dispatch function is commonly relegated to a separate microgrid controller. This is required when the island consists of a diverse mix of generation sources or when the microgrid is so large or complex that it requires complex frequency and voltage control strategies [4] [9] [11]. Microgrid controllers are not generally required until there are three or more DERs on a microgrid.

The PCC A25A relay performs the following tasks simultaneously to bring the microgrid into synchronization tolerance with the macrogrid:

- Dispatch multiple DERs to match the angle ($\Delta\delta$).
- Dispatch multiple DERs to match the frequency of the microgrid to the frequency of the macrogrid (i.e., bring the slip to zero).
- Dispatch multiple DERs to match the voltage amplitudes (i.e., bring the voltage difference [ΔV] to zero).
- Maintain the microgrid frequency and voltage within nominal levels. This is equivalent to maintaining load and power generation balance on the microgrid.

Fig. 4 shows a typical microgrid electrical graphical display. The display allows the operator to monitor the DER dispatch and PCC voltage, angle, and slip. It also provides a convenient method to initiate the A25A process and to confirm successful operation. The front panel of the PCC A25A relay commonly provides this display functionality [9].

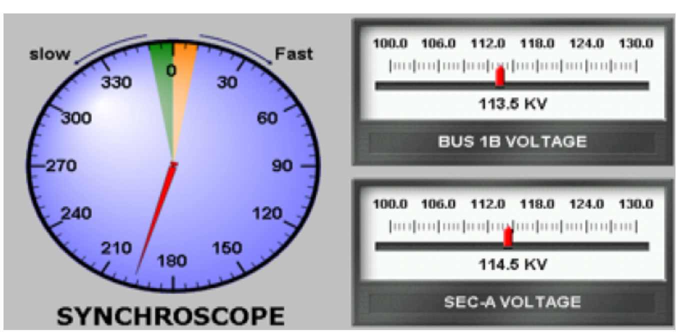

Fig. 4. PCC A25A Graphical Display

IV. Automatic Islanding

This section describes the automatic islanding functionality required at the PCC. The relay shown in Fig. 1 also includes this functionality. Protection engineers have for decades called these system decoupling and islanding detection schemes [12].

Decoupling schemes detect disturbances in the grid and intentionally island the microgrid by opening the PCC. Disturbance detection settings for such intentional decoupling systems must be capable of distinguishing internal from external system disturbances to prevent nuisance tripping. Typical disturbances include short circuit events, voltage collapse, and frequency collapse.

Islanding detection functionality is required to identify when a microgrid is inadvertently backfeeding the distribution supply with the macrogrid disconnected. Once a backfeed is detected, the PCC is opened. Backfeed conditions commonly occur when a macrogrid disconnects upstream of the microgrid following a faulted circuit. Backfeed conditions are dangerous to technicians working on the macrogrid.

A. Islanding as Defined by Legal Contracts

Legal contracts between microgrid and macrogrid owners define the disturbance ride-through requirements at the PCC. Fig. 5 depicts the IEEE 1547-2003 standard's frequency ride-through requirements; similar requirements are often referenced in legal contracts. These contracts require the PCC breaker to stay closed (i.e., prohibit decoupling) while the grid frequency is within a tolerance (ride-through) band.

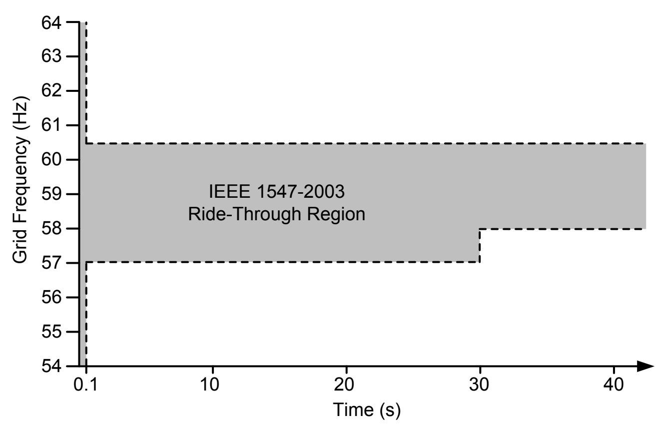

Fig. 5. Interconnection Contracts Define Decoupling Limitations

The ride-through region of Fig. 5 is designed to support the resiliency of the macrogrid with no benefit to the microgrid. These frequency ride-through requirements effectively extract all spinning kinetic energy reserves out of the microgrid in an effort to save the macrogrid. In order to avoid a microgrid blackout as a result of these challenging requirements, proactive and seamless islanding techniques are required. These are discussed in the following subsections.

B. Proactive Islanding

Proactive islanding techniques improve the chance of microgrid survival while abiding by the difficult ride-through requirements of interconnection contracts. A proactive islanding system works by sending an early (anticipatory) trip to the PCC during a high rate-of-change of frequency via the 81RF element. The relay sends the trip command in anticipation of crossing the contractual boundary and opens the PCC breaker before the microgrid frequency drops to an unrecoverable state. 81RF elements improve the probability of successful seamless islanding by tripping the PCC before the DERs trip out because of underfrequency.

Fig. 6 and Fig. 7 show the same event. Fig. 7 shows the 81RF element in action in a time domain plot. Fig. 6 shows what the relay 81RF element observes during this event.

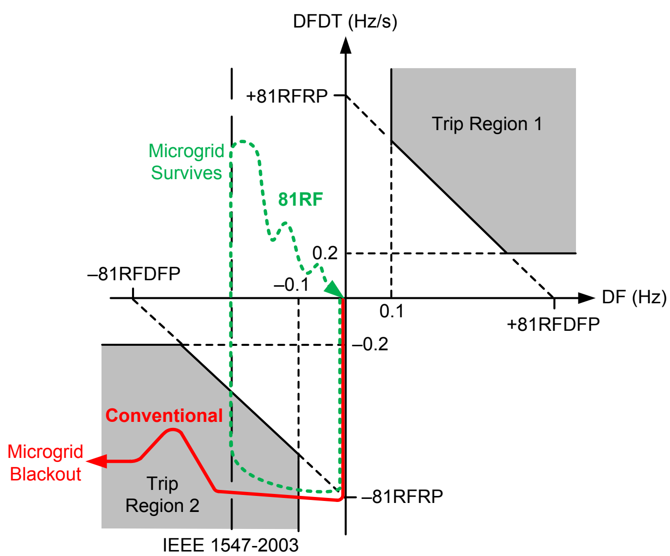

Fig. 6. 81RF Element Assists Microgrid Survival

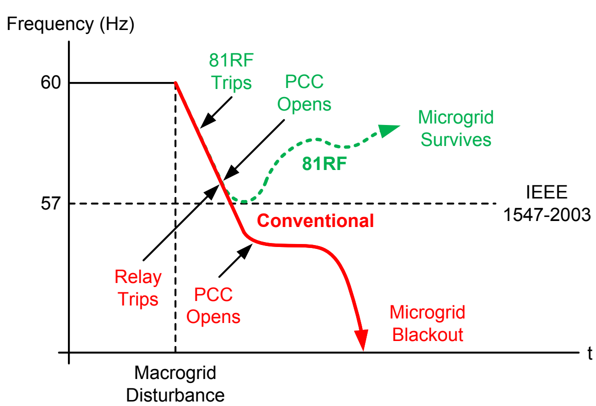

Fig. 7. Proactive Automatic Islanding Before a Microgrid Blackout

The lower, solid, red line labeled "Conventional" shows a non-seamless microgrid transition without the 81RF element that results in a microgrid blackout. The upper, dashed, green line labeled "81RF" shows a typical seamless transition with the 81RF element in use. For this transition, the PCC opens at exactly the frequency specified in the interconnect agreement, leaving margin for the microgrid to survive.

The power exchange across the PCC affects the response time of the 81RF element. An unintentional upstream disconnection (island) causes a mismatch in load and DER output, thus causing a frequency change. If the load demand is greater than the system generation, the frequency will decelerate, causing the operating point of the 81RF element to fall into Trip Region 2. Frequency acceleration occurs when local generation exceeds demand, which moves the operating point into Trip Region 1. A higher degree of mismatch causes the rate-of-change of frequency to increase, resulting in a faster response of the 81RF element [13].

C. Seamless Islanding

Once the PCC A25A relay opens the PCC and separates the microgrid, a high-speed response may be required for surviveability. If the onsite generation is less than the system load, the system DERs will experience an overburden condition and a frequency decay. Alternatively, if onsite generation exceeds the system loading, the newly formed island system frequency will increase.

High-speed generation runback, generation shedding, and load shedding are used to protect the system from a blackout after the PCC is opened. Many microgrids incorporate a mixture of mechanical and inverter-based DERs. Inverter-based DERs have a much lower inertia (resistance to frequency change). Therefore, surviveability requires even higher-speed controls. In the authors' experience, microgrids with inverter-based DERs require load-shedding systems that operate in less than 20 milliseconds.

V. Conclusion

Key conclusions of this paper include the following:

- Islanding with an 81RF element can prevent microgrid blackouts while simultaneously meeting interconnect requirements.
- PCC A25A functionality is commonly programmed into one or more multifunction relays.
- Seamless islanding commonly requires load shedding or DER runback to operate in less than 20 milliseconds.
- Although the relays are COTS, the functionalities described in this paper require customized software configurations designed by skilled engineers.

References

[1] T. Fenimore, A. Gould, and L. Wright, "Implementing a Microgrid Using Standard Utility Control Equipment," proceedings of the Power and Energy Automation Conference, Spokane, WA, March 2016.

[2] IEEE Standard 1547-2003, IEEE Standard for Interconnecting Distributed Resources With Electric Power Systems.

[3] J. Mulhausen, J. Schaefer, M. Mynam, A. Guzmán, and M. Donolo, "Anti-Islanding Today, Successful Islanding in the Future," proceedings of the 63rd Annual Conference for Protective Relay Engineers, College Station, TX, April 2010.

[4] S. M. Manson, A. Upreti, and M. J. Thompson, "Case Study: Smart Automatic Synchronization in Islanded Power Systems," proceedings of the 51st Annual Industrial & Commercial Power Systems Technical Conference, Calgary, AB, Canada, May 2015.

[5] M. J. Thompson, A. Li, R. Luo, M. C. Tu, and I. Urdaneta, "Advanced Synchronizing Systems Improve Reliability and Flexibility of Offshore Power Systems," proceedings of the 62nd Annual Petroleum and Chemical Industry Technical Conference, Houston, TX, October 2015.

[6] S. Manson, A. Khatib, M. Checksfield, and P. Duffield, "Case Study: Simultaneous Optimization of Electrical Grid Stability and Steam Production," proceedings of the 61st Annual Petroleum and Chemical Industry Technical Conference, San Francisco, CA, September 2014.

[7] K. G. Ravikumar, S. Manson, S. K. Raghupathula, T. Alghamdi, and J. Bugshan, "Complete Power Management System for an Industrial Refinery," proceedings of the 62nd Annual Petroleum and Chemical Industry Technical Conference, Houston, TX, October 2015.

[8] M. Thompson, "Advancements in Synchronizing Systems for Microgrids and Grid Restoration," proceedings of the 13th International Conference on Developments in Power System Protection, Edinburgh, United Kingdom, March 2016.

[9] IEEE Standard C50.12-2005, IEEE Standard for Salient-Pole 50 Hz and 60 Hz Synchronous Generators and Generator/Motors for Hydraulic Turbine Applications Rated 5 MVA and Above.

[10] IEEE Standard C50.13-2005, IEEE Standard for Cylindrical-Rotor 50 Hz and 60 Hz Synchronous Generators Rated 10 MVA and Above.

[11] C. E. Ortiz, J. F. Rada, E. Hernandez, J. Lozada, A. Carbajal, and H. Altuve, "Protection, Control, Automation, and Integration for Off-Grid Solar-Powered Microgrids in Mexico," proceedings of the 40th Annual Western Protective Relay Conference, Spokane, WA, October 2013.

[12] K. G. Ravikumar, A. Upreti, and A. Nagarajan, "State-of-the-Art Islanding Detection and Decoupling Systems for Utility and Industrial Power Systems," proceedings of the 69th Annual Georgia Tech Protective Relaying Conference, Atlanta, GA, April 2015.

[13] R. Anne, F. K. Basha, R. Palaniappan, M. J. Thompson, K. L. Oliver, "Reliable Generator Islanding Detection for Industrial Power Consumers With On-Site Generation," proceedings of the 61st Annual Petroleum and Chemical Industry Technical Conference, San Francisco, CA, September 2014.

Previously presented at the IEEE International Humanitarian Technology Conference, Toronto, Canada, July 2017.

20170213 • TP6801