Design and Implementation of an Anti-Islanding Protection Strategy for Distributed Generation involving Multiple Passive Protections

Aidan Foss, *Senior Member, IEEE*, and Kalle Leppik, *Member, IEEE*

***Abstract*—Experience with connecting farm biogas generation to rural distribution feeders has revealed that a particular costly barrier can be protection against unplanned islanding. When the size of the generation is small compared to the load on the feeder, the cost of anti-islanding protection is very small. However, once a certain size threshold is reached, alternative protection methods are required, and the standard solution in the past has been expensive utility-approved fast transfer trip. Recognizing that this would make many farm biogas projects uneconomic, the utility has agreed to work with biogas proponents to develop cheaper alternatives for projects less than 500kW. This paper describes the design of a novel Multiple-Passive Anti-Islanding Protection Strategy and its implementation on a 499kW biogas-fueled synchronous generator in Ontario.**

***Index Terms*—Distributed Generation, Biogas, Anti-Islanding Protection, Vector Shift, ROCOF**

I. Introduction

Experience with connecting farm biogas generation in Ontario to rural distribution feeders has revealed that a particular costly barrier can be protection against unplanned islanding. When the utility feeder becomes disconnected from the main distribution network, any generators connected to that feeder must be rapidly disconnected to avoid potential damage when the feeder re-connects with the network.

When the size of the generation is small compared to the load on the feeder, the cost of anti-islanding protection is very small as it can be included within standard interconnection protection. However, once a certain size threshold is reached, alternative protection methods are required, and the standard solution in the past has been utility-approved fast transfer trip costing around C$250K for a single recloser-set system. Recognizing that this would make many farm biogas projects uneconomic, the utility agreed to work with biogas proponents to develop cheaper alternatives for projects less than 500kW [3].

The first Ontario biogas project to experience this barrier was the Terryland Farms 180kW generator. In 2007, following a joint research program with Natural Resources Canada involving a series of simulation studies and on-site tests, this project was granted approval to connect using '*Directional Reactive Power Protection*' [1].

For the Fepro Farms 499kW biogas project, this method was not considered suitable owing to the presence of a capacitor bank on the feeder. This led to a re-opening of the research program leading eventually to the '*Multiple-Passive Strategy*', that is described in this report.

II. The Fepro Farms Project

Fepro Farms is a pioneer of Biogas technology. In 2003, they commissioned a single-phase 50kW unit using dairy manure as the digester feedstock. In 2007, they embarked on a new project to increase generating capacity to 499kW though bringing in high-energy off-farm organic wastes such as grease from restaurant grease traps. A single-line diagram of the generation site is shown below. Both generator and inter-tie protections act to trip the generator breaker.

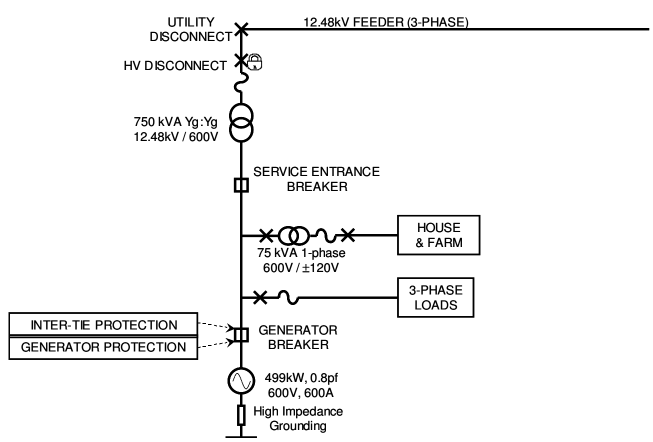

Fig. 1. Fepro Farms Generation Site Single-Line Diagram.

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The utility Connection Impact Assessment identified that transfer trip or an alternative was required for anti-islanding protection, since the generation capacity (499kW) was above 50% of the minimum feeder load (520kVA). The option of employing directional reactive power protection [1] was not considered appropriate owing to the presence of a 450kVAr fixed capacitor bank on the feeder.

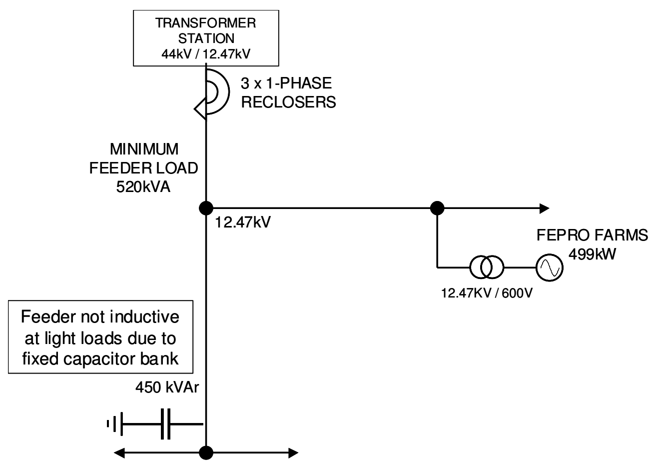

Fig. 2. Utility Feeder Single-Line Diagram.

The directional reactive power method requires the feeder to which the DG is attached to be always inductive. The generator is set to slightly leading VARs, typically around 0.97pf. If the feeder becomes islanded from the main part of the grid, the inductive load on the feeder forces the generator to export reactive power, which is used to detect an island condition. As the feeder to which Fepro Farms is connected does not become inductive at light loads, this method was not proposed.

III. Review of Anti-Islanding Protection Methods

The rural distribution network in Ontario make extensive use of single-phase hydraulic reclosers to provide rapid re-connection of load customers following a transitory feeder fault. They are employed both in substations, and on poles to sectionalize a feeder. Distributed Generations may find up to 4 sets of reclosers between it and the transformer station bus. These reclosers have fixed reclose times (1-2 seconds) and no mechanism for providing an output status contact. This makes conventional fast transfer trip very expensive as it involves recloser replacement, communication masts, two-way secure radio and recloser control. The utility requirement is for disconnection within 0.5 sec [3], significantly faster that the 2.0 second requirement of IEEE 1547 [2].

A review of potential anti-islanding methods for this type of generation project was undertaken [6,10]. The main findings are summarized below:

- Fast Transfer Trip (FTT): This is the conventional method involving recloser status contacts, fast secure two-way communications and recloser control. Typically involves recloser replacement and erection of communication masts. Much too expensive for small biogas, typically costing around C$250K for a single recloser-set implementation, and more if multiple recloser-sets are involved.
- Uni-directional Transfer Trip: Reduces cost by requiring only one-way communications and no upgrade to recloser control. As recloser status and fast communications are still required, this is still too expensive for small biogas.
- Less fast Transfer Trip: Used in some jurisdictions – not suitable in Ontario owing to the recloser times.
- Under-current Transfer Trip: Avoids the need for recloser replacement by using CTs to indicate an open circuit. This still requires fast communications, and may have nuisance tripping risk associated with current zeros not caused by an open recloser event.
- Moving reclosers downstream of generation: The objective is to enable the feeder section to which the generation connects to have a minimum load of at least twice the generation size. Potentially cost effective, but very limited opportunity for application.
- Increasing reclose times: Generally requires new reclosers and would impact on load customers. Could allow low-cost passive protections to operate over a much wider load range.
- Recloser voltage blocking: Recloser closing would be inhibited if voltage is sensed on the downstream side. Requires new more expensive reclosers equipped with voltage transformers.
- Directional Reactive Power: Low cost, but requires the feeder to always be inductive. Some nuisance tripping risk associated with motor starting transients. Successfully applied at Terryland Farms in 2007 [1].
- Power-line Pulse (ENERPULSAR) [8,9]: A pulse is generated at the transformer station and detected by a pulse detector at the DG site. The DG is tripped if no pulse is measured. This can be used on a feeder with multiple sets of reclosers and with multiple generators. Although cheaper than FTT, the estimated cost for the signal generator is generally considered too expensive for protecting a single small biogas generator. Currently under development, with plans for a field trial on a biogas plant in Ontario in fall 2009
- Multiple-Passive Strategy (MPS): Described below and piloted at Fepro Farms in spring 2009.

IV. Multiple-Passive Strategy (MPS)

Following discussions with the utility, it was agreed to pilot the Multiple-Passive Anti-islanding Protection Strategy at Fepro Farms. The key requirement of an anti-islanding protection system is to ensure that the generator is disconnected ahead of first reclose in order to avoid damage from out-of-phase reclosing. The multiple-passive anti-islanding protection strategy has three parts:

1. Fast Detection of Feeder Faults
2. Fast Imbalance Detection
3. Multiple Passive Island Detections

A. Fast Detection of Feeder Faults

The aim is to detect all short-circuit faults on the feeder ahead of recloser opening and with rapid tripping of generation. This covers all fault types (3P, P-E, P-P, P-P-E), at any location on the feeder, including beyond downstream reclosers. Possible protections include over-current, directional over-current, distance and under-voltage. Based on the results of the protection study, instantaneous over-current protection was selected, with phase under-voltage included as a fast backup.

B. Fast Imbalance Detection

Unbalanced feeder faults (P-E, P-P and P-P-E), or when one or two reclosers are open, will cause considerable voltage and current imbalance on the feeder. This will be detected by negative sequence and zero sequence protections. Initially negative sequence voltage and current protection were used, but consideration is now being given to using negative and zero sequence voltage protections, due to the potential impact of single-phase farm load on negative sequence current.

C. Multiple Passive Island Detections:

In the event of parts 1 and 2 of the strategy failing to disconnect the generator, multiple passive anti-islanding protections with sensitive settings are used to detect an island condition. By using a combination of all these protections, the intent is to reduce any non-detection zone to virtually zero. The following protections were used:

- Under-frequency: 59.0 Hz for 0.5 second. Takes into account that during normal operation, the system frequency may drop to 59.3 Hz [3].
- Over-frequency: 60.5 Hz for 0.1 second – in line with normal utility requirements.
- Under-voltage: 0.65pu for 4 cycles – the fast setting was chosen to provide a fast backup for detecting feeder faults. The generator AVR control mode is regulation about unity power factor.
- Over-voltage: 110% for 0.5 second and 120% for 0.1 second in accordance with normal utility requirements.
- Power Export: 110%kW for 0.4 second. The detects islanding based on the generator trying to supply all load on the feeder The kW margin above 100% is to allow for governor response to small disturbances.
- Rate-of-Change-of-Frequency (ROCOF): Initially set to 0.4 Hz/sec for 0.1 second based on a site-specific simulation study [4].
- Vector Shift (Change in generator power angle): Although a site-specific simulation study proposed 4 degrees [4], it was agreed with the utility to take a cautious approach and to start with the protection set to its minimum pickup of 2 degrees.

V. IMPLEMENTATION

The Inter-tie protection with the MPS Anti-Islanding Protection Strategy was commissioned at Fepro Farms in Spring 2009. The main inter-tie protection relay contained all the required protections except Vector Shift, which was available in the generator loss-of-mains protection relay. In view of the Yg:Yg interface transformer winding configuration, it was possible to implement the strategy using measurements of only LV phase voltages and currents, thus avoiding the expense of medium voltage measurement transformers.

A. Commissioning

Commissioning included signal injection testing of all protections, including ROCOF and Vector Shift. Prior to first synchronization it was noted that the ROCOF protection was triggering with no load or generation connected. Its setting was increased to 0.5 Hz/sec for 0.1 sec. Some triggering of the ROCOF protection also occurred during synchronization. Rather than increase the ROCOF setting further, it was decided to only arm this protection at generation levels above 75kW (15% of rated), and this overcame the problem.

B. Initial Operation

Initial operation gave a very high number or ROCOF trips. Following discussions with the utility, the ROCOF timeout was increased to 0.25 second. This is in accordance with the 0.2-0.7 second range used in several other jurisdictions [5,6].

Following the de-sensitizing of the ROCOF protection, this enabled attention to be directed at the Vector Shift protection that was producing daily nuisance trips. Increasing the setting from 2 degrees to 3 degrees significantly reduced the number of these trips. Figure 3 below shows the vector shift angles of the three phase-phase voltages during a trip event. The setting was subsequently raised to 4 degrees in line with the recommendation of reference [4], and further work on optimizing this setting is in progress. Typical settings for loss of mains protection in other jurisdictions are 4-6 degrees for a strong (low impedance) network to 10-12 degrees for a weak (high impedance) network [5,7].

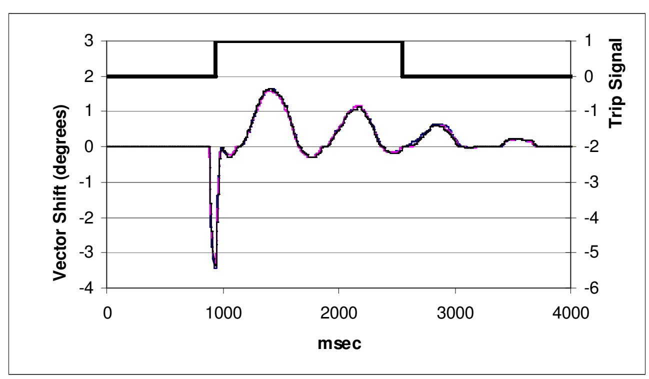

Fig. 3. Vector Shift Trip

One requirement of the MPS anti-islanding strategy is to rapidly disconnect the generator in response to a fault on the feeder. Figure 4 below shows the response of the instantaneous over-current protection to a feeder phase-phase fault. It can be seen that the protection promptly disconnected the generator from the faulted feeder in three cycles.

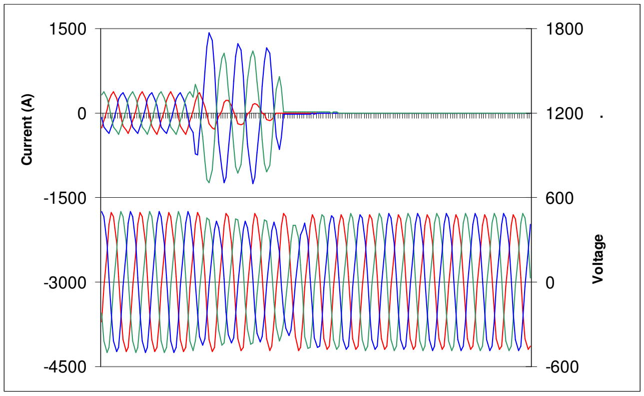

Fig. 4. Response to Feeder Phase-Phase fault

C. *Longer-term Assessment*

As part of the Pilot Implementation of the MPS strategy, it was agreed to monitor over a 12-month period in order to ensure year-round optimization of settings, and in particular for ROCOF and Vector Shift protections. In addition, in order to facilitate multi-party co-operation, a low-cost web-portal to the inter-tie protection relay was implemented. The facility operates by polling Modbus® registers of the relay, and provides real-time monitoring, time-histories and fault reports. A sample of the real-time display is shown below.

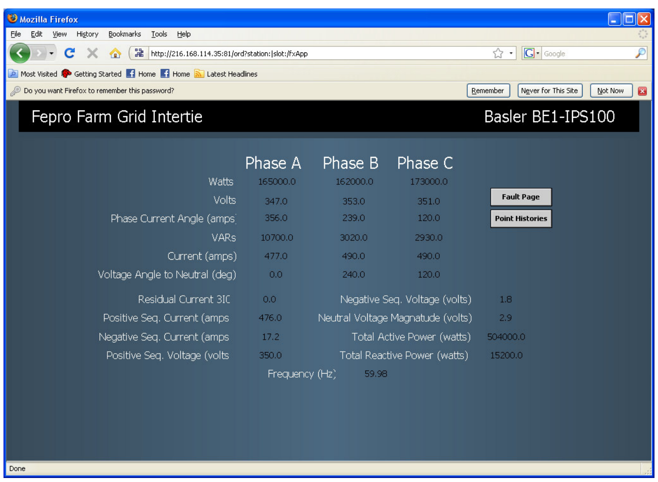

Fig. 5. Web-portal Monitoring Facility

CAVEAT

This paper reports on work performed over 2008 and 2009. At the time of writing, the situation for DG in Ontario is rapidly evolving with major changes proposed for power purchase, interconnection cost-sharing and connection standards. One possibility is that utilities would take on the costs associated with anti-islanding protection. This would significantly impact on the drive for lower-cost anti-islanding protection methods for distributed generation.

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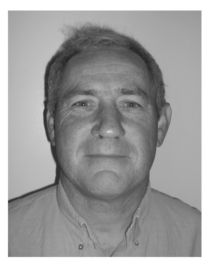

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