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Commercial Relays Field Tests for Passive Anti-Islanding Protection Schemes of Synchronous Generator Based DGs

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SUMMARY

According to current standards, distributed generation is required to rapidly disconnect from the utility feeder in the event of loss of mains, in order to: prevent poor power quality; and prevent out-of-phase reclosing that might lead to equipment damage. Islanding detection methods can be divided into three main groups: communication based methods; passive methods; and active methods. This paper presents the results of a series of field tests of passive anti-islanding protection schemes for a synchronous generator based distributed generator. These tests were conducted using various types of voltage and frequency based passive anti-islanding protection schemes to determine their operating time in response to opening of the upstream recloser, to evaluate their ability to detect an islanding situation. The tests were performed by CanmetENERGY in collaboration with the Hydro Quebec research centre (IREQ) using IREQ's 25 kV voltage test facility and three commercial (off-the-shelf) protection relays.

KEYWORDS

Distributed generation, field tests, passive anti-islanding, protection, rate-of-change-of-frequency, synchronous generator, and vector shift.

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1. INTRODUCTION

Anti-islanding protection is considered by utilities to be one of the main protection requirements for the interconnection of a distributed generation (DG) to medium and low voltage grids [1]. Distributed generations must, according to the current standards, cease to energize the grid upon the loss of the main system. These standards refer to anti-islanding protection as one of the main protection requirements for interconnecting rotating machine based distributed generation to medium and low voltage grids [2, 3]. Unintentional islanding of distributed generation may result in equipment damage, power quality issues, interference with grid protection devices, and personnel safety hazards (however, utilities' line workers have safety procedures that must be followed before operating on electric networks which should eliminate such hazards). Islanding detection methods can be divided into three main groups: *Communication based methods* that depend on transmitting signals to and from utilities and DGs sides; *Passive methods* that depend on monitoring a certain parameter and comparing it with a threshold value; and *Active methods* that interfere with the power system operation by creating an abnormal condition once the DG is islanded, causing voltage and/or frequency to quickly diverge outside the normal operating ranges, causing the DG passive protection to trip the generator [4, 5]. Significant work has been conducted during the last decade to investigate the performance of conventional over/under voltage and frequency relays as well as application specific frequency–based relays (rate-of-change-of-frequency (ROCOF) and vector shift (VS) relays) for anti-islanding protection of rotating machine based DGs [6] – [10]. However, few efforts has been reported on field testing commercial, off-the-shelf relays to investigate and assess their performance [11].

This paper summarizes the results of a series of passive anti-islanding protection schemes field tests on a synchronous generator based distributed generator. These tests were conducted on various types of voltage and frequency based passive anti-islanding protection schemes to determine their operating time in response to opening of the upstream recloser, to evaluate their ability to detect an islanding situation. The tests were performed by CanmetENERGY in collaboration with the Hydro Quebec research centre (IREQ) using IREQ's 25 kV voltage test facility and three commercial protection relays.

The response time of passive anti-islanding schemes for islanding detection is very dependent on the power mismatch level between demand and generation prior to disconnection of the main grid. In general, the performance of passive anti-islanding protection schemes under small power mismatch conditions (below 25%) has been unclear. Therefore, tests were performed targeting small power mismatches (below 12.5%) between generation and demand.

2. IREQ 25 KV TEST LINE

A series of passive anti-islanding protection schemes field tests was performed on synchronous generator based distributed generation. These tests were conducted by CanmetENERGY in collaboration with the Hydro Quebec research centre (IREQ) using IREQ's 25 kV voltage test facility and three commercial protection relays. The IREQ test facility is a 25 kV, 370 m, 3-phase line mounted on 24 poles. The test line is fed from IREQ's 120 kV substation by a dedicated feeder. The test line is also equipped with circuit breakers, remote controlled switches with their control cabinet, protective relays, measuring equipment, synchronous and induction machine based distributed generation, and variable RL load connected at the 600 V buses. Figure 1 presents the single-line diagram of the IREQ 25 kV test facility, with only the synchronous machine connected.

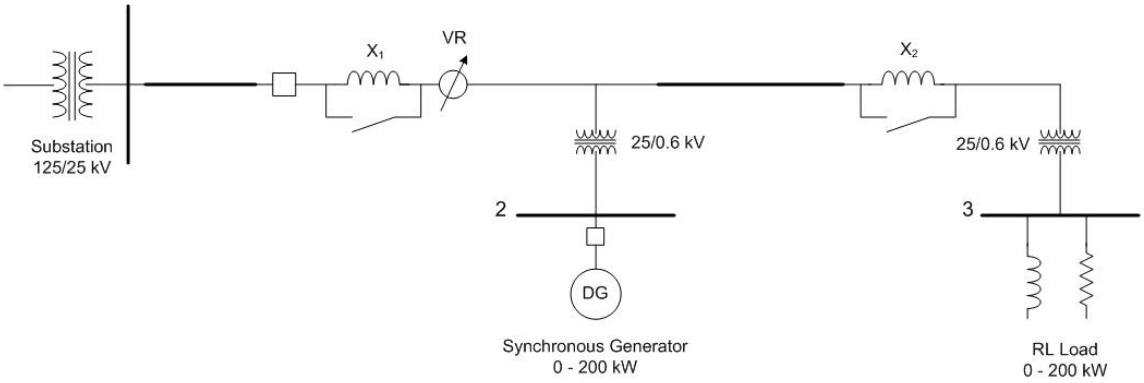


Figure 1. IREQ 25 kV test line

3. TEST CASE STUDIES

Three protective relays and multiple voltage/frequency based schemes were tested for passive anti-islanding application with a synchronous generator. Table 1 shows protection schemes and relay types used for this test. Eight different test cases were performed targeting small power mismatches (below 12.5%) between generation and demand. In some cases, the reactive power of the load was also varied. The test system was set to a pre-specified power mismatch operating condition, given in Table 2, and then the system's recloser was opened. The system dynamics were captured over a long time interval (20-30 seconds) after opening the recloser, sufficient to observe whether the relays will detect the islanding condition or not. During these series of tests, the synchronous generator based DG was operated as a grid-tied unit; therefore, it does not attempt to sustain the island. Matlab software environment was used to analyze the field measurement data and visualize the results.

Table 1. Relay types and protection schemes

Relay Type	Protection Scheme	Description
Crompton Relay 1	ROCOF/VS	Crompton Rate-of-Change-of-Frequency (ROCOF) relay
Crompton Relay 2	UV1	Crompton SPR relay - Under voltage scheme
Crompton Relay 2	OV1	Crompton SPR relay - Over voltage scheme
Crompton Relay 2	UF1	Crompton SPR relay - Under frequency scheme
Crompton Relay 2	OF1	Crompton SPR relay - Over frequency scheme
SEL Relay	UV2	SEL relay - Under voltage scheme
SEL Relay	OV2	SEL relay – Over voltage scheme
SEL Relay	UF2	SEL relay - Under frequency scheme
SEL Relay	OF2	SEL relay – Over frequency scheme

Table 2. Passive anti-islanding test case studies

Test Case	Description	$I_{L,real}$ (A)	$I_{L,reactive}$ (A)	$I_{gen,real}$ (A)	$I_{gen,reactive}$ (A)	ΔP (%)	ΔS (%)
1	Zero mismatch, Resistive load	180	0	180	0	0.0%	0.0%
2	12.5% mismatch, Resistive load	160	0	180	0	12.5%	12.5%
3	9.1% mismatch, Resistive light load	110	0	100	0	-9.1%	-9.1%
4	Zero mismatch, Resistive light load	100	0	100	0	0.0%	0.0%
5	11.1% mismatch, Resistive light load	90	0	100	0	11.1%	11.1%
6	4.4% mismatch, Resistive/Inductive load	180	55	180	0	0.0%	-4.4%
7	4.4% mismatch, Resistive/Capacitive load	180	-55	180	0	0.0%	-4.4%
8	10.6% mismatch, Resistive load, Generation with non-unity power factor	180	0	180	85	0.0%	10.6%

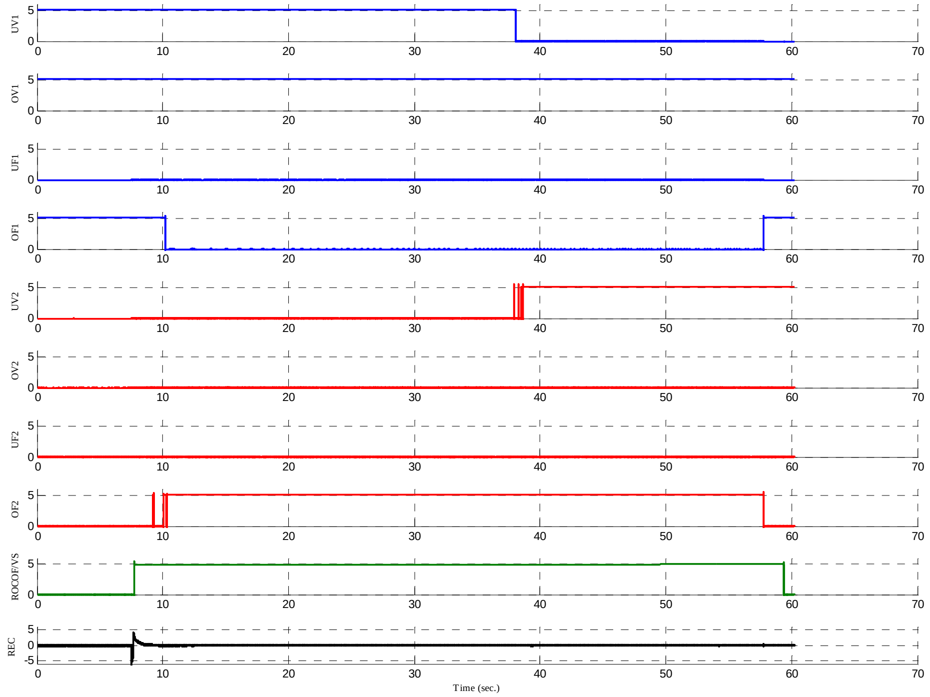
4. RESULTS

Figures 2 – 4 present samples of the relay signals and the system waveforms for test cases 2, 6 and 8, respectively. The recorded operating (response) times of the relays are recorded in Table 3. The recloser operating time, reported in Table 3, is the actual opening time of the recloser in second as measured in the field (from beginning of the test). The relay response times are then calculated considering the the recloser operating time as the zero time reference. Hence, each relay response time value is a representative of typical operating time for the specific protection scheme under the test condition.

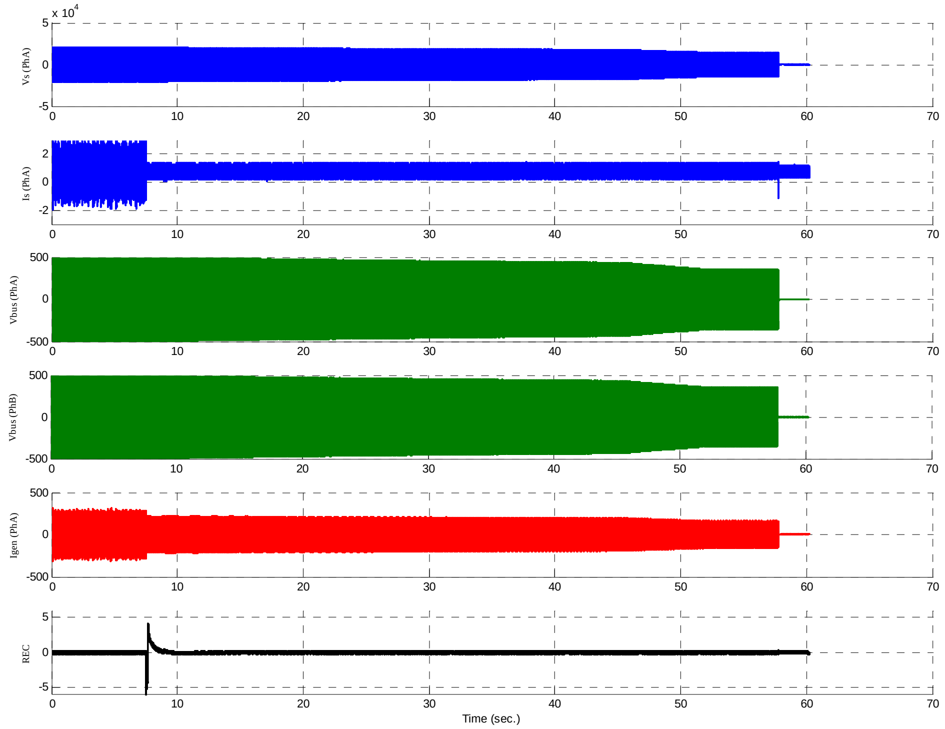
Table 3. Response times of different schemes for anti-islanding tests

Test Case Study	Recloser Operating Time (s)	Crompton Relay 1	Crompton Relay 2				SEL Relay			
		ROCOF/VS	UV1	OV1	UF1	OF1	UV2	OV2	UF2	OF2
1	7.44	N/D	25.55	N/D	N/D	15.16	25.82	N/D	N/D	14.37
2	7.49	0.27	30.60	N/D	N/D	2.71	30.83	N/D	N/D	2.85
3	6.58	N/D	37.02	N/D	N/D	27.32	37.43	N/D	N/D	26.20
4	6.78	N/D	39.17	N/D	N/D	28.48	39.54	N/D	N/D	28.07
5	6.33	N/D	40.53	N/D	N/D	19.09	41.10	N/D	N/D	30.99
6	6.39	6.20	4.14	N/D	N/D	5.18	4.03	N/D	N/D	4.81
7	6.62	N/D	N/D	13.30	N/D	N/D	N/D	13.75	11.74	N/D
8	6.50	0.19	17.32	6.94	N/D	N/D	17.11	6.73	1.73	N/D

N/D: No Detection of the opening of the recloser.



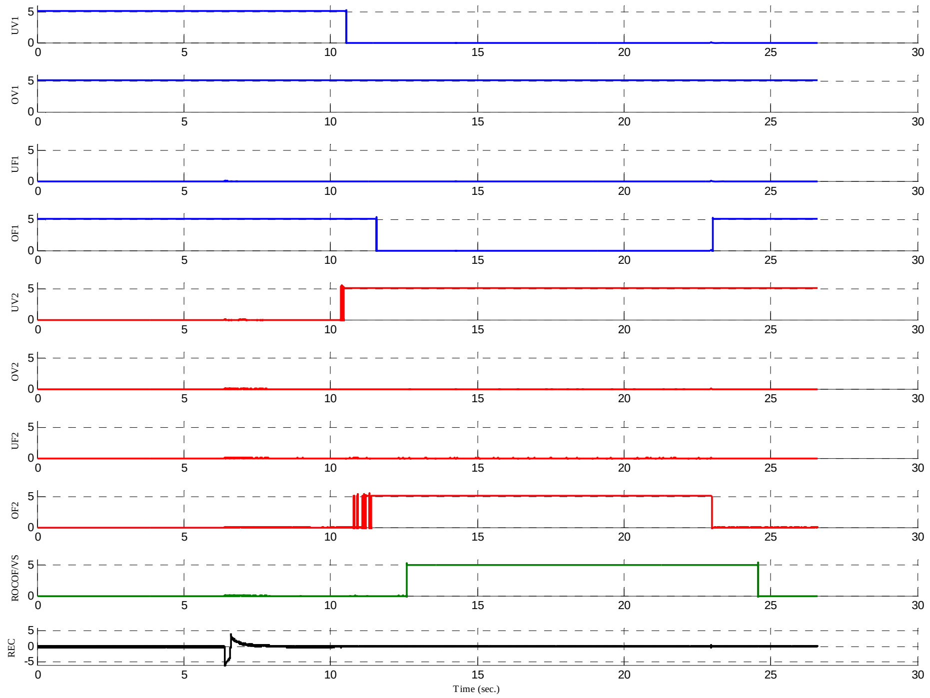
a) Recorded relays' signals



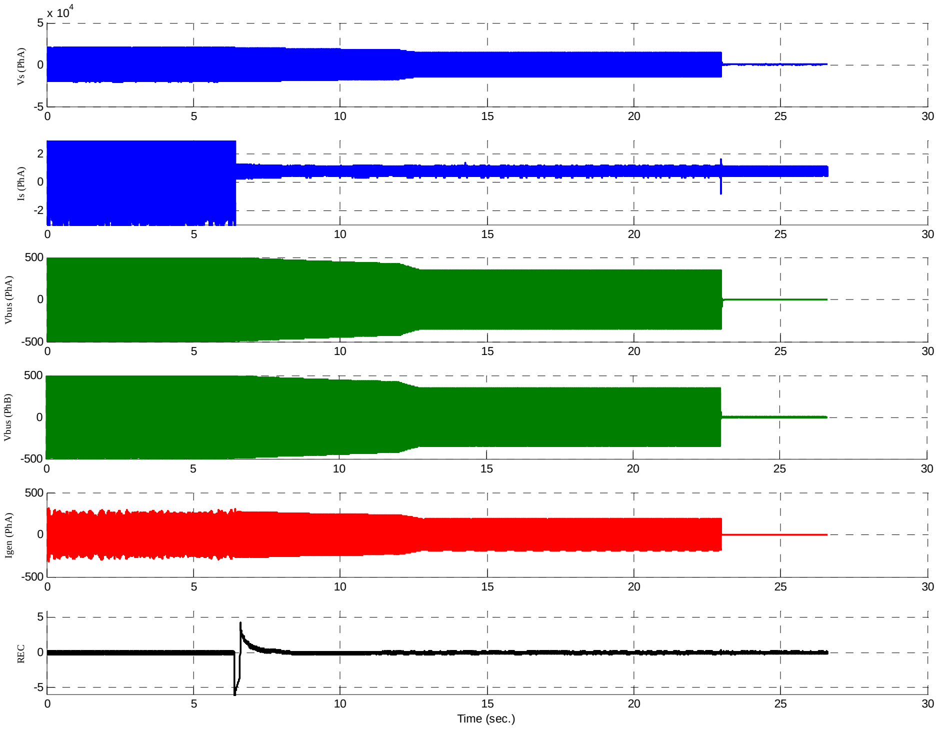
b) Recorded waveforms

Vs(PhA): Phase 'A' voltage at substation; Is(PhA): Phase 'A' current from substation; Vbus(PhA): Phase 'A' voltage at the generator bus; Vbus(PhB): Phase 'B' voltage at the generator bus; Igen(PhA): Phase 'A' generator current

Figure 2. Recorded relays' signals and recorded waveforms for Case Study 2.

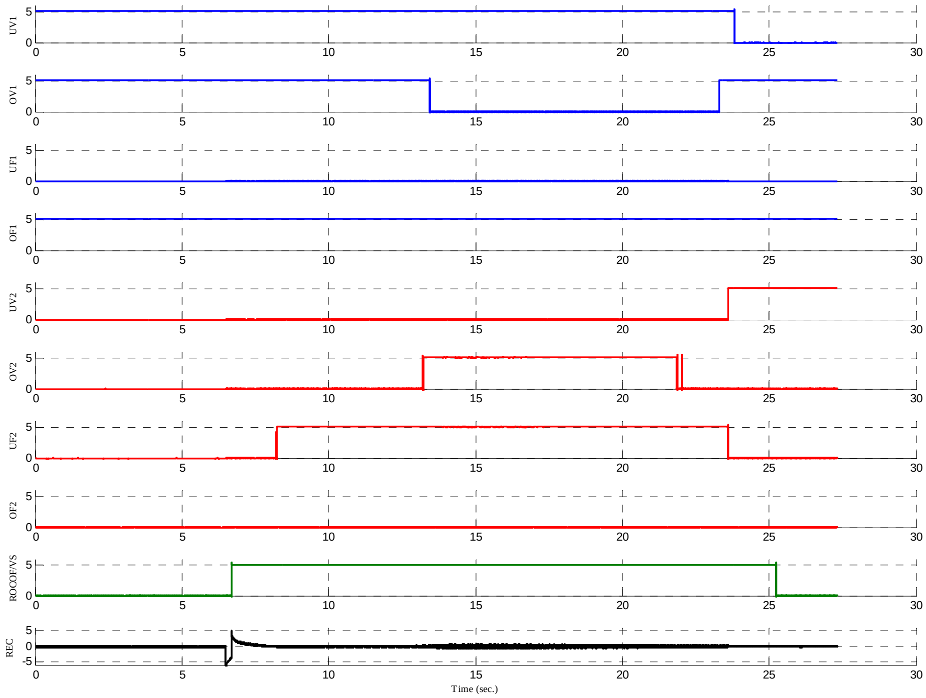


a) Recorded relays' signals

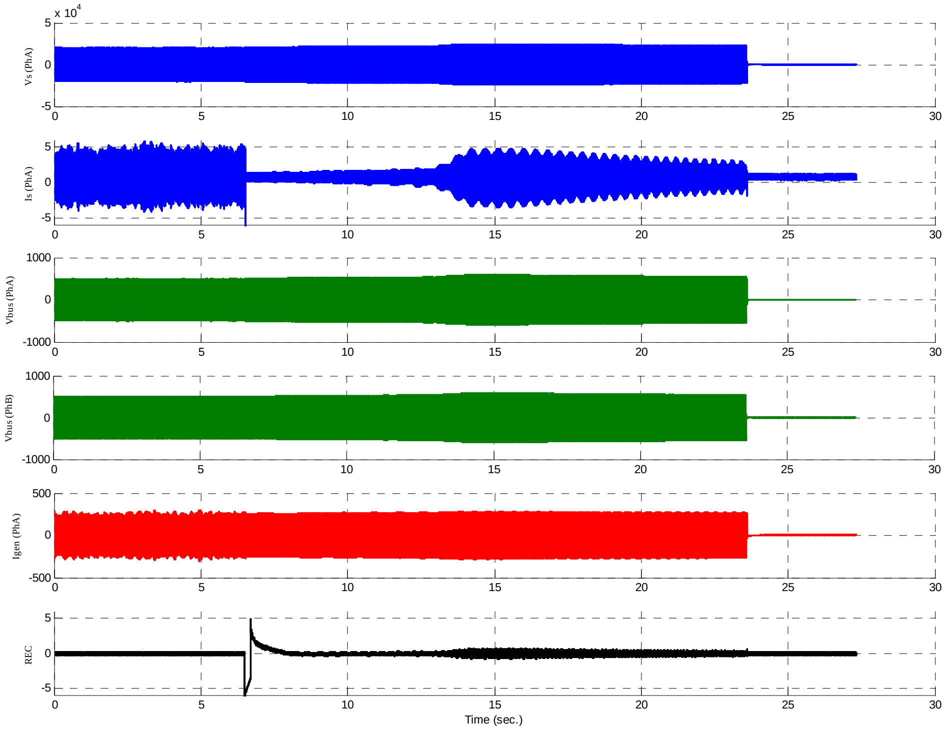


c) Recorded waveforms

Figure 3. Recorded relays' signals and recorded waveforms for Case Study 6.



a) Recorded relays' signals



d) Recorded waveforms

Figure 4. Recorded relays' signals and recorded waveforms for Case Study 8.

The results presented in Table 3 show that, in most cases, typical under voltage and over frequency relays were capable of detecting the islanding conditions but with a very slow response. Test case 7 (4.4% mismatch with resistive/capacitive load) was detected by both the over voltage and under frequency relays. As for test case 8 (10.6% mismatch with resistive load and non-unity power factor generation), that experienced under voltage conditions followed by over voltage conditions, it was detected by both under and over voltage relays. Moreover, this case has been also detected by the under frequency relay (UF2) 1.73 seconds after the recloser operating time.

For the ROCOF/VS relay, it has been able to detect islanding, under studied test cases, with power mismatch levels above 10% with the exception of the light resistive load test case. The detection time of the relay for those cases was below 0.3 seconds.

5. CONCLUSIONS

Based on the limited number of the considered test cases, it was observed that typical under/over voltage and frequency relays have very slow response times at low levels of power mismatch between demand and generation. This is mainly because of the absence of adequate level of voltage and frequency excursions to trigger the schemes in a reasonable time. A combination of the Rate-Of-Change-Of-Frequency (ROCOF) and the Vector Shift (VS) schemes could detect islanding of a synchronous generator for all power mismatches above 10%. The combined scheme also showed a very promising detection time of below 0.3 seconds; however, the scheme failed to detect islanding for power mismatches below 10%.

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