Comparison of Anti-Islanding Schemes
Operating Times for Distribution Systems with Large Capacity Wind Turbines

Walid El-khattam, Member, IEEE, Tarlochan S. Sidhu, Fellow, IEEE, and Ravi Seethapathy, Member, IEEE

Abstract—Installing large capacity wind turbines in distribution systems severely impacts the existing protection schemes. In case of disturbance events, local distribution companies (LDC) require fast disconnection of wind turbines to prevent sustainable islanding and thus minimize damages to system equipments. In this paper, comparison of the operating times for passive local detection and communication-based (using different media) schemes was carried out through laboratory testing. The two schemes were examined on two commercial relays to disconnect a self-excited induction generation wind turbine (SEIG-WT) that has a matching load real power. The SEIG-WT disconnection should take place before main breaker reclosure action within the specified LDC practice. The recorded results and conclusion are discussed.

I. INTRODUCTION

Wind turbine power generation is increasingly being installed in existing distribution systems [1]. As a part of the renewable distributed generation (DG) resources, wind turbines contributed to the positive impact of adding DG into the system [1]. However, many negative impacts increasingly occurred due to unexpected high fault currents and possible islanding occurrences [2]. These impacts affect the existing protection system, especially relay and auto-recloser timing when islanding occurs. An island may occur when an upstream main breaker opens manually or automatically to isolate faults or troubles. This island may sustain if the DGs generation in the islanded system have a close match with the load demand. This scenario represents the most challenging case for anti-islanding detection schemes [3]. If this sustainable islanding is not detected, it may cause severe over voltage, operating power quality problems, create safety hazards, damage customers’ loads and harm DGs during main breaker out-of-phase reclosing without synchronization [4]. Thus LDCs do not allow sustainable islanding and request disconnecting DGs in the islanded system as fast as possible as recommended by IEEE specifications [5]. Some of the available anti-islanding techniques are illustrated in [3], [6], and [7].

This paper compares the operating times of islanding detection schemes using laboratory testing on commercial relays. Passive local detection and communication-based schemes are evaluated. Various relay functions are tested for the passive local detection scheme. For communication-based schemes; direct fiber optic, radio frequency communication, and internet connection are examined. The islanding detection time and disconnection of DG has to be done before the action of an existing auto-recloser, following a main breaker opening either for manual switching or due to a fault in the system. The evaluated anti-islanding detection schemes are discussed in Section II. In Section III, the radial distribution system and the laboratory scheme setups under study are presented. The obtained results are illustrated in Section IV. In Sections V and VI, a comparison summary and conclusions are discussed.

II. ANTI-ISLANDING DETECTION SCHEMES

Anti-islanding detection schemes vary from local detection to communication-based. Local detection includes active and passive schemes. They are located on DG sites and operate if the local electrical information (voltage and current signals) exceeds certain predetermined thresholds. Active local detection scheme injects a periodic small fault disturbance to the main system and detects islanding by local measurements. However, this disturbance injection affects system power quality [4] and thus is not examined in this study. On the other hand, passive local detection operation is based on system parameters’ measurements. It does not impact the main system electric parameters. It operates due to a change in DG voltage, frequency or both resulting from a sudden change of its loads caused by an islanding process. Some of the electrical information used at the instant of island occurrence is shown in Fig. 1:

1) Over/under voltage (OV/UV) and over/under frequency (OF/UF) caused by a reactive and active powers imbalance between DGs and loads respectively [4].
2) Rate of change of frequency (ROCOF) [4] and [7].
3) Phase-angle-vector-shift (Vshift) [4].
4) Voltage magnitude variation [6].

Although, passive local scheme is inexpensive, it suffers from non-detective-zones (NDZ) depending on the type of DGs.
On the other hand, communication-based schemes do not depend on DG technology. They are implemented on the LDC side to communicate the LDC and the DG relays to trip DGs when an island occurs. Several communication-based techniques (Fig. 1) are in practice. In this study, three media will be evaluated: direct fiber optic, radio frequency, and Internet connection which have several advantages such as:

a) They work even with de-energized sound power-lines.
b) They do not have NDZ or impact the system power quality.
c) For radio frequency techniques, the signal is used to continuously check the connection establishment.

However, they suffer from:
1) High cost due to implementation of direct fiber optic connection,
2) Cost of radio transceivers for radio frequency,
3) Radio frequency schemes require line-of-sight,
4) Network delay in case of Internet connection.

II. APPLICATIONS

A. Radial Distribution System under Study

A practical radial distribution feeder (shown in Fig. 2) is used to implement both passive local detection and communication-based schemes. The feeder is equipped with a six 1.8 MVA SEIG-WT units located 15 Km away from the main breaker. The system is simulated on PSCAD/EMTDC with PI feeder sections, capacitor bank, a main feeder breaker with an automatic recloser, and loads and transformers at different voltage levels. The SEIG-WT is simulated as a coherent unit (10 MVA capacity with their associated capacitor) running at unity power factor. A delta/star grounded ($\Delta/\gamma$) 27.6/0.6 kV transformer is used to interconnect the SEIG-WT to the main feeder at the point of common coupling (PCC). Two commercial relays (DG_Relay_1 and DG_Relay_2) were used for testing passive local detection and communication-based schemes under study respectively. These relays were assumed to be connected to PCC. The DG breaker is assumed to be completely open after receiving a signal from the DG’s Relay (DG_Relay_1 or DG_Relay_2) in 50 ms. The feeder’s main breaker has 500 ms reclosing time characteristic. Therefore, the LDC aim is to disconnect SEIG-WT in a maximum of 300 ms from the disturbance event inception time.

Fig. 2. The LDC’s radial distribution system under study

B. Steady-State and Disturbance Events under Study

Installing SEIG-WT in the radial distribution system affects the steady-state PCC voltage, system voltage profile, as well as the current and active power fed by the SEIG-WT. Therefore, the system with SEIG-WT is examined to ensure that the electrical system parameters at steady-state operation lie within the LDC acceptable limits. In this study, the SEIG-WT penetration levels (PDG) are assumed to nearly match the distribution system loading (PL), which represents the worst scenario facing anti-islanding detection.

After validating the SEIG-WT steady-state operation, disturbance events were implemented to study the response of the two islanding detection schemes. In this study, a main breaker is assumed to be opened manually or due to a fault in the system, which will lead to an island condition. This islanding condition has to be detected and SEIG-WT should be disconnected as fast as possible. Two disturbance events may lead to a main feeder breaker opening as follows:

1) Manual Main Breaker Opening Case

The feeder’s main breaker is assumed to be opened without a fault. Therefore, no power is fed from the grid and an island is created which is still energized from the SEIG-WT.
2) Fault Case (Sustainable and Self-Cleared)

The feeder’s main breaker is assumed to open due to a fault in the system. Various ground faults are examined at two locations (F1 and F2) as shown in Fig. 2. The feeder’s main breaker is assumed to be completely opened at 100 ms from the fault inception. For sustainable fault events, the feeder’s main breaker remains open during the rest of simulation where an island is established. For self-cleared fault events, the system is subject to a temporary fault for 120 ms. Hence, an island is created with a temporary fault which is self cleared within 20 ms after the feeder’s main breaker completely opens.

C. Laboratory Scheme Setups

Two test sets were built to examine passive local detection and communication-based schemes in the power system protection laboratory at the University of Western Ontario. The times taken by these two schemes to disconnect SEIG-WT in case of an island are compared. Two commercial relays are assumed to be connected to SEIG-WT PCC. Although the IEEE standard 1547 defined the maximum time required for 10MVA DG relays to detect and de-energize the island within 2 s [5], in this study, the SEIG-WT should be disconnected before reclosing the feeder’s main breaker. These two test sets are described as follows:

1) Passive Local Detection Scheme Test Set

Fig. 3 shows the schematic diagram of the passive local detection scheme test set. The islanding condition is simulated using PSCAD/EMTDC by opening the main breaker manually or as a result of a fault (sustainable or self-cleared) as a disturbance event. The PCC voltage and current signals are saved in a ComTrade file format. This file is later sent to Real Time Player (RTP) to play it back. The analog signals are applied to DG_Relay_1 after being amplified. Thus, the recorded disturbance responses (relay operating time and pickup functions) can be examined.

2) Commercial-Based Scheme Test Set

The schematic diagram for the communication-based scheme is shown in Fig. 4. Three main communication media were used: Direct fiber optic, Radio frequency communication (without/with a repeater), and an Internet connection. In this study, a signal representing the starting of a main breaker to open, due to a disturbance event, is sent from the Main-Breaker Relay directly to the DG_Relay_2. The DG_Relay_2 operating time (set to operate instantaneously) was recorded after receiving a transmitted signal from the Main-Breaker Relay through different communication media. The three communication media tests are:

- **Direct Fiber Optic**
  A fiber optic wire was used to directly connect the Main-Breaker Relay and the DG_Relay_2 through fiber optic transceivers.

- **Radio Frequency Communication**
  A pair of radios (transceivers) was used. The Main-Breaker Relay is connected to a transmitter radio (master), while the DG_Relay_2 was connected to a receiver radio (slave). Furthermore, one repeater (two extra transceivers) was used for long feeders. It is important to point out that the implemented transceivers utilize the Mirror-Bit application, to continuously check the connection existence.

- **Internet Connection**
  A public Internet connection was used to transmit the signal from the Main-Breaker Relay to DG_Relay_2. The relays were connected directly to the Internet through an Ethernet card.
IV. ANALYSIS AND RESULTS

The previous discussed detection schemes and their laboratory set ups were tested and results were recorded as follows:

A. Steady State Operation

The steady-state operation of the radial distribution system under study was simulated without/with SEIG-WT. Table 1 shows the three-phase PCC voltages and SEIG-WT fed currents. The recorded electrical parameters were found to be within the LDC limits. Furthermore, the wind speed and the SEIG-WT capacitor values are listed.

### Table 1

<table>
<thead>
<tr>
<th>Tests</th>
<th>Voltage (PU.)</th>
<th>DG Current (AMP.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phase-A</td>
<td>Phase-B</td>
</tr>
<tr>
<td>No DG</td>
<td>1.037</td>
<td>1.032</td>
</tr>
<tr>
<td>With DG</td>
<td>1.044</td>
<td>1.043</td>
</tr>
</tbody>
</table>

### B. Disturbance Events (Passive Local Detection Scheme)

In the study, LDC specifications were used for setting the DG_Relay_1 five functions as follows:

1) Over current (OI) setting is 1.25 pu. of the SEIG-WT rated current
2) OV/UV settings are +/-10% of the nominal voltage
3) Vshift is set to be 10 degrees
4) OF/UF settings are +/-0.5 Hz of the nominal frequency.
5) ROCOF is set to two stages +/- 200 mHz/s

All tripping functions have a 20 ms delay time except the Vshift. Although, the detection of only one of the relay functions is sufficient to operate the relay, for multi-function relay, other functions are used to ensure relay operation. Two disturbance events were carried out as discussed below:

#### Manual Main Breaker Opening

The simulation was carried out and tested on DG_Relay_1 where the recorded detection times are reported in Table 2. Results indicate that DG_Relay_1 was able to detect this case and disconnect SEIG-WT. For relay operating functions, DG_Relay_1 correctly did not detect OI. On the other hand, the DG_Relay_1 was not able to detect voltage variations, since its frequency tracking algorithm was not able to track the system frequency causing a reset for the voltage detection function. Furthermore, DG_Relay_1 was not able to detect Vshift function as it was less than the relay setting. The setting for this function can not be lowered as it will detect the system transient which is not desired. Fortunately, both OF/UF and ROCOF functions were detectable by DG_Relay_1.

### Table 2

<table>
<thead>
<tr>
<th>Tests</th>
<th>OI</th>
<th>OV/UV</th>
<th>Vshift</th>
<th>OF/UF</th>
<th>df/dt</th>
<th>Detection Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>X</td>
<td>106.1</td>
<td>199.8</td>
<td>106.1</td>
<td></td>
</tr>
</tbody>
</table>

#### Sustainable and Self-Cleared Faults

A total of twelve fault disturbance events were simulated at both F1 and F2 locations. The main breaker was assumed to open due to single-, double, and three-phase fault events which lead to an islanding occurrence. For each fault event, the DG_Relay_1 receives the voltage and current signal shown in Fig. 3. The recorded DG_Relay_1 detection times and pick-up functions are shown in Tables 3 and 4. The Tables indicate that DG_Relay_1 was able to detect the twelve fault disturbance events and disconnect the SEIG-WT. However, some of Vshift and ROCOF functions were not detectable due to failure of DG_Relay_1 to track the high frequency changes which reset the frequency as well as the voltage functions.

### Table 3

<table>
<thead>
<tr>
<th>Fault types (Location)</th>
<th>OI</th>
<th>OV/UV</th>
<th>Vshift</th>
<th>OF/UF</th>
<th>df/dt</th>
<th>Detection time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-Phase (F1)</td>
<td>32.4</td>
<td>40.8</td>
<td>X</td>
<td>198.3</td>
<td>286.9</td>
<td>32.4</td>
</tr>
<tr>
<td>Two-Phase (F1)</td>
<td>36.7</td>
<td>45.2</td>
<td>53.6</td>
<td>152.9</td>
<td>241.6</td>
<td>36.7</td>
</tr>
<tr>
<td>Three-Phase (F1)</td>
<td>32.6</td>
<td>41.0</td>
<td>23.8</td>
<td>293.5</td>
<td>23.8</td>
<td></td>
</tr>
<tr>
<td>Single-Phase (F2)</td>
<td>44.5</td>
<td>44.5</td>
<td>19.1</td>
<td>202.0</td>
<td>290.7</td>
<td>19.1</td>
</tr>
<tr>
<td>Two-Phase (F2)</td>
<td>35.3</td>
<td>43.7</td>
<td>26.6</td>
<td>268.7</td>
<td>357.1</td>
<td>26.6</td>
</tr>
<tr>
<td>Three-Phase (F2)</td>
<td>32.6</td>
<td>41.0</td>
<td>23.8</td>
<td>167.1</td>
<td>X</td>
<td>23.8</td>
</tr>
</tbody>
</table>

### Table 4

<table>
<thead>
<tr>
<th>Fault types (Location)</th>
<th>OI</th>
<th>OV/UV</th>
<th>Vshift</th>
<th>OF/UF</th>
<th>df/dt</th>
<th>Detection time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-Phase (F1)</td>
<td>33.8</td>
<td>42.5</td>
<td>X</td>
<td>200.1</td>
<td>288.7</td>
<td>33.8</td>
</tr>
<tr>
<td>Two-Phase (F1)</td>
<td>37.2</td>
<td>45.7</td>
<td>54.1</td>
<td>153.4</td>
<td>242.4</td>
<td>37.2</td>
</tr>
<tr>
<td>Three-Phase (F1)</td>
<td>36.1</td>
<td>44.6</td>
<td>X</td>
<td>297.0</td>
<td>385.5</td>
<td>36.1</td>
</tr>
<tr>
<td>Single-Phase (F2)</td>
<td>45.8</td>
<td>45.8</td>
<td>20.4</td>
<td>195.0</td>
<td>439.1</td>
<td>20.4</td>
</tr>
<tr>
<td>Two-Phase (F2)</td>
<td>36.4</td>
<td>27.9</td>
<td>44.7</td>
<td>236.1</td>
<td>332.7</td>
<td>27.9</td>
</tr>
<tr>
<td>Three-Phase (F2)</td>
<td>35.5</td>
<td>43.9</td>
<td>18.6</td>
<td>169.7</td>
<td>X</td>
<td>18.6</td>
</tr>
</tbody>
</table>

Based on the recorded operating time of DG_Relay_1 in Tables 2, 3, and 4, DG_Relay_1 was able to detect manual main breaker opening and all fault disturbance events. Thus, no island can be sustained for a SEIG-WT.

#### C. Disturbance Events (Communication-Based Scheme)

Laboratory tests were carried out to examine various media for communication-based schemes according to point-to-point communication. Three media were tested: direct fiber optic, radio frequency communication (without/with a repeater), and an Internet connection. The time taken to transmit a signal between a Main-Breaker Relay and DG_Relay_2 is measured and compared for each of the media under study as shown in Fig. 4. An average value of the transmitted signal time is obtained from several tests to avoid any human or measurement errors. Table 5 shows the average time of the recorded transmitted signal trip time from the Main-Breaker Relay to DG_Relay_2. The direct fiber optic was found to have the least signal transmission time. The radio frequency using 38.4 KHz Baud Rate had higher times. On the other hand, the signal trip time based on Internet communication was found to be extremely high.

### Table 5

<table>
<thead>
<tr>
<th>Fault types (Location)</th>
<th>OI</th>
<th>OV/UV</th>
<th>Vshift</th>
<th>OF/UF</th>
<th>df/dt</th>
<th>Detection time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-Phase (F1)</td>
<td>33.8</td>
<td>42.5</td>
<td>X</td>
<td>200.1</td>
<td>288.7</td>
<td>33.8</td>
</tr>
<tr>
<td>Two-Phase (F1)</td>
<td>37.2</td>
<td>45.7</td>
<td>54.1</td>
<td>153.4</td>
<td>242.4</td>
<td>37.2</td>
</tr>
<tr>
<td>Three-Phase (F1)</td>
<td>36.1</td>
<td>44.6</td>
<td>X</td>
<td>297.0</td>
<td>385.5</td>
<td>36.1</td>
</tr>
<tr>
<td>Single-Phase (F2)</td>
<td>45.8</td>
<td>45.8</td>
<td>20.4</td>
<td>195.0</td>
<td>439.1</td>
<td>20.4</td>
</tr>
<tr>
<td>Two-Phase (F2)</td>
<td>36.4</td>
<td>27.9</td>
<td>44.7</td>
<td>236.1</td>
<td>332.7</td>
<td>27.9</td>
</tr>
<tr>
<td>Three-Phase (F2)</td>
<td>35.5</td>
<td>43.9</td>
<td>18.6</td>
<td>169.7</td>
<td>X</td>
<td>18.6</td>
</tr>
</tbody>
</table>
### TABLE 5

<table>
<thead>
<tr>
<th>COMMUNICATION-BASED SCHEMES</th>
<th>SIGNAL AVERAGE TRIP TIME (MS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct fiber optic</td>
<td>8.1</td>
</tr>
<tr>
<td>Internet</td>
<td>15.4</td>
</tr>
<tr>
<td>Radio frequency with a repeater</td>
<td>200</td>
</tr>
<tr>
<td>Radio frequency without a repeater</td>
<td>10.8</td>
</tr>
</tbody>
</table>

### V. COMPARISON SUMMARY

To calculate the total time from the disturbance event inception time to the complete disconnection of the SEIG-WT from the islanded system, the DG breaker opening time has to be added. As mentioned earlier, a typical DG breaker requires 50 ms to completely open after receiving a signal from the DG_Relay. Therefore, the 50 ms time has to be added to recorded times reported in this study (Tables 2 to 5). The time taken by the passive local detection and the communication-based schemes can be compared as follows:

**Manual main breaker opening**

Fig. 5 compares the SEIG-WT disconnection time after adding the DG breaker opening time to times in Tables 2 and 5. Furthermore, an extra 133 ms (representing the time taken by the main breaker to open) has to be added to recorded times in Table 2. Results show that all schemes under study were able to disconnect SEIG-WT within the maximum specified LDC time (300 ms). The direct fiber optic case represents the least disconnection time; however, it is considered to be very expensive especially if the DG is far from the Main-Breaker Relay. Using the radio frequency communication scheme was faster than the passive local detection scheme, but it requires line-of-sight which does not exist in all geographical areas. The Internet connection had high disconnection time as it suffers from network delay. On the other hand, the passive local detection had the highest disconnection time since it depends on the time taken by the main breaker to open.

**Disturbance Events (Sustainable and Self-Cleared Faults)**

Tables 3 and 4 show the time taken by passive local detection scheme (DG_Relay_1) to detect the islanding occurrence from the fault inception time. However, Table 5 reports the time taken to transmit a communication signal between the Main-Breaker Relay and DG_Relay_2. Therefore, to compare both schemes the Main-Breaker Relay’s fault detection time has to be added to the recorded results in Table 5. A typical LDC Main-Breaker Relay’s fault detection time was assumed to be 33 ms based on the LDC practice. Furthermore, to compare the SEIG-WT disconnection time with manual main breaker opening cases (Fig. 5), the DG breaker opening time (50 ms) has to be added to the recorded results (Tables 3 to 5) as shown in Fig. 6. The SEIG-WT disconnection times shown in Fig. 6 indicate that DG_Relay was able to detect and disconnect SEIG-WT for all disturbance events in a shorter time less than the LDC maximum specified time (300 ms). Furthermore, both schemes have a comparable SEIG-WT disconnection time except for the Internet communication-based scheme.

### VI. CONCLUSIONS

In this study the passive local detection and the communication-based schemes were tested to compare the time taken to disconnect SEIG-WT and prevent sustainable islanding. Results show that both schemes were able to detect and disconnect the SEIG-WT within the specified LDC practice time. Furthermore, no NDZ existed in the portrayed radial distribution system equipped with SEIG-WT.
REFERENCES


Walid El-Khattam (M’06) obtained his Ph.D. degrees in Electrical Engineering from the University of Waterloo, Ontario, Canada in 2005. He is currently working for University of Western Ontario as NSERC Postdoctoral Fellow. His area of research is distributed generation performance, planning, and protection.

Tarlochan S. Sidhu (M’90–SM’94–F’04) is currently the chair of the Department of Electrical and Computer Engineering, Professor and the Hydro one Chair in Power Systems Engineering at the University of Western Ontario, London, ON. His areas of research interest are power system protection, monitoring and control. Dr. Sidhu is a Fellow of the Institution of Electrical and Electronics Engineers, a Fellow of the Institution of Engineers (India) and a Fellow of the Institution of Electrical Engineer (U.K). He is also a Registered Professional Engineer in the Province of Ontario and a Chartered Engineer in the U.K.

Ravi Seethapathy (M’76) is currently Manager - Distributed Generation, and Advanced Grid Development, Hydro One Networks Inc. Toronto, Canada He sits on several T&D/DG committees at the PES/IEEE and CIGRE. He is also a Registered Professional Engineer in the Province of Ontario.