TRANSMISSION SYSTEM OPERATIONS DIVISION
SYSTEM SUPPORT DEPARTMENT
PROTECTION MAINTENANCE ENGINEERING

TESTING AND MAINTENANCE REQUIREMENTS OF
UNDERFREQUENCY LOAD SHEDDING SCHEME RELAYS
(FOR EXTERNAL USE)

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Note: The electronic copy of this document is the official version; it’s the responsibility of the reader to ensure that they are using the most recent revision.

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<thead>
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<th>Revision Number</th>
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1 Background

What is underfrequency load shedding? Underfrequency load shedding (UFLS) is a protection scheme used to maintain the stability of an electrical system through controlled load shedding in designated parts of the system when an event causes a significant drop in the system frequency. UFLS can prevent a total system blackout by removing the excess load that is compromising the balance between generation and load. If sufficient load is shed to preserve stability, system restoration can occur more rapidly.

How does generation and demand have an effect on the frequency of an electrical system? In North America, a balanced, stable system will have a frequency of 60 Hz. In an electric power system, generation and demand must be balanced. When generation is too high, system frequency will increase. When load demand is too high, system frequency will decrease.

Why is it important to maintain a nominal frequency of 60 Hz? Overloading a system will cause the system frequency to dip. When the frequency of a system decreases beyond a certain threshold, transformers and motors become inefficient and can overheat and become damaged. Damage would be costly for Manitoba Hydro and its customers.

How does Manitoba Hydro implement the UFLS scheme? Comprehensive system studies are performed at least once every five years or following any significant system changes per North American Electric Reliability Corporation (NERC) requirements. Designated parts of the system where load is to be shed are called shedding blocks. The comprehensive system studies determine the appropriate amount of load to be shed in each block and the system frequency at which that load needs to be shed in order to maintain system stability and avoid a system blackout.

There are numerous blocks with different frequency set points. When the system frequency decreases to the first frequency set point, this first block of load will be shed. If the system frequency continues to drop, more blocks will be shed in an effort to re-establish system stability.

What type of equipment is needed for UFLS and how does it work? A typical UFLS scheme consists of a frequency protection relay (81) that will operate one or more circuit breakers to shed load. The protection relay senses decreases in frequency and will send a signal to open circuit breakers when the frequency has been sitting at or below a set point for a specific duration of time (ride-through time).

Example: Assume a set point is 58.4 Hz and a Block Delay of 100 ms (6 cycles). This means that if the system frequency decreases below 58.4 Hz for 100 ms or longer, the protection relay will operate and trip the designated circuit breakers for that block. If the frequency decreases below 58.4 Hz for less than 100 ms, the protection should not operate.

Why is maintenance required on UFLS equipment? Maintenance on UFLS equipment is needed to ensure reliable operation of the UFLS Scheme. NERC has created an UFLS Maintenance Reliability Standard to address underfrequency load shedding equipment maintenance programs. NERC is a regulatory authority which has developed standards for electric utilities to assure the reliability and security of the bulk power system in North America. Manitoba Hydro must comply with NERC standards that have been adopted in Manitoba under the Manitoba Reliability Standards Regulation. In order to support compliance requirements, Manitoba Hydro customers, who are required to install UFLS equipment as part of the UFLS, must adhere to the testing and maintenance requirements identified in this document for this UFLS equipment.
2 Protection Relays and Test Equipment

2.1 Protection Relays

UFLS can be implemented using two categories of protection relays: single function protection relays and multifunction protection relays.

2.1.1 Single Function Protection Relays

Single function protection relays are typically solid state protection relays that have been manufactured only to perform one protection function. For UFLS, frequency protection relays (81) are used. Examples of such protection relays are listed below.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Underfrequency Protection Relay Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE</td>
<td>SEF</td>
</tr>
<tr>
<td>EMAX</td>
<td>SFR</td>
</tr>
<tr>
<td>ABB</td>
<td>ITE</td>
</tr>
<tr>
<td>PFR</td>
<td>PFR</td>
</tr>
</tbody>
</table>

2.1.2 Multifunction Protection Relays

Multifunction protection relays are typically microprocessor based protection relays that perform other protection functions while also having the capability to perform a frequency protection function used for UFLS.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Underfrequency Protection Relay Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEL</td>
<td>SEL-351, SEL-387</td>
</tr>
</tbody>
</table>

3 Equipment and Tools Needed for UFLS Relay Maintenance

3.1 Test Equipment

Test equipment is used to simulate voltage and current signals that occur in a power system so that protection relays can be tested for proper performance and function. When a protection relay operates in response to a simulated fault, an output signal from the protection relay is used to operate circuit breakers. This output signal of a protection relay is measured for timing by the sense input of relay test equipment. Manitoba Hydro uses Doble relay test sets for testing protection relays. Various other secondary injection test equipment from other manufacturers can also be used.

3.1.1 Doble F6150

The test set has six voltage and six current sources that are configurable. The maximum AC or DC output currents and voltages vary based on how many sources are configured by the user. The maximum AC or DC output current is 180 A for one source, 60 A for three sources, and 30 A for six sources. The maximum AC or DC output voltage is 600 V for one source, 300 V for three sources, and 150 V for six sources.
3.1.2 Other Test Equipment

Other test equipment can also be used if it is capable of performing the tests specified in section 4.3 of this document.

4 How to Test Underfrequency Load Shedding function

4.1 Test Setup

UFLS protection relays will have three settings. This section will explain how to test these settings using test equipment. Review the protection relay data sheet for location of the voltage input terminals and output contact terminals of the protection relay. In order to connect the protection relay to the test set, follow these instructions:

1. Connect the test equipment AC voltage output to the AC voltage input terminals of the protection relay.
2. Connect the output contact of the protection relay to the sense input of the test set.

When the connections are made, review the settings prior to testing. Record the setting values on the Underfrequency Load Shedding Maintenance Form (section 5.2) provided in this document.

4.2 Error Calculation and Tolerance

The formula for absolute error calculation is (frequency set point test)

\[ \text{ABSOLUTE ERROR} = (\text{Expected Result} - \text{Test Result}) \]

The formula for percent error calculation is (voltage supervision set point):

\[ \%\text{ERROR} = \left| \frac{(\text{Expected Result} - \text{Test Result})}{\text{Expected Result}} \right| \times 100 \]

If the error or percent error is within the defined tolerance range, the result of a test would be a PASS. If the error or percent error is outside of the tolerance range, the result of a test would be a FAIL.
4.3 Required Tests

The following tests are required every 6 years.

The required tests for underfrequency load shedding schemes are:

- Frequency Set Point Test
- Voltage Supervision Set Point Test
- UFLS Trip Test
- UFLS Ride-Through Test
- Circuit Breaker Trip Test

Ensure all protection relay tests have passing results. If a test fails, corrective action must be taken followed by re-testing. Possible solutions include:

- Adjust test setup and/or tolerances as per applicable maintenance standards.
- Recalibrate relay.
- Replace relay.

Note: Due to setting resolution limitations in some relays, it may not be possible to pick a time delay setting that meets the requirements of the UFLS Trip Test and the UFLS Ride-Through Test. In that case, the UFLS Ride-Through Test takes priority.

- Select the shortest possible time delay setting that does not cause a trip during State 2 (Shedding Block Delay – 5%) of the UFLS Ride-Through Test.
- Increase the duration of State 2 (Shedding Block Delay + 5%) of the UFLS Trip Test to get the relay to trip.
4.3.1 Frequency Set Point Test

The trip frequency set point is the predetermined frequency value at which the protection relay will operate.

Using a Linear Ramp, frequency test (or equivalent), the frequency set point test point should be tested using the following parameters:

- Offset Frequency: 1 Hz above the frequency set point
- Frequency Limit: 55 Hz
- Offset Duration: 1000 ms (1 s)
- Ramp Rate: -0.02 Hz/s
- Tolerance: +/- 0.1 Hz

During the frequency set point test, nominal voltage of the protection relay should be applied. The offset frequency at the beginning of the test is 1 Hz above the frequency set point for a duration of 1000 ms (1 s). At the end of the offset duration, frequency will begin to ramp down at rate of -0.02 Hz/s until the output contact of the protection relay closes at the expected trip frequency.

A passing result should be within +/- 0.1 Hz of frequency set point.

Example:

Frequency Set Point: **58.4 Hz**
The test will pass if the result is between **58.3 – 58.5 Hz**
4.3.2 Voltage Supervision Set Point Test

The voltage supervision set point is the predetermined voltage magnitude. When the voltage of a system becomes unhealthy, the frequency protection relay should not operate when it is below the voltage supervision set point.

Using a Linear Ramp, voltage test (or equivalent), the voltage supervision set point test should be tested using the following parameters:

- Frequency: 1 Hz below the frequency set point (output contact should close at test start)
- Offset Voltage: Nominal system voltage
- Offset Duration: 1000 ms (1 s)
- ± Delta Voltage: 0.1 V
- Delta Time: 166.7 ms
- Voltage Limit: 0.0 V

During the voltage set point test, the frequency level that should be applied is 1 Hz below the frequency set point. The offset voltage at the beginning of the test is nominal voltage for a duration of 1000 ms (1 s). At the end of the offset duration, voltage will begin to step down by 0.1 V every 166.7 ms until the output contact of the protection relay opens at the expected voltage.

A passing result should be within +/-5% of the expected voltage set point.

Example:

Voltage Supervision Set Point: **65.0 V**
The test will pass if the result is between **61.75 – 68.25 V**
4.3.3 UFLS Trip Test

Objective: Prove that the relay trips when the freq. dip duration is 5% longer than the UFLS Block Delay.

Example: Assume a set point of 58.4 Hz, Block Delay of 100 ms.

Suggested test steps:

1. Start by setting the relay time delay to 100 ms.
2. Run the tests described below.
3. Adjust relay time delay as necessary to achieve desired test results.

Using a State Simulation test (or equivalent), the UFLS Trip Test should be tested using the following parameters:

State 1 (Prefault):
- Amplitude (voltage): nominal system voltage
- Frequency: 60 Hz
- Duration: 120 cycles

State 2 (Fault/disturbance & Timer Start):
- Amplitude (voltage): nominal system voltage
- Frequency: 1 Hz below frequency set point
- Duration: 100 ms plus 5% (105 ms)

State 3 (Postfault):
- Amplitude (voltage): nominal system voltage
- Frequency: 60 Hz
- Duration: 120 cycles

During each state of the time delay pick up test, nominal voltage is applied. State 1 will run for 120 cycles at a frequency of 60 Hz. State 2 will then run at a frequency that is 1 Hz below the frequency set point for the time duration of the shedding Block Delay plus 5%. The timer will start in State 2. State 3 will return the frequency back to 60 Hz for 120 cycles to end the test. **The relay output contact should close during the test.**

A passing result for this test is a “Trip”.
4.3.4 UFLS Ride-Through Test

Objective: Prove that the relay does not trip when the freq. dip duration is 5% shorter than the UFLS Block Delay.

Example: Assume a set point of 58.4 Hz, Block Delay of 100 ms.

Using a State Simulation test (or equivalent), the UFLS Ride-Through Test should be tested using the following parameters:

State 1 (Prefault):
- Amplitude (voltage): nominal system voltage
- Frequency: 60 Hz
- Maximum Duration: 120 cycles

State 2 (Fault & Timer Start):
- Amplitude (voltage): nominal system voltage
- Frequency: 1 Hz below frequency set point
- Duration: 100 ms minus 5% (95 ms)

State 3 (Postfault):
- Amplitude (voltage): nominal system voltage
- Frequency: 60 Hz
- Duration: 120 cycles

During each state of the UFLS Ride-Through Test, nominal voltage is applied. State 1 will run for 120 cycles at a frequency of 60 Hz. State 2 will then run at a frequency that is 1 Hz below the frequency set point for the duration of the shedding Block Delay minus 5%. State 3 will return the frequency back to 60 Hz for 120 cycles to end the test. The relay output contact should remain open during the test.

A passing result for this test is “No Trip.”
4.3.5 Circuit Breaker Trip Tests

The underfrequency load shed relay is designed to trip a number of circuit breakers in order to shed load. After the underfrequency load shed relay has passed all the tests described above, the relay can be placed back into service.

Before any trip testing can be done, refer to all the relevant prints (see appendix B for examples) associated with the underfrequency load shedding protection system to gain an understanding on:

- How to isolate the voltage signal of to the relay in service
- Where to inject the voltage signal (underfrequency fault conditions) into the relay while in service.
- How many breakers will need to be tested.
- How to isolate each breaker from tripping. (All breakers in the underfrequency load shedding scheme are to be tested separately.)

In order to perform trip testing for a specific relay, all breakers associated with that relay must be tested to ensure its performance in the underfrequency load shedding scheme. Ensure that clearances have been given to test and operate all circuit breakers in the underfrequency load shedding scheme. Review all prints, then refer to the following trip test example to trip test all breakers in the underfrequency load shedding scheme.

A passing result for trip testing is achieved when all breakers have been separately tripped by the underfrequency relay.
Trip Test Example for 3 Breakers (created using prints in Appendix B):

Prior conditions:

1. Test and Operate clearances given on Circuit Breaker 1
2. Test and Operate clearances given on Circuit Breaker 2
3. Test and Operate clearances given on Circuit Breaker 3

Procedure Details:

1. Isolate trip signals to the breakers
   i. Isolate (block) trip to Circuit Breaker 1
   ii. Isolate (block) trip to Circuit Breaker 2
   iii. Isolate (block) trip to Circuit Breaker 3

2. **Circuit Breaker 1 Trip Test**
   i. Close Breaker 1
   ii. Remove trip signal blocking from Circuit Breaker 1

3. Momentarily inject fault voltage onto the underfrequency load shedding relay
   i. Relay targets
   ii. Circuit Breaker 1 Opens

4. Reset relay and blocking
   i. Isolate (block) trip to Circuit Breaker 1
   ii. Reset relay target

5. **Circuit Breaker 2 Trip Test**
   i. Close Breaker 2
   iii. Remove trip signal blocking from Circuit Breaker 2

6. Momentarily inject fault voltage onto the underfrequency load shedding relay
   i. Relay tripped (Target)
   ii. Circuit Breaker 2 Opens

7. Reset relay and blocking
   i. Isolate (block) trip to Circuit Breaker 2
   ii. Reset relay target

8. **Circuit Breaker 3 Trip Test**
   i. Close Breaker 3
   iv. Remove trip signal blocking from Circuit Breaker 3

9. Momentarily inject fault voltage onto the underfrequency load shedding relay
   i. Relay tripped (Target)
   ii. Circuit Breaker 3 Opens

10. Restoration
    i. Reset relay target
    ii. Remove test equipment
    iii. Remove all additional signal blocking
5 Maintenance Form

Manitoba Hydro customers, who are required to install UFLS equipment as part of the UFLS, must adhere to the maintenance and testing requirements for this UFLS equipment.

5.1 Underfrequency Load Shedding Maintenance Form Instructions

The maintenance form is a record of maintenance that will be reviewed to ensure proper testing and maintenance have been completed.

When all maintenance and testing is completed, fill all fields in the form, attach a single line diagram of the system that has been tested, and send the information via email or mail to:

Manitoba Hydro
Manager of Transmission Services
Transmission System Operations Division -453
360 Portage Ave
Winnipeg, Manitoba
R3C OG8

TransmissionServices@hydro.mb.ca
5.2 Underfrequency Load Shedding Maintenance Form

Customer Information

Company: ____________________________
City/Town: ____________________________
Phone #: ____________________________

Technician (Contractor) Information

Name: _______________________________
Company: ____________________________
Phone #: ____________________________
Email: _______________________________

Test Equipment Information

Calibration Date: ______________________

Protection Relay Information

Make: ________________________________
Model: ______________________________
Style: _______________________________
Serial #: ____________________________

Protection Relay Settings

Frequency Set Point (Hz) __________________
Voltage Supervision Set Point (Vac): ____________
Time Delay ____________________________
Other Settings (If Applicable) ____________
Protection Relay Test Result

<table>
<thead>
<tr>
<th>TEST</th>
<th>EXPECTED</th>
<th>RESULT</th>
<th>ERROR</th>
<th>TOLERANCE</th>
<th>PASS/FAIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Set Point (Hz)</td>
<td></td>
<td></td>
<td>+/- 0.1 Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage Supervision Set Point (Vac)</td>
<td></td>
<td></td>
<td>+/- 5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Delay –Pick Up (ms)</td>
<td>Trip</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Time Delay - Ridethrough</td>
<td>No Trip</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

Trip Testing
All Breakers in UFLS Scheme has been trip tested:

Final Checklist

Attach Single Line Diagram
Send Results to TransmissionServices@hydro.mb.ca

Note: If any of the above tests fail, immediate corrective action has to be taken by the customer to bring the performance of the underfrequency protection relay within specification.
6 Appendix A: Definitions and Acronyms

**Block Delay**: Time delay associated with a frequency set point in a UFLS scheme. An UFLS relay must operate if the frequency dip is longer than the Block Delay; it is not necessarily the operate time of the UFLS relay.

**Circuit Breaker**: A switching device that opens an electrical circuit to prevent damage to connected equipment in a power system.

**Cycle**: The change in an alternating electrical sine wave from zero to positive peak to zero to an negative peak and back to zero.

**Error**: The difference between a true value and protection relay setting (expected) value.

**Hertz (Hz)**: The unit of frequency defined as 1 cycle per second.

**Fault**: Abnormal condition in power system voltage or current.

**Frequency**: The number of times a sine wave repeats for electrical voltage and current. Measured in Hertz (Hz).

**Protection Relay**: A device designed to trip a circuit breaker during the detection of a power system fault.

**Load**: The electrical component of a circuit that consumes power.

**Output Contact**: The component of a protection relay that opens/closes to operate a circuit breaker.

**Microprocessor Protection Relay**: A protection relay that converts analog signals to digital signals for a microprosessor to to detect power system faults using software algorithms.

**NERC**: North American Electric Reliability Corporation.

**Protection function**: Specific types of faults in which a protective relay will operate. ANSI numbers are used to identify these functions. (e.g. 81 – Frequency Relay)

**PME**: Protection Maintenance Engineering.

**UFLS**: Underfrequency Load Shedding.

**Solid State Protection Relay**: A protection relay that uses analog signals with comparators and level detectors along with resistors, inductors, capacitors, transistors and IC’s to detect power system faults.

**T&O**: Test and Operate.

**Tolerance**: The acceptable range of values in which the measurement will be acceptable.

**Voltage input**: The terminals in which a voltage signal is connected to a device. The device will make operation decisions based on these measured analog signals.
7 Appendix B: Print Examples

Single Line Diagram example:
AC Schematic example:
DC: Schematic example:
Wiring Diagram 1 and 2 examples:
TESTING REQUIREMENTS OF UNDERFREQUENCY LOAD SHEDDING SCHEME

EFFECTIVE: 2017/01/23