A Case Study of Implementing a Stator Ground Protection Scheme at Long Spruce G.S.

Authors:

Kris Manchur, Manitoba Hydro

Gilberto Maioli, Hitachi Energy

Presented by:

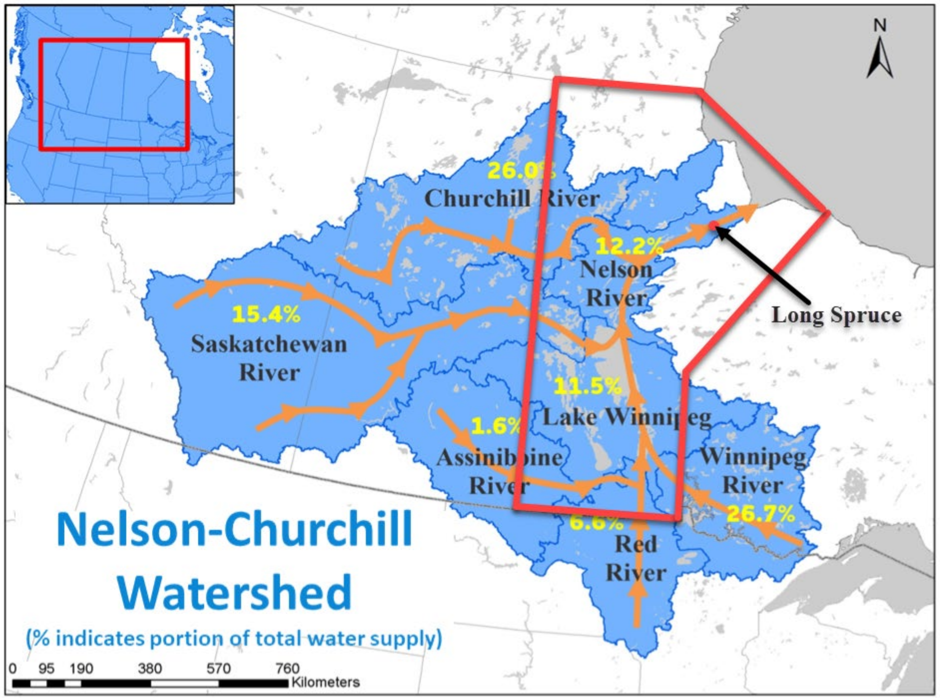
Benton Vandiver III, Hitachi Energy

Outline

- Introduction
- Principles of Operation
- Evaluation
- Design and Implementation
- Commissioning

Introduction

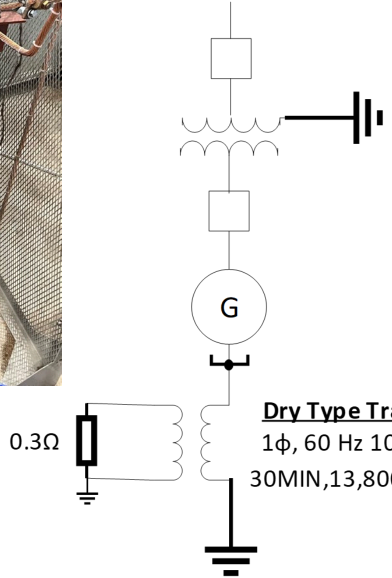
- Manitoba is in the center of Canada
- Population of 1.37 million (2019)
- Majority of load is in Winnipeg
- Sixteen Hydroelectric generating stations generating 6,100 MW



Introduction

- Long Spruce has 10 generators with an aggregate capacity of 1,010 MW
- 3rd largest generating station at Manitoba Hydro

Generator Grounding



Dry Type Transformer
1ϕ, 60 Hz 100KVA FOR
30MIN,13,800-120/240V

Stator Ground Fault Protection

- Began a protection replacement project in 2020 to upgrade all ten units from solid-state relays from the 70's
- Previous protection consisted of a 59N trip with a 3rd Harmonic voltage function alarm function
- New protection package consists of a 59N function in conjunction with an advanced injection-based protection scheme

Stator Ground Fault Issue

- Ground fault on the air gap of bar of slot 239 due to deteriorated stress control coating at the slot exit. This bar was the fourth bar from the line of circuit T3B (C-phase).
- 59G operated in approximately one second to clear the fault
- The Unit was out for one month

Evaluation

- A simplified model is used for the evaluation
- The simplified model is based on the absolute value of the total equivalent impedance to ground (Z_{tot}) on which the injection is performed.
- This equivalent impedance is equal to the parallel connection of the total equivalent capacitance Ctot and the primary equivalent resistance Rn(pri) of the generator neutral grounding equipment.

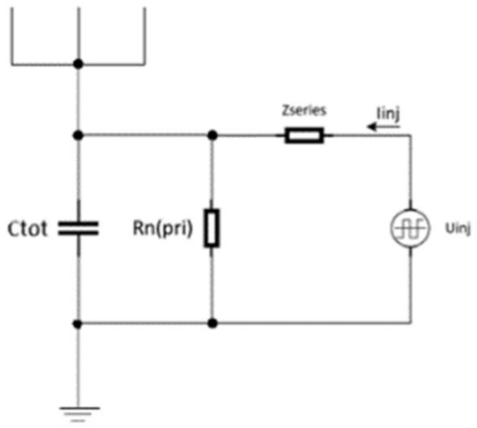


Fig 2. Equivalent circuit impedance

Evaluation

- If Ztot does not meet a minimum threshold, then there is a risk that the injected signal cannot be detected and the conventional design of injecting into the NGT cannot be used.
- The simplified model has limitations as it does not allow the definition of parameter settings in the relay used to detect a ground fault and changes to the performance of the protection function that can occur during various operating conditions.
- For this reason, the advanced injection-based solution requires installation and calibration procedures to define these parameter settings which are defined during the commissioning stage and based on the analysis of site measurements. These analyses are performed by the vendor using data provided by Manitoba Hydro.

Design and Implementation

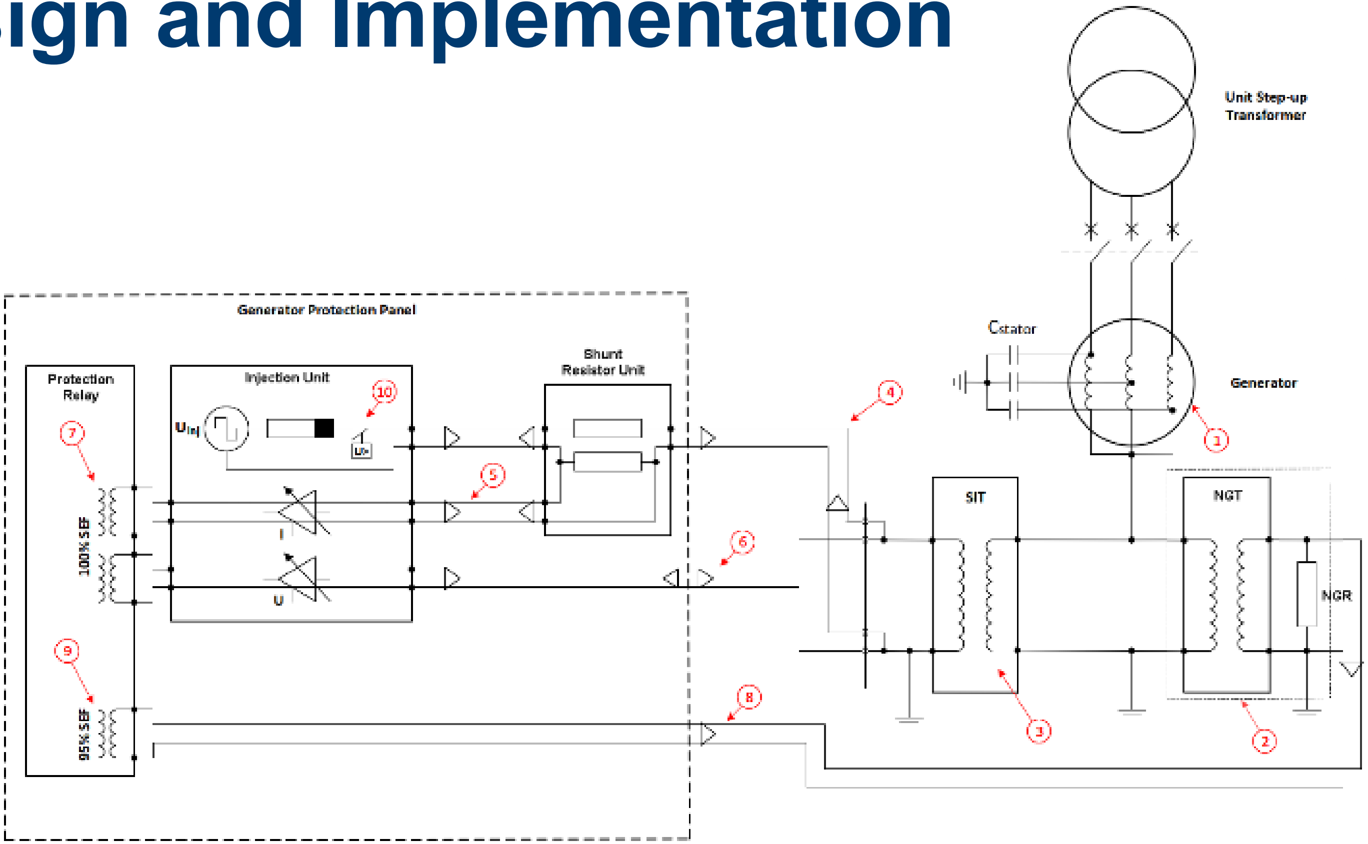
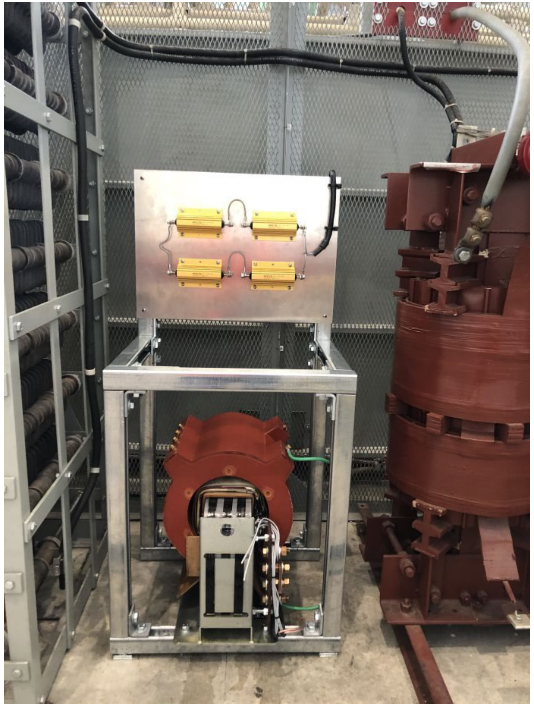


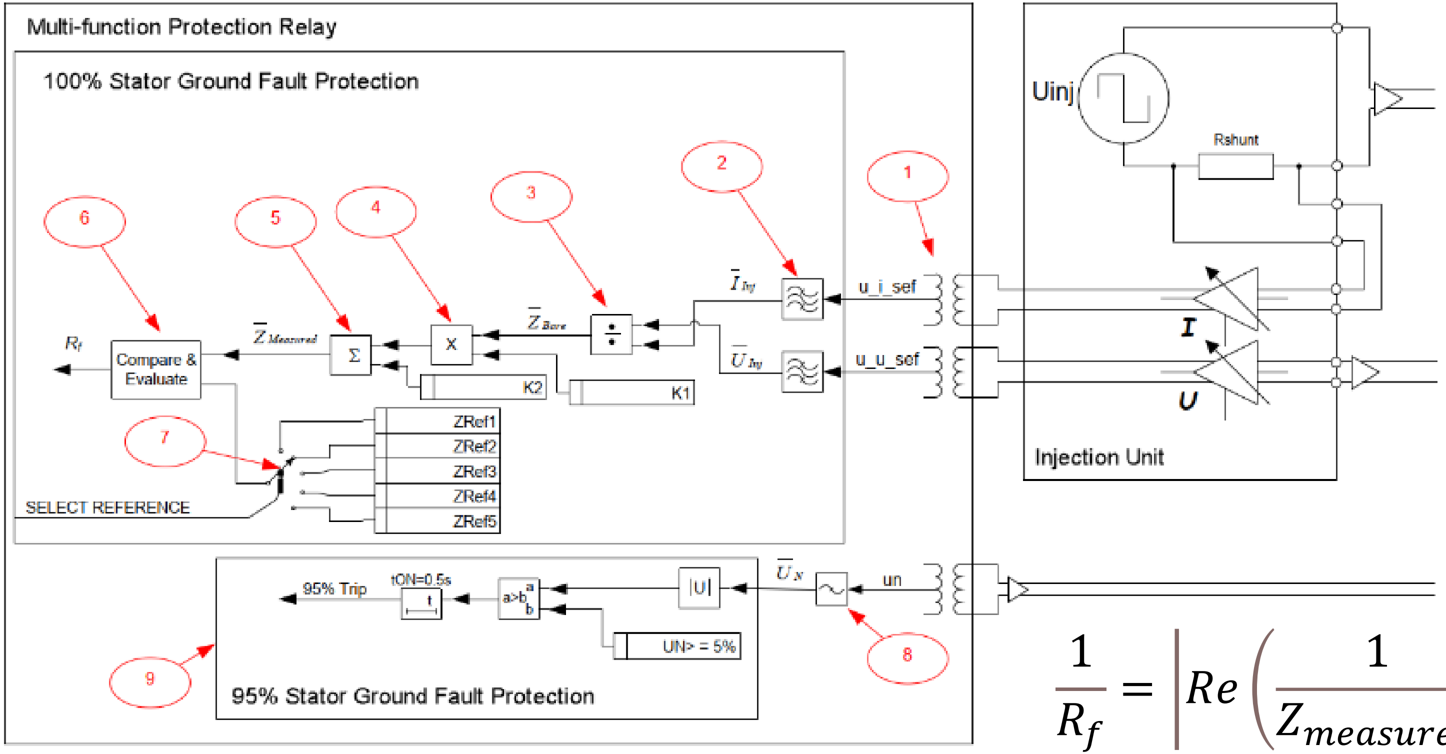
Fig. 3: Simplified Connection Drawing of the 100% Stator Ground Fault Devices

Design and Implementation

- A SIT is a dedicated injecting transformer connected in parallel with the NGT which is the additional hardware recommended by the vendor as the signal injection interface.
- The main advantage of injecting into an SIT as compared to an NGT is that it allows a more effective signal injection and eliminates the influence of small NGR values connected in the secondary circuit that limits voltage measurements.
- The SIT allows the injection of a Useful Signal into the generator neutral that is 5 to 10 times higher than without the installation of the SIT.



Design and Implementation



$$\frac{1}{R_f} = \left| Re\left(\frac{1}{Z_{measured}} - \frac{1}{Z_{ref}} \right) \right| \quad (\Omega)$$

Calibration and Commissioning

The commissioning of the 100% stator ground fault protection includes offline activities and online activities of the Injection Commissioning Tool.

Offline activities are:

- Installation procedure.
- Calibration procedure.
- Definition of additional reference impedances if they are needed.
- Applying test resistance tests to simulate ground faults to verify the behavior of the function.
- Analysis of results of the offline activities to confirm the defined parameter settings.

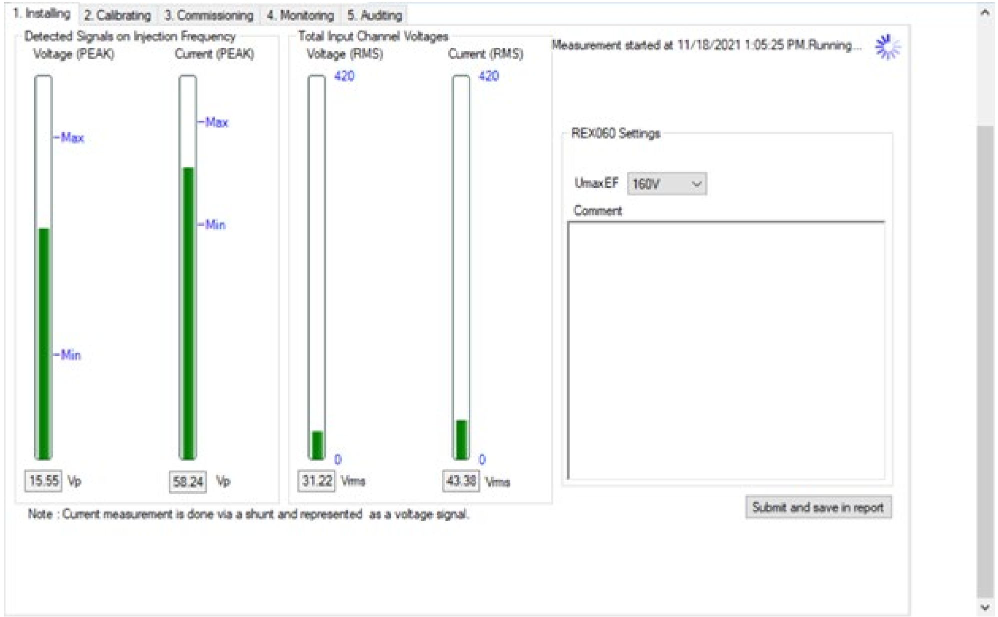
Online ICT activities are:

- Monitoring the complete sequence of generator operating conditions:
  Collect data with logging feature;
  Collect manually triggered disturbance recordings.
- Preliminary values of additional reference impedances that are defined by the ICT for each online operating condition of the generator.

Calibration and Commissioning Process

Installation Procedure

- Checks the status of the function and levels of the injected current and voltage
- Take voltage measurements of the shunt resistor unit and SIT to ensure they are within the expected ranges
- Set the injection frequency
  - 103 Hz is used at Long Spruce
- Define *UmaxEF* setting

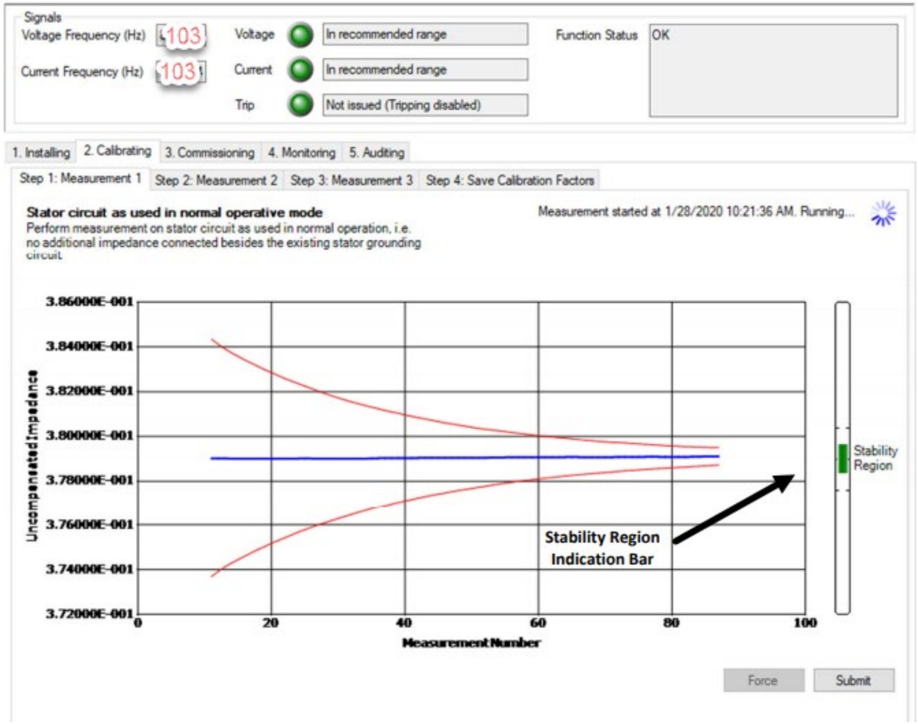


$$Umax = \frac{U_{g,\text{ph-ph}}}{\sqrt{3} * k_{\text{SIT}}} \text{ (V sec)}$$

Calibration and Commissioning Process

Calibration Procedure

- Performed by the ICT where the calibration of the parameters k1, k2, and reference impedance are presented.
- The ICT performs measurements in the following configurations to define the parameters:
  - Generator is in an off-line configuration with all grounding removed
  - A 500Ω calibration resistance is applied
  - A dead short is applied
- A three-check process is performed to ensure no errors and that the Useful Signal is above the minimum requirement.



Calibration and Commissioning Process

Definition of Additional Reference Impedances

Selection Logic Truth Table

If the following notation is used:

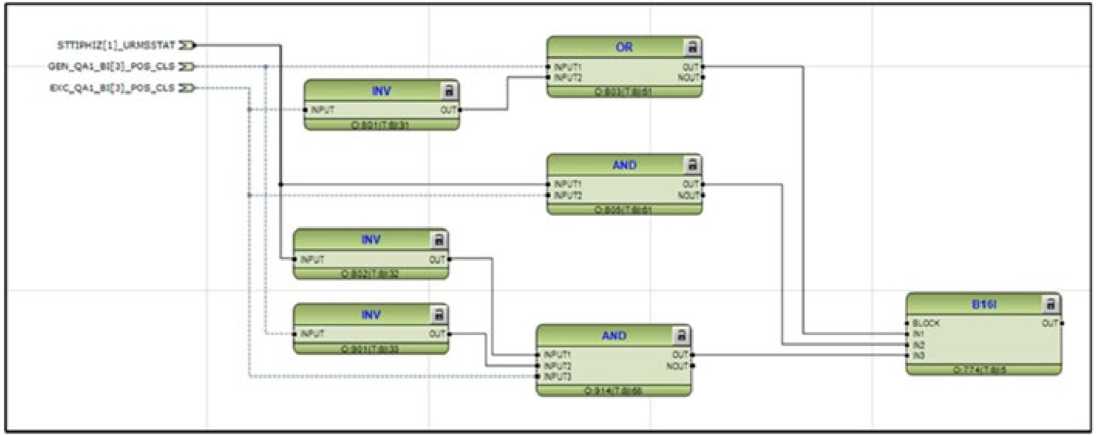
URMS = STTIPHIZ – URMSSTAT

GCB = Generator CB closed

FCB = Field CB closed

“+” = OR

“·” = AND



The following Boolean equations are extracted from the truth table:

$$B16I – IN1 = GCB + \overline{FCB}$$
$$B16I – IN2 = URMS \cdot FCB$$
$$B16I – IN3 = \overline{URMS} \cdot \overline{GCB} \cdot FCB$$

Calibration and Commissioning Process

STTIPHIZ - URMSSTAT	Generator CB closed	Field CB closed	B16I - IN1	B16I - IN2	B16I - IN3	RefZ	Operating conditions
0	0	0	1	0	0	RefZ1	Generator at standstill after trip
0	0	1	0	0	1	RefZ4	Generator during start-up, shutdown and at standstill after shutdown, if RMS neutral voltage is lower than 40V.
0	1	0	1	0	0	RefZ1	Not acceptable: the generator CB cannot be closed if the Field CB is opened.
0	1	1	1	0	0	RefZ1	Not acceptable: URMSSTAT is at "1" if the generator CB and the Field CB are closed
1	0	0	1	0	0	RefZ1	Not acceptable: URMSSTAT is at "0" if the generator CB and the Field CB are open
1	0	1	0	1	0	RefZ2	Generator at standstill before start-up and/or during start-up without/with excitation while the generator CB is open, if the RMS neutral voltage is higher than 40V
1	1	0	1	0	0	RefZ1	Not acceptable: the generator CB cannot be closed if the Field CB is opened.
1	1	1	1	1	0	RefZ3	Generator synchronized to the network and loaded

Calibration and Commissioning Process

Monitoring Procedure

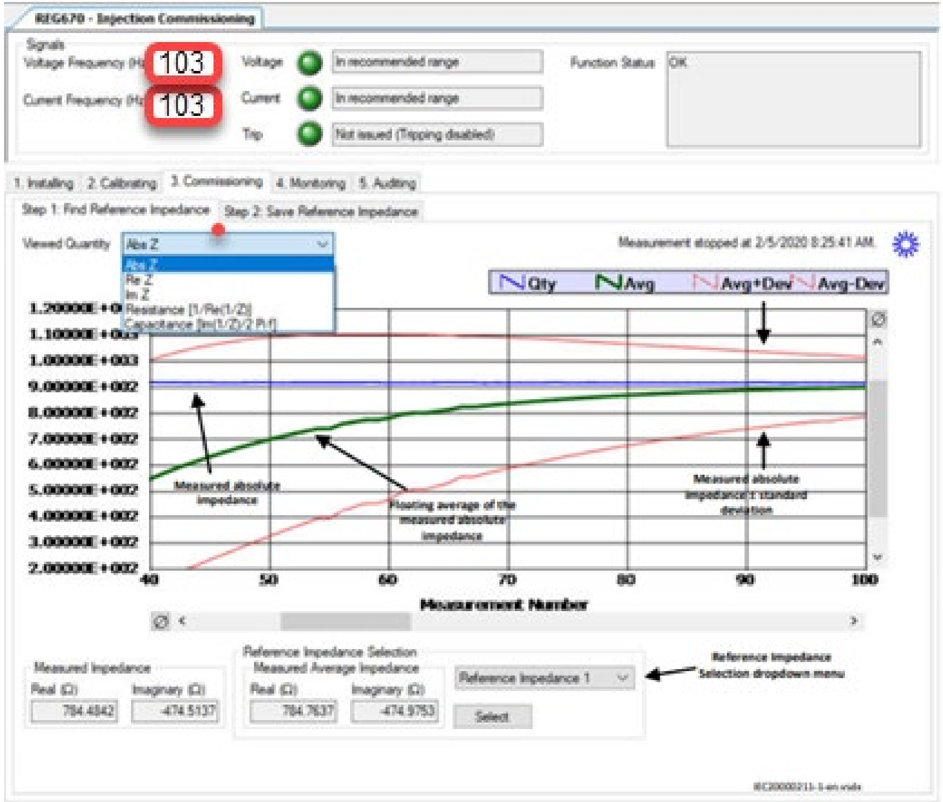
- Applying known fault resistances and comparing with the actual function measurement.
- Error is calculated to ensure its less than 10%

Off-line Staged Fault Readings						
Resistance Applied (Ω)	Disturbance Recorder Name	Alarm	Trip	Error %	Note	Measured Values
No Fault						
10,000						
9000						
7000						
5500						
5000						
4500						
4000						
3500						
3000						
2500						
2000						
1500						
1100						
1000						
900						
700						
500						
300						
100						
0 (Direct Short)						

Calibration and Commissioning Process

On-line Procedure:

- Preliminary values of the additional reference impedances that are defined by the commissioning software tool for each on-line operating condition of the generator are completed.
- The generator is run at 75% of full load for 1 hour to approach its normal operating temperature.
- When the generator is unloaded, a normal shutdown is performed, and disturbance recordings are taken during the shutdown and when the unit has stopped for 1 hour.



Calibration and Commissioning Process

- The purpose of capturing all the disturbance records and ICT log files is to analyze the following:
  - Verify no signals are interfering with the injected signals.
  - Check/define the reference impedances.
  - Check the behavior at switches between reference impedance.
  - Compare logfiles at standstill before the complete sequence and after the complete sequence.
  - Evaluate settings for Rtrip, Ralarm and tAlarm and apply.

Calibration and Commissioning Results

Confirm no signals are interfering with the injected signals.

Fig 5:
Injection On

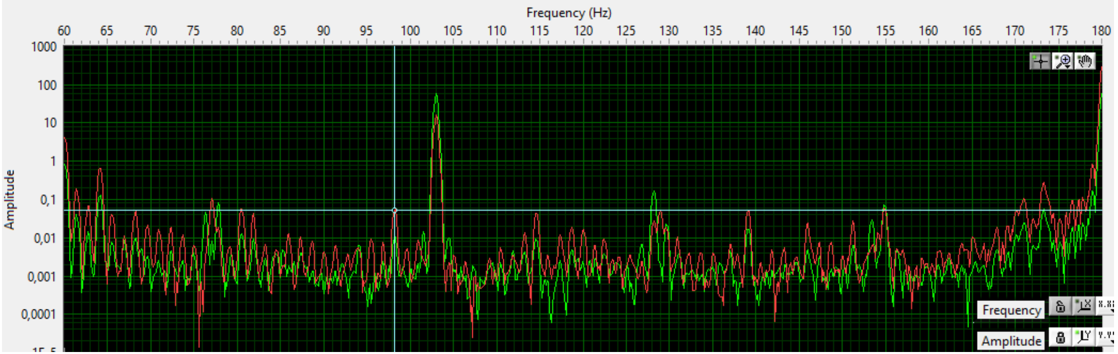
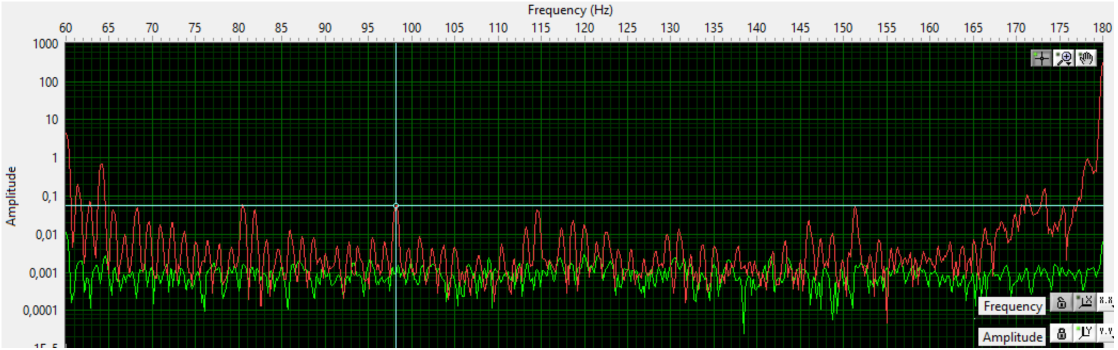


Fig 6:
Injection Off



Crosshair identifies a potential interference

Calibration and Commissioning Results

Check/define the reference impedances.

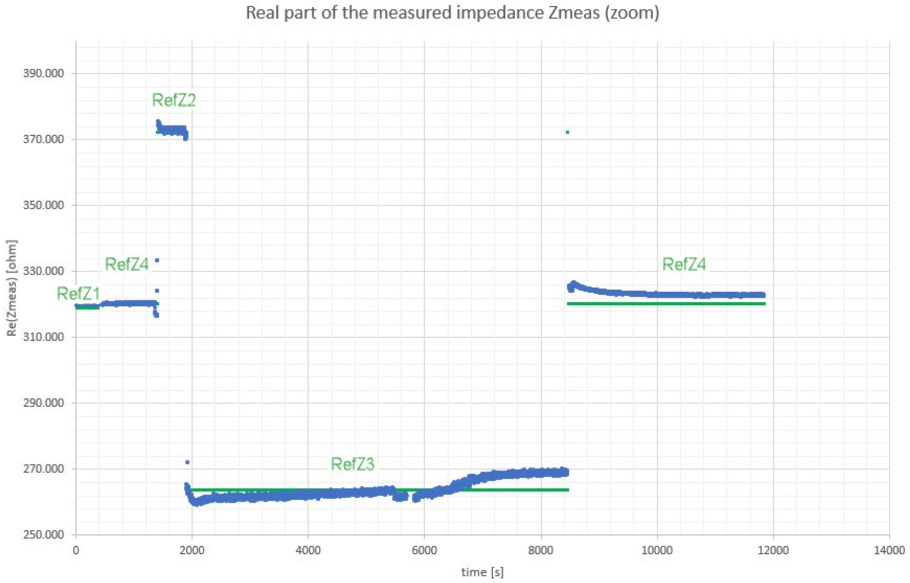


Fig. 7

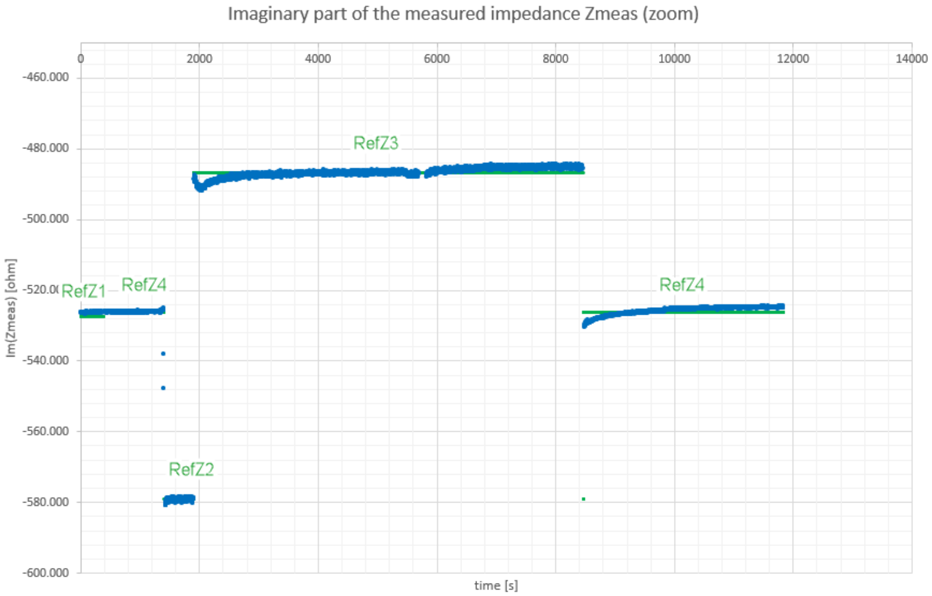


Fig. 8

Calibration and Commissioning Results

Check the behavior at switches between reference impedance.

> *When changing between the reference impedances, a short blocking time of the advanced injection-based stator ground function was added due to transient measurements caused by the transition between two operating conditions.* Disturbance records and log files are captured and analyzed to determine how long blocking delay is required.

Compare logfiles at standstill before the complete sequence and after the complete sequence.

Calibration and Commissioning Results

Evaluate settings for Rtrip, Ralarm and tAlarm.

The *FilterLength* parameter: important setting determined from the online data.

The filtering calculation does not use a normal Digital Fourier Filter, rather a special filtering algorithm that has the capability to extract accurately a signal with a selected frequency outputting it as the phasor with the highest magnitude within a certain “pass frequency band” around the set injection frequency. Two filter length values can be selected in the function: 1 second or 2 seconds.

Choosing the 2 second value:

Fig. 5 shows a voltage signal at 98 Hz that could interfere. This setting provide a pass frequency band around 103 Hz as ±1.8 Hz and the potentially interfering signal at 98 Hz is filtered out.

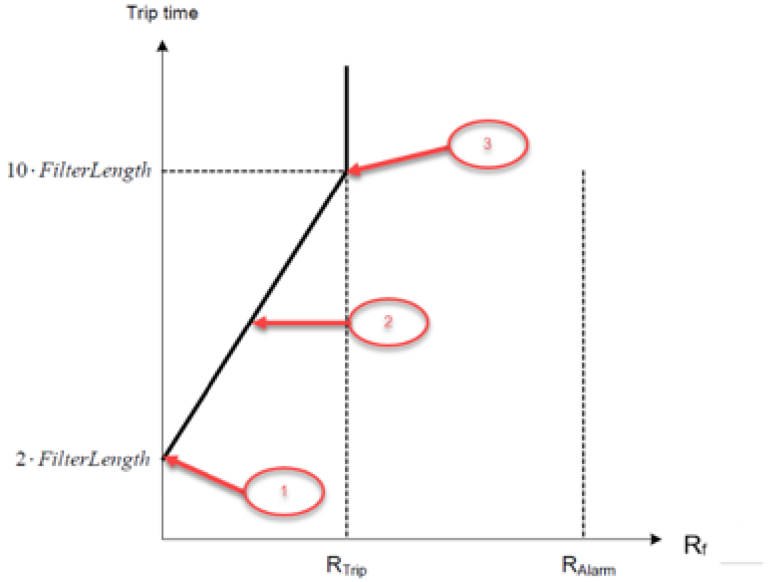
Calibration and Commissioning Results

Ralarm and tAlarm.

It was determined the minimum *FaultNoise Limit(*)* was 30kΩ corresponding to a maximum setting of 6kΩ for the alarm pickup. An alarm pickup setting of 5kΩ was used.

The definite time delay of the alarm is determined to be greater than 10**FilterLength* plus the time of the reference mismatch that can occur when switching between reference points. The alarm was set to a 30 second definite time delay.

*The alarm pickup setting for the advanced injection-based stator ground function is to be set lower than 20% of the *FaultNoise Limit* from the minimum R_f values that are calculated from each of the four defined reference impedances.



1. Trip Time is 2 x 2 = 4 seconds plus a tolerance equal to 1 *FilterLength*.
2. Trip Time is (0.016 x R_f + 4) plus a tolerance equal to 1 *FilterLength*.
3. Trip Time is 2 x 10 = 20 seconds plus a tolerance equal to 1 *FilterLength*.

Fig 9: Trip time characteristic as a function of fault resistance for Long Spruce

Calibration and Commissioning Results

The trip setting is based on all the following:

- Set below the mismatch reference impedance & reference switch.
- Typically set between 500Ω and 1kΩ.
- Coordination with the alarm setting, the trip setting is a maximum 50% below of the alarm setting.
- Below 20% of the Fault Noise Limit.
- Coordination with the neutral ground resistor.
- Result: A trip pickup of 1kΩ was selected and the time delay is based on the previous Fig 9 chart

Conclusion

Manitoba Hydro and the vendor went through an extensive and thorough process of evaluating and commissioning an advanced injection-based stator ground protection scheme at Long Spruce to provide 100% coverage of the stator winding.

Major challenge was a large total capacitance to ground and a small NGR value; implementing an injection-based protection design with strong signal strength at a frequency above 60 Hz with advanced filtering techniques to properly detect stator ground faults was accomplished.

This process has proven to be invaluable in gaining confidence on the reliable and correct operation of the overall ground protection scheme in different operating conditions and ensuring no disturbing signals interfere with the measuring of the SGP injecting signal.