Background Guide to Distributed Energy Resources Technical Interconnection Requirements at Voltages 50kV and Below

Functional

Distribution – Generation

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1 INTRODUCTION

The “Background Guide to Distributed Energy Resources Technical Interconnection Requirements at Voltages 50kV and Below” (the “TIR Background Guide”) is a guide that provides helpful background information for various sections of the main document, titled: “Distributed Energy Resources Technical Interconnection Requirements at Voltages 50kV and Below” (the “TIR”) — No. DP-12-001. The latter document outlines the technical requirements for the installation or modification of Distributed Energy Resources (DER) Facilities connecting in parallel or operating non-parallel to Hydro One Networks Inc.’s (“Hydro One”) Distribution System feeders at ≤ 50kV.

Starting with DP-12-001[1], the TIR focuses on providing customers and/or engineering consultants designing a DER Facility with only the necessary requirements to allow them to connect to Hydro One’s distribution system. Feedback from customers indicated previous revisions of the TIR were lengthy and provided background information, that although helpful for context, was typically not required from customer’s point of view when connecting a DER Facility to Hydro One. Based on the customers’ feedback, the decision was made to shorten the TIR document length and remove that information. The information, which was contained as appendices and various “Background” sections throughout the previous TIR, is now housed in this TIR Background Guide as a technical reference for those involved in DER technical interconnections. Minor changes, such as term updates, are included in this guide to ensure the content remains relevant and in-line with the TIR document.

To help reduce the repetition of information between the TIR Background Guide and the TIR, ensure this guide is easy to follow, and to keep this guide up to date, the information in this guide is organized as follow:

- All definitions, terminology, and conditions in the TIR also apply to TIR Background Guide.
- The TIR Background Guide includes a Table of Content that mostly mirrors the structure of that found in the TIR[2] with matching section numbers. Only sections with relevant background information are shown in the Table of Content of the TIR Background Guide. For instance, since section 1.1 of the TIR does not contain background information, hence, it is omitted from this guide’s Table of Content.
- The TIR Background Guide includes a Table of Figures and Table of Tables. The figures and tables are unique this document.
- Throughout the TIR Background Guide, references made to sections in the TIR document are explicitly stated as such. References to figures and tables refer to those within the TIR Background Guide.

[1] DP-12-001 R0 supersedes DT-10-015 R3
[2] Appendices are the main exception. They only appear in the TIR Background Guide’s Table of Content. They last appeared as part of DT-10-015 R3

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1.2 OBJECTIVES

1.2.1 Safety

Safety is of primary concern and shall be the main consideration when designing the DER Facility. The primary concern of the TIR is to provide interconnection specifications to ensure that safety will be maintained.

2 TECHNICAL INTERCONNECTION REQUIREMENTS

2.1 GENERAL REQUIREMENTS

2.1.4 Equipment Rating and Requirements

All existing Hydro One equipment in the distribution or transmission system shall not be overloaded beyond acceptable limits. All interrupting devices shall be capable of interrupting the maximum fault current under all operating conditions of the DER Facility. It must be ensured that conductors, voltage regulators, regulating stations, reclosers, circuit breakers, transformers, etc. in Hydro One's Distribution and Transmission System are operating within their respected ratings.

All regulating devices and metering devices which are designed for unidirectional power flow may need to be upgraded or replaced to ensure they are capable of handling bi-directional power flow.

2.1.5 Point of Common Coupling and Point of DER Connection

In addition to the items mentioned above, Hydro One will also carry out the engineering, design and construction required for additional changes to Hydro One's system in order to facilitate the connection of the DER Facility. The DER Owner may be responsible for some or all of the costs of such changes.

2.1.6 Customer Owned New Line

Distribution System reliability considerations dictate the requirement for overcurrent protection device to automatically isolate power system faults on the customer owned line. This is necessary to avoid prolonged interruption of supply to other customers on the feeder for permanent or recurring faults on a single customer-owned line. Fuses, reclosers, circuit switchers or circuit breakers may be used as an overcurrent protection. The selection of which will be determined by the specifics of the Distribution System and the connection configuration of the DER Facilities.

The use of single-phase overcurrent protection device in 3-wire systems might increase the probability of Ferro-resonance. For this reason, a three-phase gang-operated protective device is required for customer owned new line connecting to Hydro One's 3-wire systems.

Fault indicators are required on each phase of the customer owned new line, as a means to quickly identify a faulted phase on the customer's line.

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2.1.7 Isolation Device

To ensure a safe and reliable means of electrically isolating the DER Facility from Hydro One's Distribution System, an isolating device that conforms to OESC Section 84 and additional Hydro One requirements is required.

This point of disconnection is required for the purpose of work protection of Hydro One and DER Facility personnel. Operation of the isolation device shall not be a source of injury to the operator during operation, even when closed into a faulted system. It may also be used for breaker fail schemes.

The DER Facility isolation device, if motorized, must have a reliable uninterruptable power source. An AC motor supplied from the AC station service supply may be used to power the motor providing there is an auto-transfer from a DC/AC inverter. For example, if the HV disconnect switch (isolation device) motor is AC rated and powered from the AC station service and if all load derived from the AC station service are considered "non-critical", then, AC power may not be available when the HV disconnect switch is required to operate (example: backup to HVI breaker failure).

If the DER Facility consists of multiple generators, one disconnect switch must be capable of isolating all of the generators simultaneously. There may be other means of meeting this requirement and any proposals must be reviewed by Hydro One.

2.1.8 Interrupting/ Paralleling Device

Fault contribution from both the DER Facility and Hydro One's Distribution System shall be used to adequately size all fault current interrupting devices. Hydro One will provide present and anticipated future fault contribution levels from Hydro One's Distribution System.

For generators that have time variant fault contribution characteristics, the characteristics producing the highest fundamental component fault current shall be used – synchronous and induction generators shall use sub transient reactance to calculate fault contribution. Inverter based generators typically contribute fault current marginally higher than rated full load current (usually 1.2 to 1.5 times the rated load current of the inverter for self-commutated designs and less for line-commutated inverters). Depending on the design, the rotor of double-fed asynchronous motors may be shorted by crowbar action in response to severe faults causing the generator to behave like an induction generator.

The interrupting device shall have a maximum operating time such that when combined with the timings of other protection elements will ensure that the minimum clearing times are achieved. Appendix F contains sample timing diagrams.

2.1.10 Temporary Over-Voltage (TOV)

Connection of DER Facilities causes fault levels, fault current distributions and voltage profiles to change on the Distribution System. The extent of these changes depends on many factors associated with the Distribution System and the DER Facility connection. Those factors include but are not limited to:

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- Pre-fault voltages of the utility and generator sources;
- Type of fault;
- Fault resistance;
- Utility supply configuration and corresponding source impedances;
- DER Facility supply configuration and corresponding source impedances to the PCC. These are affected by:
  - generator capacity (MVA);
  - generator type(s) – synchronous, asynchronous (induction), inverters and static power converters;
  - the effective net generator impedances (that will likely change during various fault conditions and time periods);
  - generator ground connections;
  - DGIT winding configurations;
  - DGIT capacity and impedances;
  - DGIT ground connections; and
  - DER intermediate transformer impedances (where used).
- Fault location and feeder impedances:
  - Location of the fault in relation to the sources (circuit impedances between the fault and the sources); and
  - Location of the Distributor and DER Facility sources in relation to each other (circuit impedances between the sources)

A sufficiently comprehensive model of the distribution system and DER Facility connection characteristics is required to predict the extreme worst-case currents and voltages that will occur for various fault conditions. The CIA will determine this and the need for the DER Facility is to ensure that the interconnection will maintain the distribution system's effective grounding and shall not cause TOV to exceed allowable levels.

It should be noted that TOV is an issue not only when the DER Facility is islanded, but may also occur when the DER Facility is still working in parallel with Hydro One's Distribution System before Hydro One's breaker trips.

2.1.12 Interconnection Transformer Configuration

The interconnection transformer shall not cause voltage disturbances or disrupts co-ordination of distribution system ground fault protection. Since the winding configuration of any three phase transformer(s) between the DER Facility and Hydro One will have an impact on the distribution system, both under steady state and fault conditions, Hydro One has analyzed the different options and has standardized the DGIT configuration to a few specific alternatives. This section presents a description of the allowable transformer configurations for the connection of a DER Facility to Hydro One's 3-Wire and 4-Wire Distribution System. Other connections may also be allowed if they are electrically equivalent. Hydro One will accept any

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alternate proposals and if approved, will add them to the available options in this section. Written approval from Hydro One will be required for any alternate configuration. The DGIT may supply unbalance current to support the unbalanced load on the feeder. This unbalance current may be present even if the generator is out of service. The proportion of unbalance load current from the DGIT will vary based on the feeder topology, unbalanced loads, voltage and the DER Facility location.

2.1.12.1 DER Facility Interconnection to 4-Wire Distribution Systems

HONI requires that interconnections to the 4-Wire distribution system do not cause excess Temporary Overvoltages (TOV) and ground protections to become compromised. To achieve this, HONI requires that DGITs are effectively grounded. This will prevent the damaging TOV associated with high side ungrounded transformer configurations. However, this introduces a HV ground source which desensitizes HONI`s protections and increases ground fault short circuit levels. To minimize these effects, a neutral grounding reactor at the primary winding (HV) may be necessary to limit the ground short circuit current.

When HONI's feeder Low Set instantaneous protection operates, the HV ground sources along with the generators shall be disconnected. This allows the timed overcurrent protection on HONI's distribution system, such as feeder breakers, inline reclosers, and fuses, to detect all faults on HONI's Distribution System and coordinate properly after HONI's supply is reconnected. Please refer to Appendix A.9 for an explanation of HONI's Distribution System protection scheme.

Different options are provided for DER Owners to choose from when selecting the transformer winding configuration for their DER Facility. All are electrically equivalent with the exception of the option provided in Item (iii) for DER Facilities smaller than 1 MVA.

The Wye-Ground:Wye-Ground with a Delta tertiary is an option. The delta tertiary is required to limit the harmonic distortion to HONI's distribution system and to limit the TOV's on HONI's distribution system due to the introduction of the DER on the feeder if the generator is ungrounded or high impedance grounded. This configuration should eliminate the need for grounding transformers on both the HV and LV side of the DGIT.

DER Facility installations which utilize multiple transformers that step up the voltage directly to the distribution voltage level and connect to HONI distribution system through a common PCC may wish to utilize a DGIT with a HV Delta winding. This option will require a grounding transformer (zig-zag) to be connected on the HV side of the DGITs to limit the TOV on HONI's distribution system. This grounding transformer shall be sized by the DER Owner and reviewed during the Connection Impact Assessment. Since this makes this configuration electrically equivalent, an HVI is required to ensure all HV Ground Sources are disconnected from HONI`s Distribution System. This option may be preferable for inverter based DER Facilities as it may be more economical to use grounding transformers as opposed to neutral reactors due to the impedance required – Refer to Section 2.1.11 Item (ix) of the TIR for sizing requirements.

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If the option available to only DER Facilities smaller than 1 MVA is chosen, and if there is single phase reclosing upstream of the DER Facility on HONI's distribution system, consideration should be given to use 3 separate single phase transformers. This will eliminate the problems associated with backfeed onto faulted phases due to a shared magnetic core. Therefore, in the case of a downed conductor, without the presence of a HVI at the DER Facility to disconnect the transformer, the public would not be put at risk due to magnetically coupled voltage on the conductor.

The design of the DER Facility should take into consideration the possibility of ferroresonance due to the loss of one or two phases and shall take steps to ensure that the DER Facility is protected under such an occurrence.

2.1.12.2 DER Facility Interconnection to 3-Wire Distribution Systems

HONI's 3-Wire Distribution Systems have been designed to withstand phase to phase voltage magnitudes on all phase conductors and thus there is no concern of TOV for these connections. Since TOV is not a problem, HONI does not stipulate the need for an effectively grounded DGIT. If one is chosen, it shall be sized as required in the grounding requirements in Section 2.1.11 Item (x) of the TIR. An HVI shall be required in this case. In the absence of a HVI, an interrupting device(s) shall be installed on the LV side of the DGIT.

The design of the DER Facility should take into consideration the possibility of ferroresonance due to the loss of one or two phases and shall take steps to ensure that the DER facility is protected under such an occurrence.

Protection systems shall be designed accordingly to ensure that ground faults on HONI's distribution system are detected.

2.1.13 High Voltage Interrupting Device (HVI)

NOTE: For the purpose of the TIR, the term HVI will refer to interrupting devices on Hydro One side of the DER Interconnection Transformer (DGIT) – whether it is high voltage or medium voltage.

DER Facilities connecting to Hydro One's 4-wire distribution system require that the HV ground source is removed and thus, have a need for a high side interrupter. The only exception is for DER Facilities smaller than 1 MW which are connected through typical load transformers (Wye-Ground:wye-Ground) if it can be shown that they will not negatively affect Hydro One's protection systems. This connection is one of the options shown in Section 2.1.12.1 Item (iii) of the TIR and is allowable only if the CIA determines that TOV is not a concern with the specific DER Facility.

DER Facilities connecting to Hydro One's 3-wire distribution system through an HV Delta DGIT without the use of a grounding transformer do not require an HVI as no ground source is present that needs to be removed. For all other connections, an HVI is required. More information on allowable DGIT configurations and grounding requirements can be found in Sections 2.1.12 and 2.1.11 of the TIR respectively.

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This requirement is driven by the configuration of the DGIT and the need to remove the additional HV ground source from the distribution system before the 1st reclose to ensure that the DER Facilities will not adversely affect overcurrent protection devices on Hydro One's distribution system. The feeder and DER Facility HVI will be tripped for feeder faults or feeder islanding conditions (feeder breaker trips instantaneously and independently of DER Facility HVI tripping). Before the first reclose, all the generators and HV ground sources on the distribution feeder shall be disconnected from the feeder. Upon reclose, the feeder 51 & 51N timed overcurrent devices will co-ordinate with reclosers and lateral fuses on Hydro One's Distribution System since all current infeeds from the generators and the HV ground source are removed. Requirements for disconnection and reconnection to Hydro One's Distribution System following momentary and permanent faults can be found within Sections 2.4.6, 2.4.7, and 2.4.8 of the TIR.

An HVI is also required to prevent back-feed whenever single phase switching can occur upstream of the DER Facility on Hydro One's Distribution System. Refer to Appendix A.9 for more information regarding Hydro One's Distribution System protection practices and standards.

2.1.14 Station Service for Essential Loads

The DER Owner might classify loads at the DER Facility as being either "critical" or "non-critical" based on the outage frequency and expected duration of each outage. "Critical" loads may only tolerate a momentary loss of power and may include such loads as battery charging equipment, emergency lighting or equipment supplying safety or shutdown systems. The DER Owner may not deem any loads at the DER Facility as being "critical" for their operation.

The intent of the above requirements is to make the DER Owner be aware that the HVI at the DER Facility will be tripped from time to time, typically to clear faults on the distribution circuit, and may be out-of-service for longer periods during maintenance or severe disturbances of the distribution system. The HVI at the DER Facility will be required to remain open until the distribution circuit is re-energized and after the staggered restoration delay has expired as per Section 2.4.7 of the TIR. The DER Owner should recognize and accept these extended outages if all DER Facility's loads are supplied from the LV side of the DGIT. The DER Owner may also consider a backup generator to supply critical loads as an alternative to a dedicated station service supply.

If a separate station service AC service power source is obtained from either Hydro One or a local distribution company, the DER Owner shall ensure that the above station service AC power source cannot be electrically connected to the DER Facility's electrical system that is associated with the power transfer from the DER Facility to Hydro One's distribution system (example: the intent is to prevent reverse power from the DER Facility to the station service AC supply source and vice versa).

2.1.17 Insulation Coordination

Unavoidable transient overvoltages might occur on the Distribution System and the DER Facility due to lightning and switching surges. The DER Facility equipment must be protected as

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required against these voltage stresses to prevent equipment damage and to prevent the propagation of these transients into Hydro One's Distribution System. Overvoltage protection usually includes using station and line shielding against direct lightning strikes and surge arresters for all wound equipment.

2.2 PERFORMANCE REQUIREMENTS

2.2.2 Power Quality

2.2.2.1 Voltage

Hydro One's station LV bus voltages are regulated within 1.035~1.055 p.u. regardless of load levels. This ensures that the voltage anywhere in the feeder, including the PCC, is within 0.94~1.06 p.u. of the nominal voltage under normal operating conditions. To conform to the existing practice, DER Facilities shall not decrease the pre-connection PCC voltages under all normal operating conditions. During abnormal conditions, voltage variations may exceed the values.

Hydro One's Distribution System was designed to operate for unidirectional power flow (flowing from the substation to the customers). Voltage regulating devices were designed to correctly operate under these conditions. However, with the addition of DER Facilities into the system, the power flow can be reversed when the DER Facility is supplying power. This may inhibit the voltage regulators to properly regulate the voltage on the feeder. If there is a possibility of reverse power flow, regulating devices (line voltage regulators, regulating stations and transformer under-load tap changers at the Transformer Station (TS) or Distribution Station (DS)) on Hydro One's distribution system may need to be either upgraded or replaced with suitable devices that allow bi-directional flow. Note: Hydro One operates all voltage regulating devices on its distribution system to 125V ±1.5V on a 120V base.

Without DER Facilities, the short-term voltage fluctuation on Hydro One feeders are well below 1%, or half of the dead band of voltage regulating facilities. This ensures the voltage regulating facilities respond only to necessarily voltage fluctuations and the quality of supply to customers during normal (non-emergency) operating conditions. Existing DER Facilities connected to Hydro One's system have shown continuous minute-to-minute power fluctuations in the range of 10%~30% of their ratings and this would cause higher levels of voltage fluctuation. In order to maintain similar duty imposed on the voltage regulating facilities, and similar quality of supply to the customers, DER Facilities shall not contribute to feeder voltage short-term fluctuation by more than 1%.

The post-tripping voltage requirement of the DER Facility is consistent with the Transmission System Code and the IESO System Impact Assessment criteria. DER Facilities that do not have ride-through capability are likely to trip off due to a feeder fault close to the Station's LV bus, regardless of the feeder to which the DER Facilities are connected. This requires that reactive power drawn by the DER Facility at a given power output level and therefore lost

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immediately after the tripping of the DER Facility, should be minimized to prevent excessive voltage change before ULTC/feeder VR tap changers can react.

2.2.2.2 Voltage and Current Unbalance

Voltage and current unbalance are normal on many distribution feeders as they supply many single phase loads and thereby all three phases are never equally loaded. Phase voltage unbalance of 2% and phase current unbalance of 10-20% of total feeder load is common. Unbalanced loads that result in unbalanced phase voltages and currents can cause high neutral currents, negative sequence voltages and currents, zero sequence voltages, thermal overloading of transformers and three-phase motors, and can cause protective relaying to mis-operate.

To protect Hydro One's distribution system and customers, the DER Facility must not further deteriorate existing unbalance conditions at the PCC and the distribution system. The phase-phase voltage unbalance at the unloaded generator terminals of three-phase DER Facilities must not be greater than 1%. The DER Facility and its interconnection transformer's design shall take into consideration the unbalance current it may supply to support the unbalanced load on the feeder. This unbalance current may be present even if the generator is out of service. The proportion of unbalance load current from the DGIT will vary based on feeder topology, unbalanced loads, voltage and DER location. During abnormal conditions such as faults and single pole reclosing, the unbalance may be very high (current unbalance may be significantly higher than 20%) and it is up to the DER Owner to ensure that the DER Facilities are protected from damage due to unbalance.

Single phase DER Facilities connected to a single phase of Hydro One's distribution system are limited in size (kVA rating) due to the potential impact they may have on distribution system voltage unbalance.

2.2.2.4 Voltage and Current Harmonics

CAN/CSA C61000-3-06 details methods for evaluating the effects of a load or generation facility on actual network characteristics. Although the limits in stage 1 may be respected, DER Facilities must still ensure that global network effects are within the limits specified in CAN/CSA C61000-3-06.

2.2.2.6 Power Factor

Hydro One shall determine the required operating power factor of the DER Facility during the CIA study and shall specify this to the DER Owner. Typically, this operating power factor will be in the range of 1.0 to 0.95 leading (importing reactive power from Hydro One's Distribution System).

2.2.4 Resonance Analysis

The design of the DER Facility should include a careful examination of resonance. Resonance can cause damage to Hydro One's Distribution System, electrical equipment of Hydro One's customers, and the electrical equipment at the DER Facility.

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Ferro-resonance in a distribution feeder can take place, primarily, under single-phasing conditions on three-phase segments of feeders. In this case, overvoltages would last until anti-islanding, or open-phase protection removes all DER Facilities from the affected feeder.

2.3 PROTECTION REQUIREMENTS

2.3.1 General Requirements

The protection schemes shall be designed to detect the conditions presented in this section of this requirements document including but not limited to:

- balanced and unbalanced faults (line to ground, line to line, three phase) at the DER Facility and Hydro One's distribution system (entire distribution feeder that DER Facility is connected to);
- abnormal frequencies;
- abnormal voltages; and
- islanding conditions.

The protection schemes employed shall coordinate with Hydro One's distribution system protections and shall be designed for current and anticipated future fault levels. Dedicated communications may be required to facilitate timely clearing of faults. In some cases, communication facilities between the TS and recloser may be required to facilitate coordinated tripping and reclosing for all of the protective devices.

Protections must not be interlocked with the position of any isolating/interrupting devices. This avoids un-necessary protection complexity that would cause reliability to be compromised.

All protection operations shall ensure that the DER Facility's generator(s) and all sources of ground current are tripped within the required time from the start of the disturbance. For DER Facilities utilizing a DGIT with Wye-Ground configuration on the high voltage side (refer to Section 2.1.12 of the TIR), both the DGIT and the generators must be tripped within the required clearing time (refer to Section 2.1.8 of the TIR).

All protection scheme proposals will need to be reviewed and accepted by Hydro One.

2.3.3 Protection Operating Times

Example: For any phase and ground faults: "a maximum of 500ms from inception of the fault condition and islanding conditions for DER Facilities equipped with Transfer Trip". This time is measured from the start of the abnormal condition to the time the generator will cease energizing Hydro One's distribution system. This is a maximum clearing time and in certain instances, the clearing time may be more stringent. Hydro One will determine this in the CIA.

Timing diagrams for different events are shown for reference in Appendix F.

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2.3.4 Breaker Fail (BF)

Breaker Fail protection needs to be included in the DER Facility's interconnection protection design for both the High Voltage Interrupter and Low Voltage Interrupter to ensure that a breaker/interrupter failure will not disrupt Hydro One's Distribution System and/or the DER Facility by ensuring that faults are cleared in a timely fashion. A means of automatic backup isolation is required to allow quick restoration of the distribution feeder.

DESIGN CONSIDERATION

In normal operation, when the HVI isolates the facility, the motorized disconnect switch will follow, opening a short period afterwards. It can also be designed to open sequentially – motorized disconnect opens if the HVI does not OPEN following a trip initiation.

2.3.8 Open Phase Protection

Open-phase protections are required to detect open-phases condition between the Distribution System and a DER Facility to prevent uncontrolled voltages from appearing on the conductors isolated from the Hydro One source of supply. The probability of open-phase conditions is highest when the DER Facility is installed on a section of Hydro One's distribution system that utilizes single phase tripping.

Uncontrolled Voltage from Generation

Any connected DER Facility's generation will directly energize the phase conductor that is islanded from the Hydro One source, but the voltage will not be regulated and can be expected to deviate outside of acceptable limits.

Uncontrolled Voltage from DGIT Back-Feed

If the DER Facility's generation is not connected, the open-phase conductor can be back-energized from the remaining connected phases via the three-phase shared-core DGIT. This back-feed produces abnormal voltages (high or low). In some cases extreme over-voltages associated with ferroresonance can occur if the DGIT is ungrounded and there is significant phase-ground capacitance on the open phase circuit.

In both cases the voltage on the open-phase Distribution System conductors will pose a safety hazard to maintenance personnel and will not be maintained within acceptable limits.

Open-phase protections may also be used for a single-phase DER Facility to detect islanding condition.

In all cases the generators must be isolated from Hydro One's distribution system within 500ms to prevent the phase from remaining energized during recloser operations.

2.3.9 Feeder Relay Directioning

Non-directional over-current protections provide adequate protection for the clearance of downstream phase and ground faults for a radial (single source) distribution system feeders. These simple over-current protections include non-directional feeder relay over-current elements, inline reclosers and fuses.

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Connection of DER Facilities provides additional sources of fault current that can cause non-directional over-current protections to operate for reverse faults, upstream of the protected zone[7]. For these non-radial situations, directioning of the protections will be required to prevent operation for the reverse faults.

2.3.12 Anti-Islanding Protection

An electric island is a section of the distribution system which, when disconnected from the rest of the Hydro One system, remains energized by DER Facilities connected to the feeders. At the present time, Hydro One will not allow islanded operation. Anti-islanding protection is required to:

- ensure that Hydro One customers do not experience power quality problems;
- prevent out-of-phase reclosing between Hydro One's distribution system and the DER Facility
- reduce the risks of safety hazards caused by islanding; and
- add redundancy to other protections.

Anti-islanding protection may involve different protection functions. Each DER Facility connected to Hydro One's system shall contain this protection and must demonstrate that the DER Facility will not sustain an island longer than permitted. In certain installations, the installation of dedicated communications (transfer trip) and protection schemes may be required for anti-islanding protection and is discussed in Section 2.3.13 of the TIR. Appendix D has detailed information on Anti-Islanding Protection and discusses the different requirements for Transfer Trip. Please refer to this appendix for more information. Induction generators, due to the possibility of self-excitation, also have this requirement.

To facilitate the connection of DER Facilities 250kW and less, passive Anti-Islanding protections, specifically Rate of Change of Frequency and Vector Surge, may be considered as an interim solution until other effective low-cost alternate solutions are available and approved. These special considerations for DER Facilities less than 250kW have been made to enable these generators to connect with the associated risks of passive anti-islanding technologies without having to wait for an approved standardized solution.

DER owners that decide to connect without TT must understand the risks and shall accept the liabilities associated with adverse impacts caused by prolonged islanding of their generation for greater than 500ms.

The DER Facility, instead of using transfer trip for anti-islanding protection may use an approved Hydro One Anti-Islanding Protection Scheme. At present, there are tests being conducted and if and when any of these schemes are approved by Hydro One to meet anti-islanding protection requirements, they will be posted in this section in a future revision.

[7] Mis-operation will occur if the aggregate DER Facility fault in-feed exceeds the operational setting of the over-current protection.

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2.2.13 Transfer Trip

Hydro One utilizes transfer trip (TT) teleprotections to reduce and/or eliminate unacceptable conditions on the Distribution System. The criteria were established based industry standards in conjunction with acceptable risk tolerances.

Hydro One is aware of the cost associated with TT for its customer and is always looking for ways to reduce those costs when possible, while balancing the resulting system risks. For instance, for non-Exporting DER Facilities > 250kW and ≤ 3MW, described in in Section 2.2.13(vii) of the TIR, Hydro One is able to leverage the knowledge gained over the last several years along with technological advancements to be able to offer modified connection requirements under certain conditions provided that system anti-islanding, temporary over-voltage, protection coordination and reclose concerns are otherwise mitigated through system upgrades and/or other requirements.

2.3.14 Distributed Generator End Open (DGEO)

Distributed Generator End Open (DGEO) is a real-time signal that is continuously sent from the DER Facility to the Hydro One supply source breaker or recloser. It establishes the connection status of the generation equipment. Hydro One will utilize this signal for auto-reclose supervision of the TS feeder breaker or any upstream protective device. This will ensure that out-of-phase reclosing of the DER Facility does not occur.

2.3.15 Low Set Block Signal (LSBS)

A Low Set Block Signal (LSBS) is a transient signal that is sent from the DER Facility to the Hydro One supply source breaker or recloser, whenever a large DGIT is being energized. Detection of this signal transition at the Hydro One supply source breaker or recloser location will cause the most sensitive low-set (fuse-saving) protection to be temporarily blocked. This will prevent tripping of the Hydro One supply source during the period when there is large energizing inrush current due to the DGIT. Refer to Appendix E for more information regarding the LSBS signal.

2.3.16 DGEO and LSBS Design

The DGEO signal must be derived from the logical combination of all breakers/circuit switchers at the DER Facility interconnection between the DER Facility and the PCC necessary to establish connectivity of the DER Facility. DGEO is required at the Hydro One connection location to block closing of the breaker while the DER Facility is connected. DGEO may also be required to be sent as real-time-operating data to the OGCC, so the controlling authorities of the distribution system are aware of the connection status (as per Section 2.5 of the TIR). The momentary LSBS signal will always be sent just prior to reconnection, (near the end of the DGEO open condition).

“Design Considerations” and timing information can be found in Appendix E.

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2.4 OPERATING REQUIREMENTS

2.4.5 Single Connection Path

Alternate (abnormal) supply configurations may be required from time-to-time to circumvent planned or unplanned contingency situations (equipment failures, maintenance, upgrading and repairs) for the purpose of maintaining or restoring an adequate supply to load customers. DER Facility connections to alternate supply configurations would cause changes to short circuit levels, circuit loading, steady-state voltage profiles, transient overvoltages, protection coordination and DER island configurations.

DER Facility generation, if stipulated in their DCA, must be disconnected during alternate supply configurations unless specific provisions have been made by the CIA and implementation stages of the connection to assure the DER Facility can safely and reliably remain connected for the specific alternate connection according to all of the Technical Requirements outlined in the TIR.

Although other supply configurations may be of concern, the expected most common alternate Distribution System supply configurations that may not facilitate DER connection are as follows:

- Back-up supply of load customers from the adjacent TS feeder breaker (TS feeder tie switch closed);
- Back-up supply of load customers from another TS; or
- Extending supply to load customers connected to an isolated section of an adjacent feeder normally supplied from another source by closing a normally-open feeder-end switch.

The expected most common alternate Transmission System supply configurations that may not facilitate DER connection are as follows:

- Transfer of a TS or DS that is supplied from a single 115kV or 230kV circuit to another main terminal station that does not have adequate minimum load connected or does not have adequate TT facilities in place to prevent Wide-Area DER islands.

Different conditions need to be met before reconnecting to Hydro One's system, depending if the outage is a momentary outage or sustained outage or shutdown. They are explained in Sections 2.4.7 and 2.4.8 of the TIR. Automatic Reconnection of the DER Facility to Hydro One's system is subject to specific requirements which can be found in Sections 2.4.1, 2.4.7, and 2.4.8 of the TIR.

2.4.6 Automatic Disconnection of DER and HV Ground Sources

The DER Facility generation cannot remain connected to any part of the Distribution System in island mode, for many reasons, as outlined in Appendix D.

Hydro One uses a very sensitive high-speed low-set protection to clear the first occurrence of a fault on overhead circuits. This protection normally clears the fault from Hydro One in-feed in less than 100ms (from fault inception to breaker fault current interruption). Such rapid clearance

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is intended to be fast enough to minimize fault duration and equipment damage, and avoid melting fuses for the most common transient faults on overhead circuits such as lightning, wind and momentary foreign contacts. For overhead circuits, Hydro One also uses an automatic reclosure scheme that quickly re-energizes the circuit. The Hydro One feeder breaker or recloser is automatically reclosed after a short delay that allows time for transient faults to extinguish and motor loads to disconnect. For transient faults, automatic reclosure restores supply quickly to load customers to avoid prolonged outages[8].

Similarly, all DER Facilities must be disconnected quickly, to avoid the following:

- prolonged fault current contributions that could increase equipment damage and melt fuses;
- a sustained DER island condition;
- interference with successful Hydro One automatic reclosure that quickly restores supply to load customers for the most common transient faults; and
- asynchronous reclosure that can damage the generator(s) at DER Facility, other load customers connected to Hydro One's distribution system and/or Hydro One equipment.

At the time of manual or automatic reclosure, Hydro One low-set protection is temporarily blocked (typically for 10 seconds). This allows Hydro One timed protections to selectively isolate a faulted section of the feeder, should the fault be "permanent" (re-strike immediately after reclosure).

Additional sources of fault current from DER Facilities can reduce Hydro One in-feed to faults and cause current back-feeds. This would interfere with the time-coordination of the Distribution System protections for the selective isolation of non-transient faults. For this reason all DER Facility ground sources that can provide significant in-feed to faults on the Distribution System must be disconnected before the Hydro One source reconnects. A 500ms disconnection of DER Facility ground sources following protection operations should ensure that they will not be present when Hydro One re-energizes the circuit.

2.4.7 Automatic Reconnection of DER and HV Ground Sources

All DER Facility generation shall be disconnected following protection operations as outlined in Section 2.4.6 of the TIR.

The following outlines what must take place before the DER Facility can reconnect. Refer to Appendix G for a detailed sequence of events and timing diagram. Figure 10 illustrates a typical successful reconnection sequence for a transient fault. Figure 11 illustrates a typical lock-out sequence for a permanent fault.

As noted in Section 2.4.6 of the TIR, at the time of manual or automatic reclosure, Hydro One low-set protection is temporarily blocked (typically for 10 seconds). This allows Hydro One

[8] Typical reclosing times are 0.5 to 1 second for feeder breakers and 1.5 to 2 seconds for reclosers

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timed protections to selectively isolate a faulted section of the feeder, should the fault be "permanent" (re-strike immediately after reclosure).

Blocking of the low-set protection also prevents an immediate trip upon energizing, caused by the cumulative inrush current associated with energizing customer transformers and cold-load effects.

Hydro One feeder protections should be restored to their normal state (complete with the low-set protections enabled) approximately 10 seconds after a successful manual closure or automatic reclosure. Restricting auto-reconnection of DGIT to 15 seconds allows the Hydro One protections to return to their normal state prior to re-energizing the DGIT. That allows the load customers to be restored first without the additional inrush associated with re-energizing the DGIT.

For large DER facilities not equipped with an HVI, there may be a requirement to send out a Low Set Block Signal prior to closing of the disconnect switch to energize the DGIT. (Refer to Section 2.3.15 of the TIR for LSBS requirements.)

For persistent or re-occurring faults, automatic restoration attempts will be unsuccessful and the Hydro One supply will have to be manually restored. Manual restoration of the feeder will be attempted by the Hydro One Controlling Authority. That may occur within a few minutes where remote control is available. If a remote-controlled manual restoration attempt is successful, and within 15 minutes of the loss of supply, then DER Facility reconnection can proceed in accordance with Section 2.4.7 of the TIR.

If normal Distribution System voltages are not restored within 15 minutes, it is likely that there is a permanent fault or other serious problem with the Distribution System or Hydro One's Transmission System. This will require manual assessment and restoration by the Controlling Authority. All DER Facility automatic reconnection schemes must be disabled after 15 minutes to avoid interference with these restoration efforts.

DESIGN CONSIDERATIONS

Hydro One's feeder reclosers may have multiple reclose attempts to allow sectionalizers to operate to clear the fault. Some protective devices have as many as four reclose attempts before reclosing is locked out the Distribution System voltages must be stable within normal limits[9] for a continuous period of 15 seconds that will only occur after the final successful reclose. The healthy voltage time delay must be reset every time the feeder is de-energized.

The HVI automatic reclosing must initiate immediately following the 15-second healthy voltage time delay, and must be set between 0 and 15 seconds. For multiple DGITs, there may be a need to stagger re-energization to minimize the effects of inrush on Hydro One's distribution

[9] For normal limits refer to Appendix A.3 for details on operating characteristics of Hydro One's Distribution system)

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system and the resulting voltage sag and flicker. Hydro One shall assign the individual delay times if this is the case.

Protections for feeders with extensive underground cable sections are not likely to use instantaneous low-set protections and auto-reclosure, because cable faults are much more likely to be permanent requiring repairs. Automatic reconnection of DER Facilities would not be used for these configurations.

2.5 CONTROL AND MONITORING REQUIREMENTS

2.2.1 General

As DER penetration increases, it is more important for system operators to have timely information about the state of the distribution system. Hydro One requires DER customers to establish SCADA communication with Hydro One's Advanced Distribution Management System (ADMS) to reduce latency and achieve a cost-effective DER interconnection process. HONI's ADMS will be used to directly poll DER facilities for critical information related to the facility's connection status, energy storage status, power flow, and power quality. Alarming from DER Facilities will also provide HONI with confidence that customers' protective relaying systems are functioning and available to protect both customers' and HONI's equipment from damage in the event of abnormal system conditions.

Hydro One provides DER customers requiring SCADA with a Tabulation of Functions (TOF), which is a record of the communication settings and Distributed Network Protocol (DNP) configuration details. The TOF specifies a unique list of points for each DER Facility and generally consists of up to four primary type of DNP points:

i. **Alarms and Statuses (Binary Inputs)**

   Alarm points are used to convey loss/failure of the intertie protection or DER's main protection with a clear identification of the power system elements, including the DER unique Operating Designation (NC#), Hydro One supplying station and circuit.

   Status points are used to communicate connection status of an interrupting or isolation device (e.g. motorized disconnect switch), inverter (s), etc. They can also be used to communicate status associated with each control command (binary outputs). Other examples of statuses required may include but not limited to: statuses of individual generating units at the POC if flexible generation or special operations are required and charge/discharge (towards grid) status of the Energy Storage System (ESS).

ii. **Analog Telemetry (Analog Inputs)**

   Real-time measurements of power, current, voltage, and other analog quantities at the PCC/POC to ensure reliable operation of the distribution system.

iii. **Control Commands (Binary Outputs)**

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Binary Output commands provide HONI the ability control or adjust the DER devices or/and service parameters to manage the Hydro One distribution system.

The DER Facility shall be able to accept and execute binary outputs (control commands) issued by Hydro One. These can include, but not limited to:

a) HVI/LVI OPEN:

An Open command on the control point, HVI/LVI OPEN, shall open the HVI/LVI immediately.

No SCADA Close command from Hydro One shall be allowed or accepted by the DER Facility.

If multiple HVIs/LVIs are arranged in a parallel connection at the PCC/POC, the HVI/LVI OPEN command shall open all those isolation devices simultaneously to disconnect the DER from the distribution system. For Behind the Meter (BTM) or Load Displacement DER applications, the load can remain connected to the grid upon receipt of this command.

The HVI Open control command should also remove the HV ground source from the system.

b) DER Permit Generation (OFF/ON)

When “On,” this signal permits the DER to enter and/or remain in service. When “Off,” the DER must disable service (cease to energize) within 2 seconds. When the DER Permit Generation Off command is executed, the DER can remain in the cease to energize state, in which the DER shall not export active power to the POC, but small amounts of passive reactive power flow are allowed.

c) KW/MW Limit (OFF/ON)

This control point is used to turn Off/On the active power curtailment function to limit or stop the generation export. The actual limit set point is provided by the associated analog output “Allowed KW/MW (%) Limit.” When the mode is on, the associated set point becomes effective. When the mode is off, the DER can generate up to the lesser of its nameplate or contractual capacity.

Please note that Control type shall be configured as one-second pulse-on, exclusively, for all binary control points. Also, Interrupting Device Open and DER Permit Generation shall take precedence over KW/MW Limit (OFF/ON) and its associated set point Allowed KW/MW (%) Limit.

iv. Set Points (Analog Outputs)

Adjusting DER’s operating parameters, via set points, can improve the usage of the hosting capacity in DER interconnections and provide operating flexibility. The DER shall

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be able to accept and execute set points (Analog Outputs), such as Allowed kW/MW (%) Limit, issued from Hydro One.

Generally, the active power limit set point will be issued as a percentage of the nameplate active power rating. In cases where the DER is supplying loads at the DER Facility, the active power limit set point may be implemented as a maximum active power export at the PCC. The associated feedback analog signal, an analog input, shall be provided as dictated by the TOF.

Point Verification

All DNP points specified in the DER TOF template are subject to Point Verification (PV) testing prior to in-servicing the DER Facility. This commissioning activity usually takes place once DER local data reading and control command verification are completed through its gateway or RTU, and after the Link Test is completed. The PV involves end-to-end testing between Hydro One staff and DER personnel. It verifies the configuration and functions of each DNP point to ensure correct configurations on both DNP Master (Client) and Out Station (Server) instances.

2.9 COMMISSIONING AND VERIFICATION REQUIREMENTS

2.9.2 Commissioning and Verification Generic Requirements

IEEE Std. 1547.1 – "*Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems*" specifies the type, production, and commissioning tests that shall be performed to demonstrate that the interconnection functions and equipment of the distributed resources (DR) conform to IEEE Std. 1547.

2.10 MAINTENANCE REQUIREMENTS

2.10.1 Protection and Control System Equipment

Maintenance requirements are equivalent to what Hydro One requires for re-verification of its own facilities that have similar potential impact to the Distribution System.

3.0 REFERENCES

The list of references is provided in the TIR document.

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A APPENDIX A – HYDRO ONE SYSTEM CHARACTERISTICS *(INFORMATIVE)*

This section describes the characteristics of Hydro One's Distribution System and identifies aspects that must be taken into consideration when designing a generation connection. The DER Owner must be able to operate within the ranges specified in this section. In the TIR, Distribution System may refer to either three phase systems or single phase systems operating at voltages of 50kV and below – includes systems falling under the definition of distribution lines and sub-transmission lines. This section contains no requirements for the connection of DER Facilities and has been provided for informational purposes only.

A.1 GENERAL CHARACTERISTICS

Most distribution circuits or feeders in Hydro One's distribution system are supplied radially from a single substation (point of supply). In some areas, some feeders may have alternate points of supply, but will be operated with more than one source of supply only momentarily during switching operations. Hydro One's distribution feeders operate at the following voltages (phase-phase/phase-neutral): 44kV (3-Wire), 27.6/16kV, 25/14,4kV, 13.8/8kV, 12.48/7.2kV, 8.32/4.8kV, 4.16/2.4kV.

A.2 SYSTEM FREQUENCY

The nominal frequency of Hydro One's system is 60Hz. During normal operation (steady state), the frequency may deviate from 59.3Hz to 60.5Hz, or as supplied by the transmission system. Under contingencies the frequency deviations may be larger.

A.3 VOLTAGE

The CSA Standard CAN3-C235-83 "Preferred Voltage Levels for AC Systems, 0 to 50,000V Electric Power Transmission and Distribution" provides general guidance for the steady state service voltage levels on the distribution system. Customers supplied by the distribution feeder must have voltage levels in accordance with this standard, with and without distributed generation supplying power for minimum and maximum loading conditions. The operating voltages found on the distribution feeder vary depending on load variation, generation variation and contingency situations. Hydro One's standard for voltages on the Distribution System at the point of delivery during normal operation is typically in the range of +/- 6% of nominal voltage as shown in Table 1.

These values may be exceeded under abnormal conditions. Voltage transients and swells can occur on the distribution system at any time due to lightning strikes, single phase to ground faults, and switching, among others.

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Table 1: Voltage Limits 0 to 50 kV on Distribution System

Low Limit (% of nominal)	Nominal Voltage (%)	High Limit (% of nominal)
94	100	106

A.4 VOLTAGE REGULATION

Hydro One utilizes voltage regulating devices throughout the distribution system to maintain an adequate voltage profile along the feeders and ensure that customers receive voltages in the range specified in CSA Standard CAN3-235-83. These regulating devices include line voltage regulators, regulating stations and transformer under-load tap changers at the Transformer Station (TS) or Distribution Station (DS). Hydro One operates all voltage regulating devices on its distribution system to 125V ±1.5V on a 120V base.

A.5 VOLTAGE AND CURRENT UNBALANCE

Voltage unbalance due to unbalanced loading and single phase voltage regulation is typically under 2% but may be higher in some areas. The voltage unbalance is calculated using the root-mean square (rms) voltage levels at the fundamental frequency measured at the service entrance (Point of Connection) under no-load and no generation as in the following equation:

$$Voltage\ Unbalance\ (\%) = 100 \times \frac{V_2}{V_1}$$

$$where\ V_2\ is\ the\ negative\ sequence\ voltage\ (fundamental\ frequency\ component)$$
$$V_1\ is\ the\ positive\ sequence\ voltage\ (fundamental\ frequency\ component)$$

Current unbalance is usually 10-20% of total feeder load current but may be higher in some areas. During abnormal conditions such as faults and single pole reclosing, the unbalance may be very high (current unbalance may be significantly higher than 20%).

A.6 POWER QUALITY

In Hydro One's distribution system, all interconnected equipment must comply with Hydro One's standards for power quality. IEEE Std. 519, *IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems,* has been accepted by industry to provide guidance for appropriate performance and power quality limits such as voltage flicker and harmonic contribution limits. This standard states that the recommended practice for utilities is to limit individual frequency voltage harmonics to 3% of the fundamental frequency and the total voltage harmonic distortion (THD) to 5% on the utility side of the PCC.

A.7 FAULT LEVELS

Fault levels on Hydro One's distribution system vary greatly throughout the system and are in accordance with the Transmission System Code Appendix 2. Some factors such as location,

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generation pattern and contingencies all contribute to varying fault levels. These fault levels may also change with time as the system expands and new generation comes online.

A.8 SYSTEM GROUNDING

Hydro One's distribution facilities are typically operated as uni-grounded (for three-phase 3-wire systems) or multi-grounded (for three-phase 4-wire systems). The transformer neutral at the substation is either solidly grounded, without any impedance, or effectively grounded through a low impedance at the station through a neutral reactor, a resistor, or a grounding transformers to limit the fault levels on ground faults.

A.9 DISTRIBUTION SYSTEM FEEDER PROTECTION

The general feeder protection scheme utilized on Hydro One's distribution system where DER Facilities are connecting is described below for M Class feeders emanating from TSs. The feeder protections can be divided into three states:

High Set Instantaneous – Instantaneous protection for close-in feeder faults is usually set to the first tap on the feeder and traditionally employed High Set 50A/50NA elements. The current Hydro One standard for feeders with DER Facilities connected is to use the Zone 1 distance (21 – Phase & Ground) element to set the High Set Instantaneous protection.

Low Set Instantaneous – Instantaneous protection for faults on the entire length of the feeder. This is used primarily as a fuse saving scheme to clear transient faults before fuse elements start melting. It is traditionally utilized using Low Set 50B/50NB elements. The current Hydro One standard for feeders with DER Facilities connected is to use the Zone 2 distance (21 – Phase & Ground) element to set the Low Set Instantaneous protection.

Timed – Directionally supervised 51/51N overcurrent elements load/fault discrimination are used for timed protection of Hydro One's distribution feeders. They are set to detect and clear faults in their required zone. All timed overcurrent elements on the distribution system are coordinated with each other to ensure that a minimum number of customers are affected in the case of permanent faults. For the timed overcurrent elements to function properly, all DER Facility sources (both positive sequence and zero sequence sources) need to be removed from the distribution system – refer to the requirements in Section 2.1.13 of the TIR.

F Class feeders radiating from DSs have varying levels of sophistication in their protection schemes.

A.10 AUTOMATIC RECLOSING (FAULT CLEARING)

Hydro One's Distribution System utilizes automatic reclosing to quickly clear non permanent faults on the sub-transmission and distribution system, thus, quickly restoring supply. In general, feeder circuit breakers at Transmission Stations use single-shot reclosing. Reclosers at Distribution Stations and other locations along the distribution feeder may use single-shot or multi-shot automatic reclosing. Reclosers can trip a single phase, when single phase loads are

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connected to the feeder, or all three phases. If after a number of preset reclose attempts the fault persists, then the recloser will lockout and stay open (single phase or three phases will be tripped). The reclose “dead time” (time that the distribution line is de-energized between reclose attempts) varies depending on location and type of recloser. That data can be obtained from Hydro One along with all other relevant protection data.

A.11 PHASING

Conductor phasing may not be standardized and as such, the phase sequence and the direction of rotation can be obtained from Hydro One.

A.12 MULTIPLE SOURCE (NETWORKED) SYSTEM

In some areas of Hydro One’s Distribution System, there may be instances where portions of a distribution feeder are supplied from two different sources (such as during switching events). There is added complexity in these instances as the risk of out-of-phase reclosing for a DER Facility is now from multiple possible sources.

A.13 FREQUENCY OF INTERRUPTION

Hydro One’s distribution feeders are mainly unshielded overhead lines spanning vast distances. They are equipped with insulation levels adequate to withstand expected voltages. Lightning strikes directly to Hydro One’s distribution line result in flashovers of the insulators on the feeder and result in protection systems tripping the distribution line. The faults may be temporary in which case a successful reclose will occur. Most faults on overhead distribution lines are temporary in nature. If they are permanent, and they trip the line, repair crews are dispatched and repair the feeder.

Due to the vast distances of the lines and the possibility of frequent momentary trips, the DER Facility proponent may consider a design that will be suitable for these conditions such as auto-restart.

A.14 ABNORMAL CONDITIONS

Many disturbances can occur on the distribution system at varying frequencies. These disturbances can include, but are not limited to the following:

- Faults on the system;
- Frequency excursions;
- Partial or complete loss of load;
- Transient overvoltages – caused by lightning strikes or switching operations;
- Temporary overvoltages;
- Single phasing of the three phase system – caused by Hydro One’s protection equipment, switching or broken conductors; and

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- Ferroresonance overvoltages due to resonance conditions.

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B APPENDIX B – DEVICE NUMBER DESCRIPTION *(INFORMATIVE)*

The following is a list of relevant device numbers and their meaning:

21 - Distance Relay
25 - Synchronizing or Synchronism-Check Device
27 - Undervoltage Relay
31 - Separate Excitation Device
32 - Directional Power Relay
37 - Undercurrent or Underpower Relay
42 - Running Circuit Breaker
46 - Reverse-phase or Phase-Balance Relay
47 - Phase-Sequence Voltage Relay
49 - Machine or Transformer Thermal Relay
50 - Instantaneous Overcurrent
51 - AC Time Overcurrent Relay
52 - AC Circuit Breaker
53 - Exciter or DC Generator Relay
55 - Power Factor Relay
57 - Short-Circuiting or Grounding Device
59 - Overvoltage Relay
60 - Voltage or Current Balance Relay
61 - Machine Split Phase Current Balance
64 - Ground Detector Relay
67 - AC Directional Overcurrent Relay
68 - Blocking Relay
79 - AC-Reclosing Relay
81 - Frequency Relay
86 - Lockout Relay
87 - Differential Protective Relay
88 - Auxiliary Motor or Motor Generator
89 - Line Switch
90 - Regulating Device
91 - Voltage Directional Relay
92 - Voltage and Power Directional Relay

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C APPENDIX C – NEUTRAL REACTOR AND GROUNDING TRANSFORMER IMPEDANCE CALCULATIONS FOR DER FACILITIES *(INFORMATIVE)*

C.1 INTERCONNECTING TO HONI'S 4-WIRE DISTRIBUTION SYSTEM

For Inverter based DER Facilities connecting to Hydro One's 4-wire Distribution System, grounding transformers can be used to serve as a ground source whenever the DGIT winding configuration is not Wye-Ground:delta. Examples 1 and 2 are to provide the impedance calculations for Inverter based DER Facilities that require separate grounding transformers. As per Section 2.1.11 Grounding, the Zero Sequence Reactance (X_{DG0}) of the DER Facility should be about 0.6 times the base impedance, where the base impedance is calculated based on the total MVA rating of the DER Facility.

Example 1: **A 10MVA DER Facility is connected at 27.6kV**, **via ten parallel 1MVA DGITs, and the DGITs have Delta-connected 27.6kV windings.**

Base impedance = $27.6kV^2$ / (10 x 1MVA) = 76.2Ω,

Then the required Zero Sequence Reactance of the DER Facility is:

X_{DG0} = 0.6 x 76.2Ω ± 10% = 45.7Ω ± 10%

Therefore, if a separate 27.6kV zig-zag grounding transformer is used to serve as a ground source, the impedance of the grounding transformer should be 45.7Ω per phase with a tolerance of ±10%.

Example 2: **A 2MVA DER Facility is connected at 27.6 kV, via a single 2MVA DGIT**, **and the DGIT has Wye-Ground:wye-Ground windings.**

Base impedance = $27.6kV^2$ / 2MVA = 381Ω,

Then the required Zero Sequence Reactance of the DER Facility is:

X_{DG0} = 0.6 x 381Ω ± 10% = 228.6Ω ± 10%

Therefore, if a separate 27.6kV zig-zag grounding transformer is used to serve as a ground source, the impedance of the grounding transformer should be 228.6Ω per phase with a tolerance of ±10%.

The continuous rating of the grounding devices shall be able to handle the maximum expected voltage unbalance with margin. As per Hydro One's Conditions of Service, the voltage unbalance on Hydro One feeders can reach 5%. Therefore, the grounding device should be sized for a minimum of 5% continuous voltage unbalance. The short time (5 sec) fault rating shall be sized

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for the maximum fault current that will flow through the grounding device for a close-in fault.

For Inverter based DER Facilities connecting to Hydro One's 4-wire Distribution System, neutral reactors may be required to limit the fault current contributions from DER Facilities for ground faults on the interconnected feeder when the DGIT winding configuration is Wye-Ground:delta. Examples 3 and 4 are to provide the impedance calculations for neutral reactors that can be connected between the neutral of Wye-Ground:delta DGITs and the ground. As per Section 2.1.11 of the TIR, Grounding, the Zero Sequence Reactance (X_{DG0}) of the DER Facility should be about 0.6 times the base impedance, where the base impedance is calculated based on the MVA rating of individual DGIT. The size of neutral reactor (X_n) for each DGIT should be one third of the required Zero Sequence Reactance of the neutral reactor ($X_{0,NGR}$):

Example 3: **A 10MVA DER Facility is connected at 27.6kV**, **via ten parallel 1MVA DGITs, and the DGITs have Wye-Ground:delta windings.**

Base impedance = $27.6kV^2$ / 1MVA = 762Ω,

Then the required Zero Sequence Reactance of the DER Facility is:

X_{DG0} = 0.6 x 762Ω ± 10% = 457.2Ω ± 10%

Assuming the reactance of each DGIT is 0.05p.u. on a 1 MVA base,

Then the required Zero Sequence Reactance of neutral reactor is:

$X_{0,NGR}$ = (457Ω – 0.05 x 762Ω) ± 10% = 419Ω ± 10%

Therefore, the size of neutral reactor for each DGIT is:

X_n = 419Ω / 3 ± 10% = 140Ω ± 10%

Example 4: **A 2MVA DER Facility is connected at 27.6kV, via a single 2MVA DGIT, and the DGIT has Wye-Ground:delta windings.**

Base impedance = $27.6kV^2$ / 2MVA = 381Ω,

Then the required Zero Sequence Reactance of the DER Facility is:

X_{DG0} = 0.6 x 381Ω ± 10% = 228.6Ω ± 10%

Assuming the reactance of the DGIT is 0.05p.u. on a 2 MVA base,

Then the required Zero Sequence Reactance of neutral reactor is:

$X_{0,NGR}$ = (229Ω – 0.05 x 381Ω) ± 10% = 210Ω ± 10%

Therefore, the size of neutral reactor for the DGIT is:

X_n = 210Ω / 3 ± 10% = 70Ω ± 10%

The continuous rating of the grounding devices shall be able to handle the maximum expected voltage unbalance with margin. As per Hydro One's Conditions of Service, the voltage

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unbalance on Hydro One feeders can reach 5%. Therefore, the grounding device should be sized for a minimum of 5% continuous voltage unbalance. The short time (5 sec) fault rating shall be sized for the maximum fault current that will flow through the grounding device for a close-in fault.

C.2 INTERCONNECTING TO HONI'S 3-WIRE DISTRIBUTION SYSTEM

For DER Facilities connecting to Hydro One's 3-wire Distribution System, neutral reactors are required to limit the fault current contributions from DER Facilities for ground faults on the interconnected feeder when the DGIT winding configuration is Wye-Ground:delta. Examples 5 and 6 are to provide the impedance calculations for neutral reactors that can be connected between the neutral of Wye-Ground:delta DGITs and the ground. As per Section 2.1.11 Grounding, for DER Facility with Conventional (Rotating) Generators, the Zero Sequence Reactance (X_{DG0}) should be greater than 8 times the Positive Sequence Reactance (X_{DG1}). For DER Facility with an Inverter Interface, the Zero Sequence Reactance (X_{DG0}) should be greater than 24 times the reactance of the DGIT.

Example 5: **A 10MVA Rotating Machine DER Facility is connected at 44kV, via a single 10MVA DGIT, and the DGIT has Wye-Ground:delta windings.**

Base impedance = $44kV^2$ / 10MVA = 193.6Ω,

Assuming the Positive Sequence Reactance of the DER Facility is:

$X_{DG1} = X"_d + X_t$ = 0.12p.u. + 0.05p.u. = 0.17p.u. on a 10MVA base,

Then the required Zero Sequence Reactance of the DER Facility is:

$X_{DG0} > 8 \times 0.17 \times 193.6\Omega = 263.3\Omega$

The required Zero Sequence Reactance of neutral reactor is:

$X_{0,NGR} > 263.3\Omega - 0.05 \times 193.6\Omega = 263.3\Omega – 9.7\Omega = 254\Omega$

Therefore, the size of neutral reactor should be greater than:

$X_n = 254\Omega / 3 = 85\Omega$

Example 6: **A 10MVA Inverter based DER Facility is connected at 44kV, via a single 10MVA DGIT, and the DGIT has Wye-Ground:delta windings.**

Base impedance = $44kV^2$ / 10MVA = 193.6Ω,

Assuming the reactance of the DGIT is 0.05p.u. on a 10MVA base,

Then the required Zero Sequence Reactance of the DER Facility is:

$X_{DG0} > 24 \times 0.05 \times 193.6\Omega = 232.3\Omega$

The required Zero Sequence Reactance of neutral reactor is:

$X_{0,NGR} > 232.3\Omega – 0.05 \times 193.6\Omega = 232.3\Omega - 9.7\Omega = 223\Omega$

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Therefore, the size of neutral reactor should be greater than:

$X_n = 223\Omega / 3 = 74\Omega$

The continuous rating of the grounding devices shall be able to handle the maximum expected voltage unbalance with margin. As per Hydro One's Conditions of Service, the voltage unbalance on Hydro One feeders can reach 5%. Therefore, the grounding device should be sized for a minimum of 5% continuous voltage unbalance. The short time (5 sec) fault rating shall be sized for the maximum fault current that will flow through the grounding device for a close-in fault.

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D APPENDIX D – ANTI-ISLANDING PROTECTION *(INFORMATIVE)*

The following is background information on Anti-Islanding Protection, its purpose, and some rational behind some requirements. Transfer Trip and Distributed Generator End Open is discussed. Also, a typical distribution system is shown and possible island formations are discussed. This information is provided as informational only. Requirements are listed in Sections 2.3.12 and 2.3.13 of the TIR.

D.1 DER ISLANDING

A DER island is formed if a DER Facility remains connected to a portion of the Distribution System after that portion is separated from the normal Hydro One supply. DER islanding can expose Hydro One's Transmission and Distribution Systems and customers to unstable voltage and frequency and other adverse impacts. Most typically, DER islanding can occur when the feeder breaker or other isolating device at a TS or DS or along a radial-connected feeder is opened. Some of the causes that may lead to DER islanding are as follows:

i. A fault that is detected and cleared by the utility before it can be detected and cleared by the DER Facility. Most DER islands will be established this way;
ii. Emergency switching of the Distribution System and loads;
iii. Equipment malfunction;
iv. Operating or human error; and
v. Foreign interference or other acts of nature.

D.2 SUMMARY OF ADVERSE IMPACTS CAUSED BY DER ISLANDING

Potential adverse impacts of DER islands include but are not limited to following:

i. Abnormal voltage and frequency excursions outside of the acceptable ranges because of DER Facility voltage regulation limitations;
ii. Excessive temporary overvoltage (TOV) can occur if DER Facility sources that are not effectively grounded back-feed single-line-ground faults;
iii. Extreme overvoltage from ferro resonance between the nonlinear magnetizing inductance of DGIT/induction generators and connected capacitance and system capacitance;
iv. Unpredictable DER energy sources that are not controlled by the utility. This includes generation sources and abnormal phase voltages caused by back-feed through multi-core three-phase DGITs in the presence of single-phase switching or other open circuit supply conditions;
v. Failure to clear certain faults that cannot be detected by DER Facility self-clearing protections within required time;
vi. Interference with the restoration of normal supply from the utility;

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vii. Asynchronous paralleling if DER Facility is present when Hydro One supply is restored.

D.3 RISKS

The risks associated with the adverse impacts include:

i. Inadequate power quality - voltage and frequency;
ii. Damage - to customer and utility line equipment as a result of overvoltages or sustained or prolonged electrical faults where protections are insensitive or slow clearing;
iii. Prolonged customer outages resulting from failed automatic-reclosure or delays in establishing safe conditions for isolation and repair of damaged equipment;
iv. Safety hazards to public and utility workers since lines may be energized when it is assumed to be disconnected from all energy sources; and
v. Increased liability and costs associated with all of the above.

These impacts must be avoided by maintaining adequate controls over the design and operation of the DER Facility connections. Transfer Trip (TT) and Distributed Generator End Open (DGEO) schemes are important tools that are required to avoid these adverse effects for certain configurations.

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D.4 TYPES OF DER ISLANDS

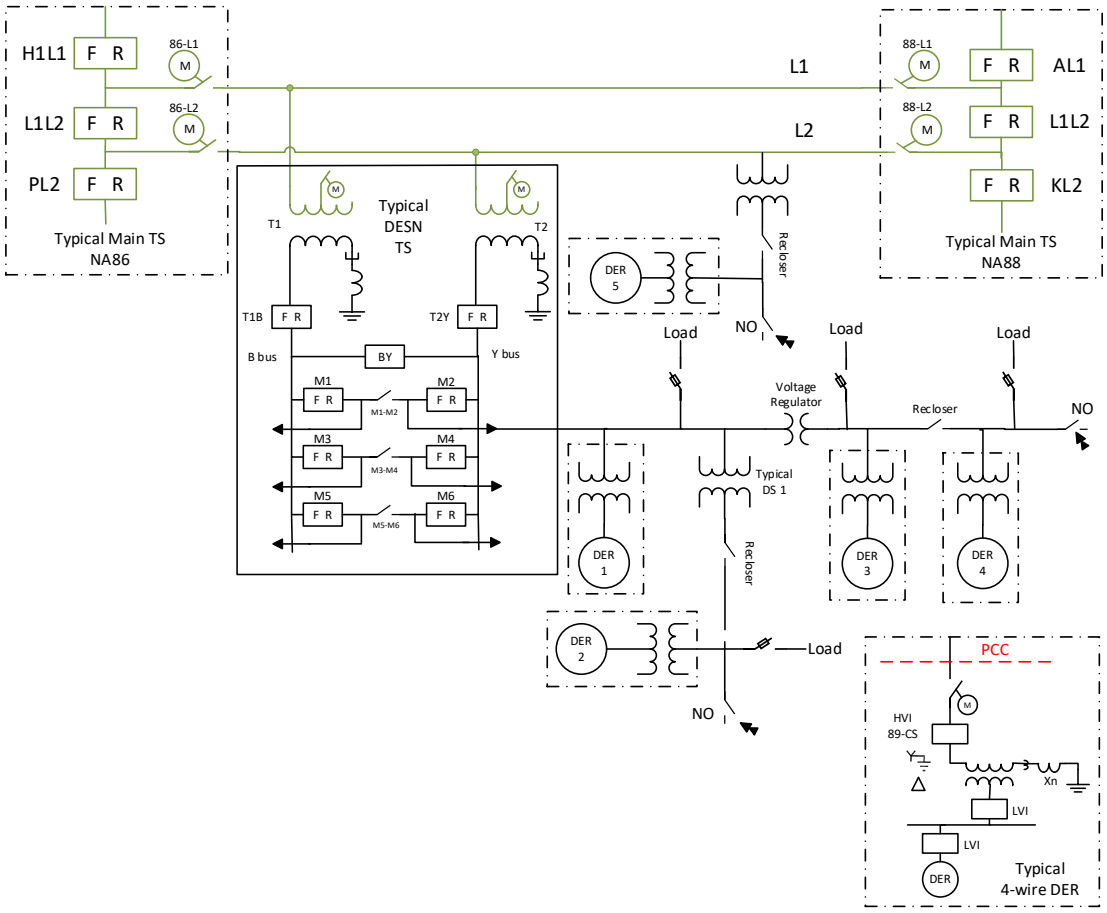


Figure 1: Typical Distribution System with DER Connections

DER Islands are formed whenever feeder reclosers or TS breakers are tripped from feeder or line protections interrupting the supply to a portion of the Transmission or Distribution System. The DER Facility must be removed from service before fuses are melted and before automatic-reclosure takes place, to avoid interference with Hydro One restoration and asynchronous reclosure.

Appendix F includes graphs that show timing requirements for TT and DER Facility self-clearing protections, for various automatic-reclosure, fault detection and breaker times. For each DER island scenario, the aggregate capacity of the islanded DER Facility must be assessed in relation to the minimum connected islanded load.

Generally, if the islanded DER Facility aggregate capacity is greater than 50% of the minimum load of the connected island, then TT will be required to be sent from the most strategic Hydro One supply location(s) to disconnect the DER Facility to ensure successful automatic-reclosure

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operations.10 The TT may be sent directly from the location of Hydro One's switching device to the DER Facility or a cascading arrangement may be used to redirect the TT to the DER Facility via another marshalling location (usually the TS).

RECLOSER DER ISLAND

i. A Recloser DER Island forms when a feeder recloser operates, interrupting the Hydro One supply to a section of a feeder to which the DER Facility is connected.
ii. In the example shown in Figure 1, DG2, DG4 and DG5 will be islanded by the adjacent Hydro One source-side reclosers opening.
iii. Typical automatic-reclose times for reclosers are 1.5 to 2 seconds.

FEEDER-BREAKER DER ISLAND

i. A Feeder-breaker DER island forms when feeder protection operates, opening a TS feeder-breaker and interrupting the Hydro One supply to the whole feeder to which the DER Facility is connected.
ii. In the example shown in Figure 1, DG1 - DG4 will be islanded by the opening of the M2 feeder breaker.
iii. Typical automatic-reclosure times for feeder-breakers are 0.5 to 1 seconds.

LV BUS DER ISLAND

i. An LV Bus DER island forms when a main terminal line protection operates for an HV line fault interrupting the Hydro One supply to a DESN TS LV bus to which the DER Facility is connected.
ii. In the example shown in Figure 1, an LV bus DER island would only occur if the bus-tie breaker BY was open and the L2 line protection opens LV transformer-breaker T2Y interrupting the Hydro One supply to the Y bus to which DG1 – DG4 are connected.
iii. Automatic-reclosure is initiated from the HV line protection and the LV transformer-breaker Transfer Trip or Remote Trip Receive protections. The typical automatic-reclosure time for a DESN TS LV transformer-breaker is typically 1 second, but that will only be completed after the HV line protection at the main terminal TS automatically recloses, typically in 5 seconds (may be as low as 2 seconds).

[10] The significance of the 50% criteria is presented later in this Appendix.

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DESN TS LV ISLAND

i. A DESN TS LV island forms when one or more main terminal line protections operate for HV line faults, interrupting the Hydro One supply to a DESN TS to which the DER Facility is connected.
ii. In the example shown in Figure 1, a DESN TS LV would occur if transformer breakers T1B and T2Y are both opened from operation of HV line protections, isolating all of the DER Facilities connected to the DESN TS (DG1 - DG4).
iii. Automatic-reclosure is initiated from the HV line protection and the LV transformer-breaker Transfer Trip or Remote Trip Receive protections. The typical automatic-reclosure time for a DESN TS LV transformer-breaker is typically 1 second, but that only after the HV line protection at the main terminal TS automatically recloses, typically in 5 seconds (may be as low as 2 seconds).

WIDE-AREA DER ISLAND

i. A Wide-Area DER island can be formed when one or more main terminal line protections operate for HV line faults, interrupting the Hydro One supply to all DESN stations and to any HV-connected DS to which the DER Facility is connected.
ii. For a two-circuit supply, both circuits would have to be interrupted to cause a wide area DER island.
iii. In the example shown in Figure 1, a wide area DER island would occur if supply to both HV lines L1 and L2 are interrupted (a double circuit interruption). This is a relatively rare event but can happen during wind storms or other adverse conditions.
iv. For a single-circuit HV supply, operation of the line protection for that circuit would cause a Wide-Area DER island.
v. A Wide-Area DER island will occur if there is no TT from the main terminal station to the DESN station or HV-connected DS or that TT fails causing the DESN station LV breakers to remain closed. In that case, automatic-reclosure of the HV lines will restore Hydro One supply to all of the affected Wide-Area, typically in 5 seconds (may be as low as 2 seconds) provided that there is no back-fed voltage detected on the HV lines by the HV breaker automatic-reclosure schemes.
vi. A Wide-Area DER island may also occur if the next zone (upstream from Terminal Stations) is tripped. This may occur if the net generation in the wide area network can sustain the load at the time of occurrence.

D.5 DER ISLANDING NOT PERMITTED

At present DER islanding is not allowed due to the fact that DER Facility is neither responsible nor capable of maintaining the integrity of distribution system. Key points are shown below:

HYDRO ONE'S RESPONSIBILITY

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Hydro One is responsible for the supply and voltage regulation of Hydro One's Distribution System and the maintenance of Distribution System voltages at acceptable levels as required by the OEB. Frequency is maintained very close to 60 Hz by the synchronized interconnection of Hydro One's Transmission System to the Eastern Interconnection of the North American Electric Reliability Corporation ("NERC"). Voltage and frequency will be maintained under normal system conditions as long as normal Hydro One supply remains connected to the Distribution System.

EXPECTED FREQUENCY AND VOLTAGE DEVIATIONS IN DER ISLANDS

When a DER island occurs, island voltages and frequency will depend entirely on the interaction between the islanded generation and load. Maintaining an island within acceptable limits would require at least one DER Facility in the island to actively regulate frequency and voltage to match changing island load demands. Furthermore the DER Facility capacity would have to be large enough to sustain the extreme range of load demands that may exist in the island. DER Facilities cannot meet these conditions for the following reasons:

i. Hydro One does not permit DER Facility voltage regulation systems to actively regulate voltage. This avoids mal-coordination of Distribution System voltage regulation and excessive operation of Hydro One's tap-changers and voltage regulators.
ii. Variable production conditions prevent DER Facility capacity from being capable of meeting the exact demands of any specific local loads or power transfers. As a result, DER island frequency and voltage can be expected to drift outside of the acceptable limits because of these inherent DER control and capacity limitations.
iii. The direction (over or under) of frequency and voltage change for a DER island will depend upon the relative mismatch of net real and reactive power between the islanded DER Facility and load. If the active power generation is less than the active power consumed by the load, the island frequency will drop. If the active power generation exceeds the active power consumed by the load, the island frequency will rise.
iv. Change in island voltage magnitude depends similarly on mismatch between distributed generation reactive power output and the reactive power demands of the islanded load.
v. The rate-of-change of frequency and voltage for a DER island will depend upon many factors. These factors include the amount of power unbalance, network impedances, voltage dependency of the feeder loads and dynamic characteristics of the islanded generation and loads (inertias of the interconnected machines and transient reactance).
vi. Even short duration DER islands may be too long to prevent adverse DER islanding impacts, unless specific design precautions are implemented.

POSSIBILITY OF EXTREME OVER-VOLTAGES AND BACK-FEEDS THROUGH TRANSFORMERS

i. Ferroresonance and single-line-ground faults can cause extreme or excessive over-voltages for some DER island configurations. These over-voltages are capable of causing damage to customer and Hydro One equipment.

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ii. Back-feeds through multi-core three-phase DGITs in the presence of single-phase switching or other open circuit supply conditions. These voltages pose a safety hazard to public and utility workers for fallen conductors or when circuits are assumed to be dead but in fact are energized.

iii. These over-voltage and back-feed effects are largely dependent upon the size, grounding and magnetic-core characteristics of the DGIT connections. There are many ways to avoid or minimize these effects. That includes the following:

- Use of Transfer Trip;
- Use of a DER HVI to be tripped whenever an unbalanced condition is detected at the DER Facility location;
- Effective-grounding of the DGIT;
- Avoiding the use of multi-core transformers for three-phase connections in the presence of single phase switching upstream, by using three individual single-phase (single-core) DGIT connections; and
- Avoiding single-phase switching of three-phase transformers (where possible) or minimizing circuit capacitance from the DGIT to these locations.

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D.6 AUTOMATIC-RECLOSURE

Transient faults on over-head line conductors caused by lightning, wind, tree branches falling, or other momentary foreign contact constitute approximately 85-90% of all faults.

Hydro One uses the standard utility practice of automatic-reclosure on distribution feeders with over-head line-sections to minimize supply interruptions for transient faults.

Automatic-reclosure is not generally used for feeders with extensive underground cable sections because cable faults are exposed to far fewer naturally occurring transient fault conditions. Also faults on cables are much more likely to be permanent requiring repairs.

D.7 BENEFITS OF AUTOMATIC-RECLOSURE

Automatic-reclosure has the following advantages:

i. It minimizes supply interruption to customers by automatically restoring the feeder to service as quickly as possible following transient faults.
ii. It minimizes damage at the fault and stress on equipment supplying the fault.
iii. It reduces operating costs. Less time and materials required to repair damage and restore service.
iv. It prevents blowing of fuses at tapped Distribution stations and lateral feeds resulting in all of the above.

D.8 HOW AUTOMATIC-RECLOSURE WORKS

i. For the first occurrence of the fault on any portion of the faulted feeder, high-speed sensitive low set protection operates quickly to de-energize the feeder.
ii. Following the first protection operation, the Hydro One feeder breaker or reclosers are automatically reclosed to restore supply to load customers as quickly as possible.
iii. Typical reclosing times are 0.5 to 1 second for feeder breakers and 1.5 to 2 seconds for reclosers.
iv. Reclosing time must allow for the fault to extinguish and de-ionize.
v. Reclosing time must also allow some time for the inertia and back emf of large motors to decay (to about 40% of normal voltage) and be disconnected by automatic controls.

D.9 AUTOMATIC-RECLOSURE REQUIRES DER TO DISCONNECT QUICKLY

Automatic-reclosure can succeed only if the fault arc is extinguished and de-ionized. Otherwise the fault is likely to re-strike after the feeder is re-energized.

i. If the DER Facility has not disconnected at the time that automatic-reclosure takes place, the automatic-reclosure would asynchronously re-parallel to all DER Facilities and any rotating motors that remained connected in the island.

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ii. Extreme mechanical stresses associated with asynchronous paralleling could damage DER Facility generators, customer motors, switching equipment and any transformers that are connected in series between these energy sources.

iii. The potential impact of asynchronous connection of inverter-fed DER Facilities is less certain and will depend on their individual design. However since island voltage can be sustained by other generators and motors that remain connected, asynchronous reclosure must be avoided.

iv. For the above reasons, all DER Facilities must be quickly disconnected whenever a feeder fault is detected, before reclosure takes place.

D.10 LIMITATIONS OF DER SELF-CLEARING PROTECTION RESPONSE TIMES

i. Based on fault in-feed, DER Facilities cannot distinguish between faults on either side of the utility feeder breaker or recloser that supplies them. To avoid nuisance trips, some time delay is required by the DER Facility's interconnection protection to allow coordination with the faster utility protections to clear those out-of-zone faults. If that delay is too long, automatic-reclosure will be impaired.

ii. The DER Facility anti-islanding protection cannot prevent DER islanding. It can only detect an island after islanding occurs.

iii. All passive DER Facility anti-islanding detection methods rely on an unbalance or mismatch between distributed generation power output and power demands of the connected load on the isolated island. DER island frequency and voltage can be expected to drift, as outlined above.

iv. Close matching of both active and reactive power would be an extremely unlikely condition for a prolonged period. Sooner or later, mismatches will cause the voltage or frequency to drift outside the protection limits specified in Section 2.3 of the TIR.

v. If by chance the active and reactive power produced by islanded DER Facility happens to be close to the islanded load demand, then the island may survive for a longer period before DER Facility self-clearing protections will detect and disconnect the generation.

vi. In some cases, DER Facility self-clearing anti-islanding protections cannot be relied on to guarantee that the DER Facility will disconnect itself before automatic-reclosure takes place. In those cases, TT and DGEO schemes are required. Refer to appropriate sections for requirement conditions.

D.11 MAXIMUM DETECTION TIMES AVAILABLE FOR DER SELF-CLEARING PROTECTIONS

AUTOMATIC-RECLOSURE CONSIDERATION

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There are limited time windows available following the formation of an island during which time DER self-clearing protections have to disconnect the generator before automatic-reclosure takes place.

i. If there is a fault on the feeder at the time the DER island is formed, the DER Facility fault protection must detect the fault and initiate clearance.
ii. If there is no fault on the feeder at the time the DER island is formed, the DER Facility's anti-islanding protection must detect the island condition and disconnect the generation from the Distribution System.

Timing diagrams and graphs for self-clearing DER Facility's interconnection protection are shown in Appendix F.

The times are based on the following assumptions and constraints:

i. The Hydro One automatic-reclosure timer is initiated without delay, immediately after the fault is detected by the Hydro One feeder protection.
ii. The assumed maximum Hydro One fault clearance time is 83ms after the fault is detected (5-cycle breaker opening time for oil dead-tank breakers).
iii. 200ms fault extinction and de-ionization time and/or drop out of motor controls is required after the last source trips, prior to reclosure.
iv. The graph shows the effect of DER Facility interrupter times on available Fault detection and Island detection times to avoid interference with Automatic-Reclosure.

For example, to prevent interference with automatic-reclosure (1 second reclosure), a DER Facility with a 5-cycle interrupter would require:

i. Self-clearing DER Facility anti-islanding protections capable of island detection within 633ms.
ii. DER Facility fault protection must be capable of detecting all three-phase and phase-ground faults to the extreme ends of the supply feeder within 717ms.
iii. For reclosure times longer than 1 second, the protection response times can be lengthened by equivalent amounts.

TT will be required to speed up DER Facility clearance if the above conditions cannot be met.

To prevent interference with automatic-reclosure with a reclose time of 500ms:

i. Self-clearing DER Facility anti-islanding protections capable of detecting an island condition within 133ms.
ii. DER Facility fault protections must be capable of detecting all three-phase and phase-ground faults to the extreme ends of the supply feeder within 217ms.
iii. It is expected that DER Facility self-clearing protections cannot selectively and reliably detect fault and island conditions in such a short time. TT and DGEO will always be required to speed up DER clearance where 0.5-second reclosure times are used.

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FUSE SAVING CONSIDERATIONS

Slow-clearing DER Facility in-feeds to faults can cause Distribution System fuses to melt can cause prolonged customer outages resulting from melted fuses. To reduce this all DER Facility shall be disconnected within 200ms of when external faults are detected on the Distribution System.

D.12 TRANSIENT RESPONSE OF DER ISLANDS (THE BASIS OF THE "50% RULE")

i. Hydro One's transient stability studies for some typical synchronous generators have demonstrated some consistent effects that various generation-to-feeder load ratios have on DER Facility voltage and speed (frequency).

ii. These studies have shown that for 50% generator rating to feeder load ratios, generator frequency declined steadily to about 53Hz within 1 second. Voltage declined rapidly to about 75% within about 100ms and recovered somewhat to about 93% within 1 second.

iii. Such frequency excursion to 53Hz should ensure that the under-frequency protections set as per Section 2.3.10 of the TIR will clear in much less than 1 second (160ms for frequency < 57 Hz).

iv. Such voltage excursion to 75% may take up to 2 seconds to clear for protection set as per Section 2.3.11 of the TIR (2 seconds for 50 ≤ V < 88%).

v. For higher generator rating to feeder load ratios, frequency and voltage does not drift outside the limits specified in Sections 2.2.2.5 and 2.2.2.1 of the TIR.

vi. Generic models for other types of generators - self-fed induction ("SFIG"), Double-fed Asynchronous ("DFAG"), inverters and static power converters are not sufficiently available to guarantee that DER Facility anti-islanding protections will operate in sufficient time for all conditions to prevent interference with automatic-reclosure.

vii. Based on the above, Hydro One has established a 50% active power unbalance threshold (DER Facility aggregate capacity / minimum load) above which TT is required to be used to avoid interference with Distribution System automatic-reclosure schemes.

viii. This only applies where automatic-reclosure time is 1-second or longer.

D.13 TRANSFER TRIP PROVIDES PREDICTABLE ANTI-ISLANDING PROTECTION CLEARANCE TIMES

Transfer Trip (TT) application provides predictable DER Facility clearance times and is the only protection which can guarantee anti-islanding. Distributed Generator End Open (DGEO) is always used with TT to guarantee disconnection of DER Facility before the feeder is re-energized or the breaker is re-closed. Thus, TT, DGEO and Re-closing shall be discussed.

There is no direct relation of Low Set Block Signal (LSBS) with anti-islanding protection, but this signal can utilize the same channel which is to be utilized by DGEO. Thus LSBS shall also be discussed briefly.

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TRANSFER TRIP APPLICATION

Transfer Trip (TT) is a protection trip signal that is sent from the Hydro One supply source breaker or recloser to the DER Facility when the DER Facility is required to be disconnected. Transfer Trip (TT) is often required to mitigate the adverse impacts of DER Facility connection and islanding.

TT TIMING REQUIREMENTS

Refer to Section 2.3.12 of the TIR and Appendix F for TT timing requirements.

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D.14 DISTRIBUTED GENERATOR END OPEN (DGEO)

DGEO is a real time signal that is continuously sent from the DER Facility to Hydro One's supply source breaker or recloser. It establishes the connection status of the generation equipment.

i. For ungrounded 3-wire connections, where the DER Facility source cannot contribute ground fault current, the DGEO signal is derived from all breakers/circuit switchers at the interface between the DER Facility generation and the PCC necessary to establish DER Facility generation connectivity. It establishes the connection status of the generation equipment and is used to block automatic-reclosure should DER Facility fail to disconnect after the Hydro One supply is disconnected. For 3-wire connections that do not have an HVI, connectivity of the generators will be established by LVI connection logic that mimics all of the possible generation connection paths.

ii. For 4-wire connections, the DGEO signal must be derived from the DER Facility HVI switch only. For 4-wire connections all DER Facility ground sources must be connected to the DER Facility side of the HVI switch and must be disconnected before Hydro One source can be permitted to energize the feeder. That is because any fault that occurs immediately following Hydro One energization of the feeder is almost certain to be permanent, and Hydro One low-set fuse-saving protections are blocked. This allows coordinated clearance of the down-stream reclosers and fuses with the Hydro One source timed protections.

DGEO requirements are specified in Section 2.3.14 of the TIR. Design recommendations are included in Appendix E.

D.15 APPLICATION OF TT AND DGEO "50% RULE" REQUIREMENTS TO DER ISLANDS

The 50% TT rule is intended to preserve the benefits of automatic-reclosure following transient line fault conditions, by ensuring DER Facilities do not interfere with the successful operation of automatic-reclosure schemes.

Automatic-reclosure is not initiated for other types of permanent faults – recurring line faults, transformer faults, bus faults or breaker failure condition. In these cases, providing other adverse impacts are minimal for short-duration DER islanding, self-clearing anti-islanding protections (over/under voltage and over/under frequency) may be sufficient to disconnect the generation from the island when frequency and voltage transcend the limits specified in Sections 2.2.2.5 and 2.2.2.1 of the TIR respectively. In all cases, high reliability is required for all protection schemes that are required to maintain the integrity of Hydro One's Distribution System.

Typical DER islands that can be formed during transient fault conditions are illustrated in Figure 1 and discussed earlier under "Types of DER islanding".

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D.16 LOW SET BLOCK SIGNAL (LSBS)

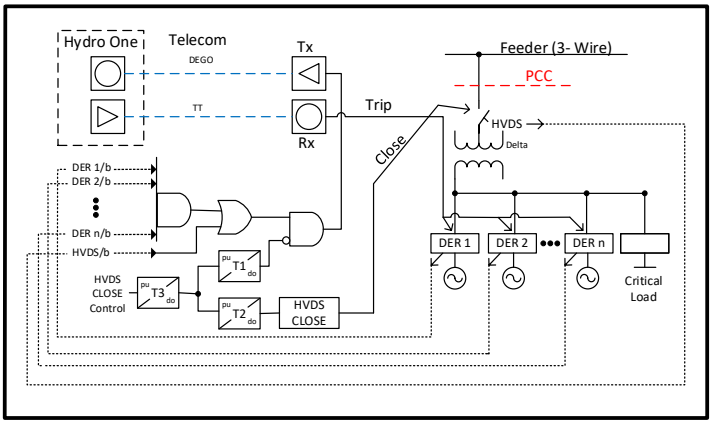
i. Low Set Block Signal (LSBS) is a signal that is sent from the DER Facility to the Hydro One supply source breaker or recloser, whenever a large DGIT is being energized. Detection of this signal transition at the Hydro One supply source breaker or recloser location will cause the most sensitive low-set (fuse-saving) protection to be temporarily blocked. This will prevent the tripping of the Hydro One supply source during the period when there is large energizing inrush current due to the DGIT. Refer to Appendix E for more information regarding the LSBS signal.

ii. Because the momentary LSBS signal will always be sent just prior to reconnection (near the end of the DGEO open condition), both DGEO and the LSBS functions shall be combined as one signal through a communication channel from the DER Facility to the Hydro One source energizing location(s).

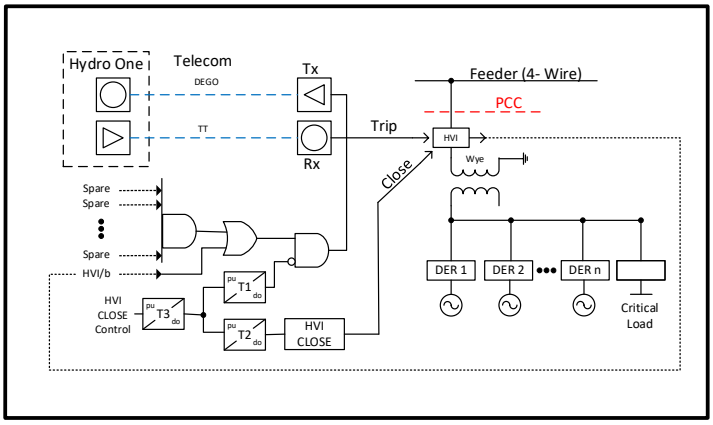
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E APPENDIX E – DGEO & LSBS DESIGN CONSIDERATION *(INFORMATIVE)*

The following information is a design consideration for Section 2.3.16 of the TIR (DGEO and LSBS Design Requirement). It is an example of how the signals can be implemented for installations utilizing a High Voltage Interrupter or a High Voltage Disconnect Switch (motorized Isolation Device – See Section 2.1.7 of the TIR). This is for informational purposes only and actual design and implementation may be different.



HVDS on 3-Wire



HVI on 4-Wire

*HVDS – High Voltage Disconnect Switch										
Based on blocking the Low Set Inst at Hydro One for 5 seconds on a falling edge DGEO signal transition										
Example #	**Teleportation Delay**		**HVI**	**HVDS**	**Timer T1**		**Timer T2**		**Timer T3**	
	TT Delay	**DGEO Delay**	**Close Time**	**Close Time**	**PU Delay**	**DO Delay**	**PU Delay**	**DO Delay**	**PU Delay**	**DO Delay**
1	16ms	16ms	100ms		0ms	0ms	1s	0ms	0ms	6s
2	16ms	16ms		1s	0ms	0ms	1s	0ms	0ms	6s
3	30ms	250ms	100ms		0ms	0ms	1s	0ms	0ms	6s
4	30ms	250ms		1s	0ms	0ms	1s	0ms	0ms	6s

Figure 2: DGEO & LSBS Design Consideration

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F APPENDIX F – TIMING DIAGRAMS *(INFORMATIVE)*

The following are a few sample timing diagrams for informational purposes. These have been created to represent a realistic sequence of events and the associated timings for different fault clearing and anti-islanding applications. These times may change due to site specific requirements and thus, timing requirements shall be confirmed with Hydro One for specific DER Facility projects.

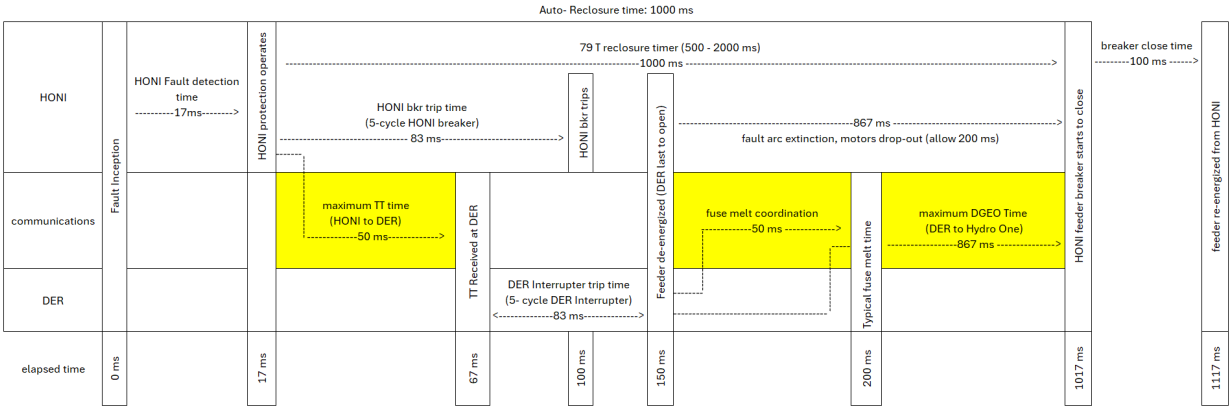


Figure 3: Typical Transfer Trip timing

Figure 3 illustrates typical trip/reclose timing for a feeder fault detected by a Hydro One feeder low-set protection. The Hydro One supply is isolated by a 5-cycle Hydro One breaker and Transfer Trip to the DER Facility. If the DER Facility interrupter opens in 5-cycles, a 50ms end-to-end TT transfer trip time is required to clear DER Facility infeed to the fault within 150ms.

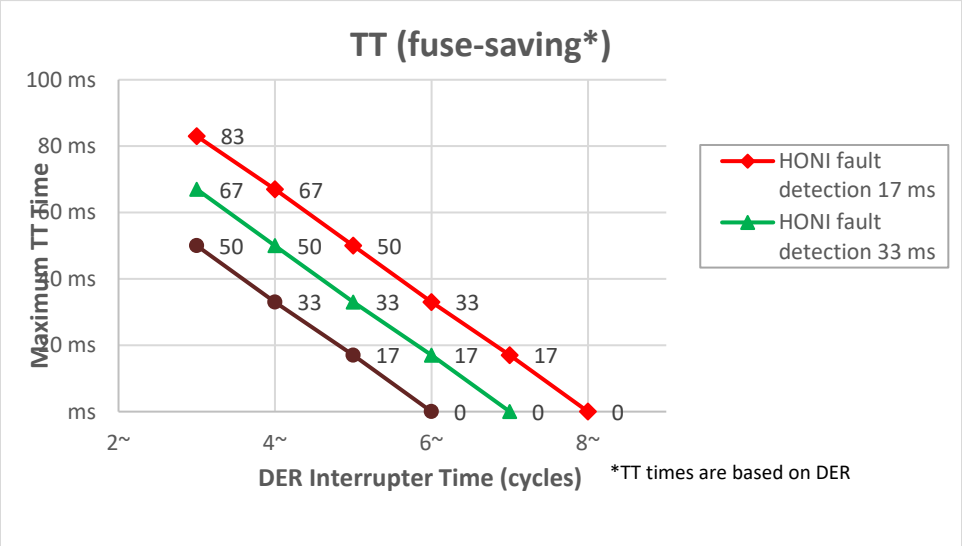


Figure 4: Relationship between timing variables for DER self-clearing

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Figure 4 illustrates the end-to-end TT timing requirements to clear the DER Facilities infeed to a fault within 150ms, for various DER Facility interrupting devices operating times. The three curves show how various Hydro One fault detection times would affect the required TT times. Hydro One instantaneous low-set protections will typically detect the fault within 17ms, so the red curve will normally apply.

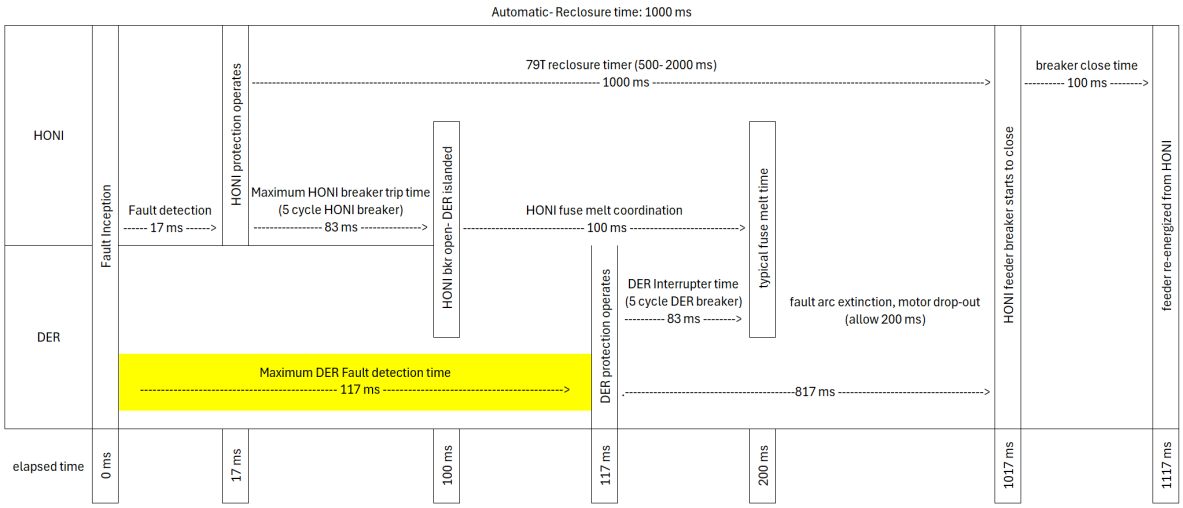


Figure 5: Typical DER self-clearing fault clearance (Fuse Saving considerations)

Figure 5 illustrates trip/reclose timing for typical feeder fault detected by a self-clearing DER Facility's interconnection protection with a 5-cycle interrupter. In order to clear the DER Facility infeed to the fault within 200ms to avoid fuse melting, the DER Facility fault detection protection needs to operate within 117ms.

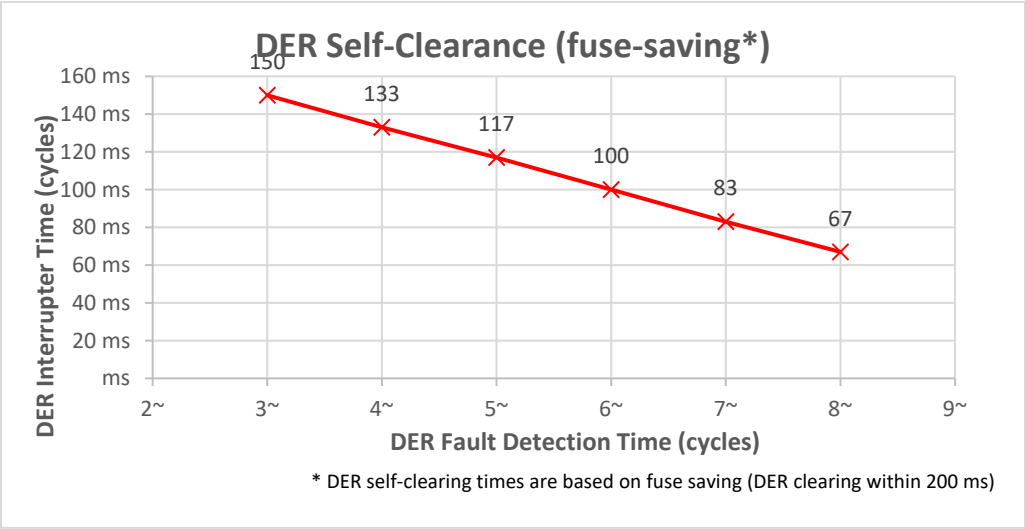


Figure 6: Relationship between DER self-clearing protection and interrupter times (fuse saving considerations)

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Figure 6 illustrates the timing requirements for DER Facility's external fault detecting protections to clear the DER Facility infeed to the fault within 150ms, for various DER Facility interrupting device operating times.

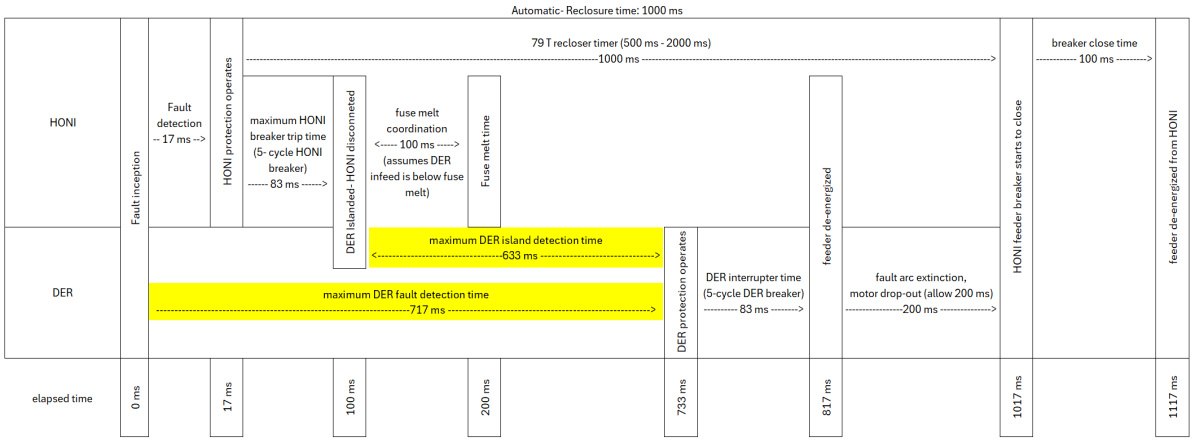


Figure 7: Typical DER self-clearing fault clearance (Auto-Reclosure timing considerations)

Figure 7 illustrates trip/reclose timing for a typical feeder fault detected by a self-clearing DER Facility's interconnection protection with a 5-cycle interrupter. In order to avoid interference with a 1-second Auto-Reclosing sequence, the DER Facility's external fault detecting protections needs to operate within 717ms. If there is no fault, the DER Facility's anti-islanding protection needs to detect faults within 633ms.

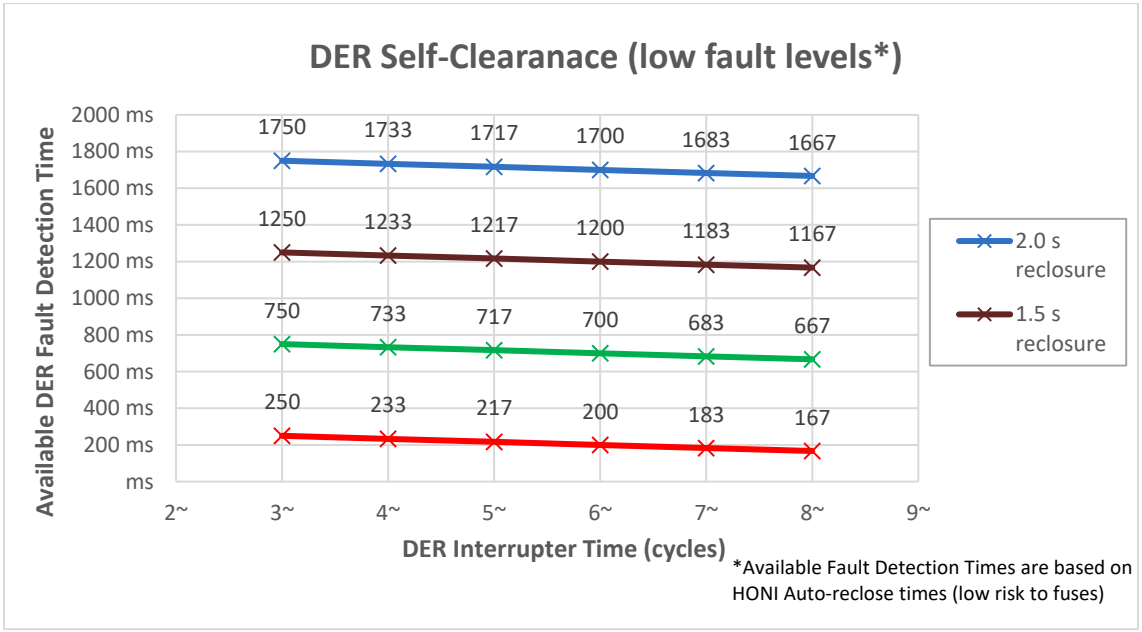


Figure 8: Relationship between DER self-clearing protection and breaker times (Auto-Reclosure timing considerations)

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Figure 8 illustrates timing requirements for DER Facility's self-clearing interconnection protection to detect external feeder faults for various DER Facility fault interrupter times, in order to avoid interference with various Auto-Reclosure times.

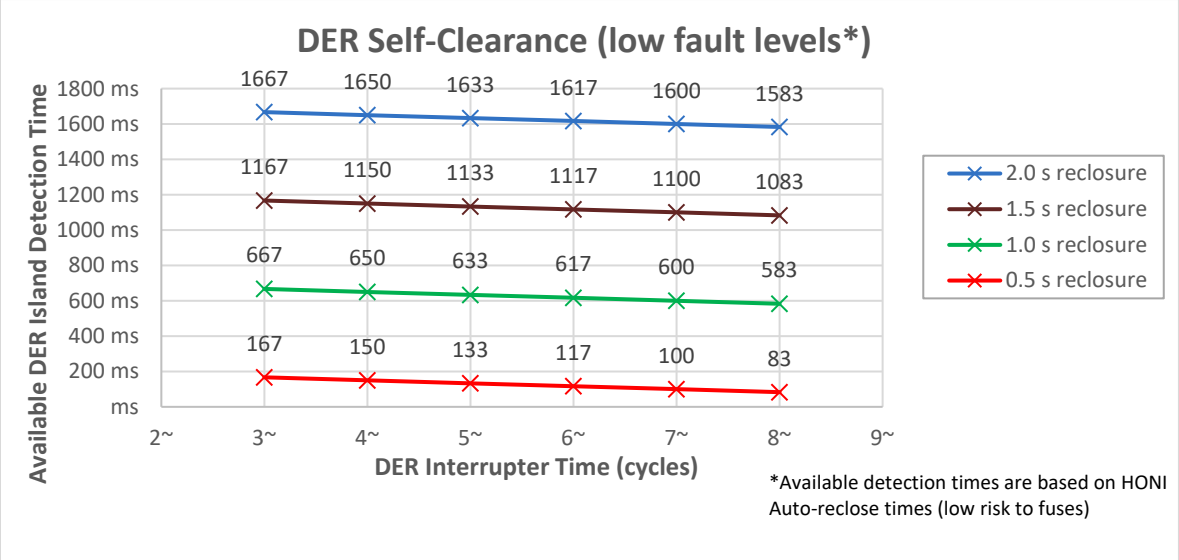


Figure 9: Relationship between DER island detection and breaker times (Auto-Reclosure timing considerations)

Figure 9 illustrates the timing requirements for DER Facility's self-clearing interconnection protection to detect island conditions for various DER Facility fault interrupter times, in order to avoid interference with various Auto-Reclosure times.

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G APPENDIX G – SEQUENCE OF EVENTS DURING FAULT CONDITIONS: EXAMPLE *(INFORMATIVE)*

The following two figures are a typical sequence of events during abnormal conditions, for both a transient fault and a permanent fault. Note: These diagrams assume that the DER Facility requires Transfer Trip and an HVI. This is for informational purposes only. Note: Viewing may be easier if viewed on computer and zoomed in.

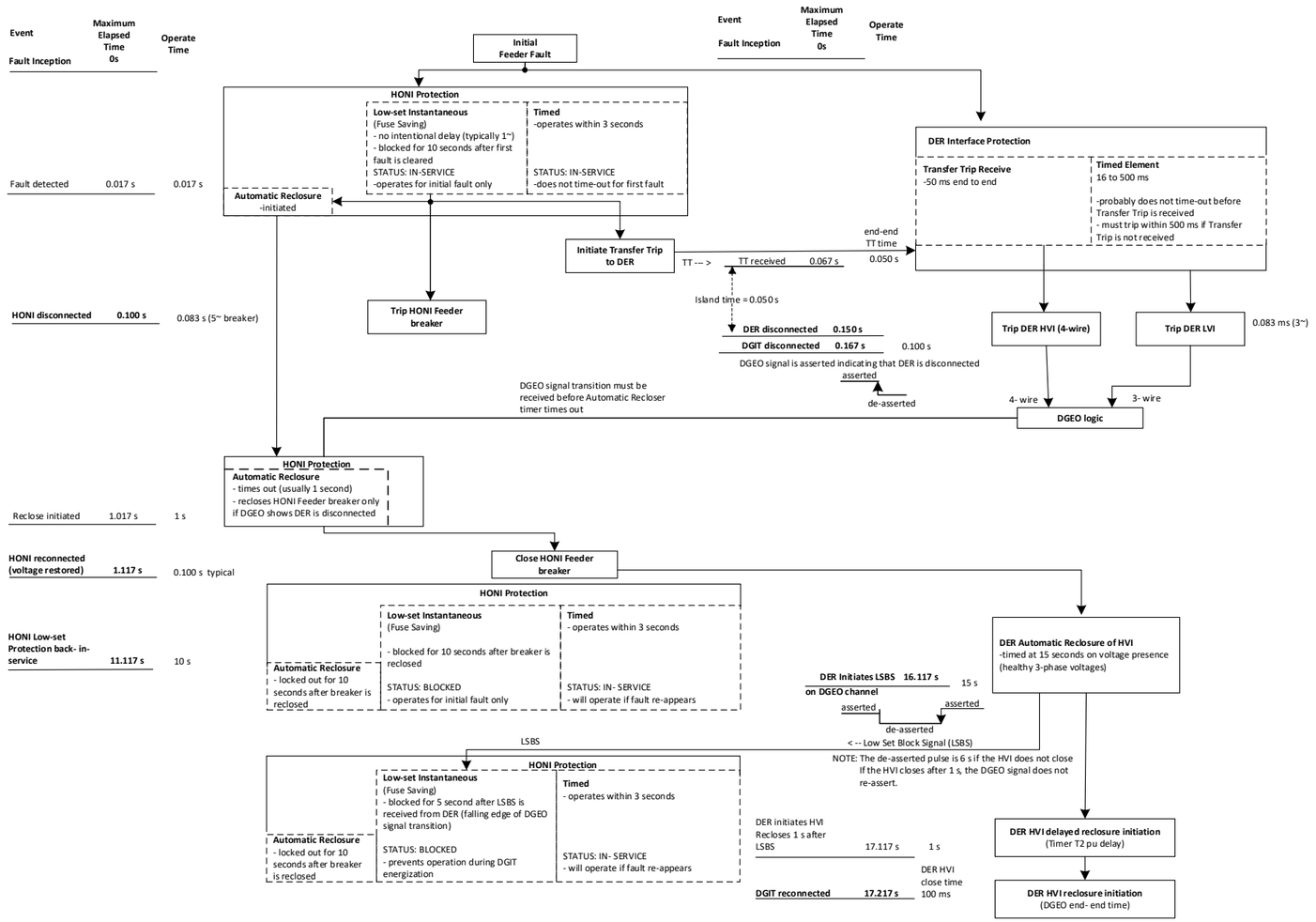


Figure 10: Sequence and Timing Diagram for Transient Faults

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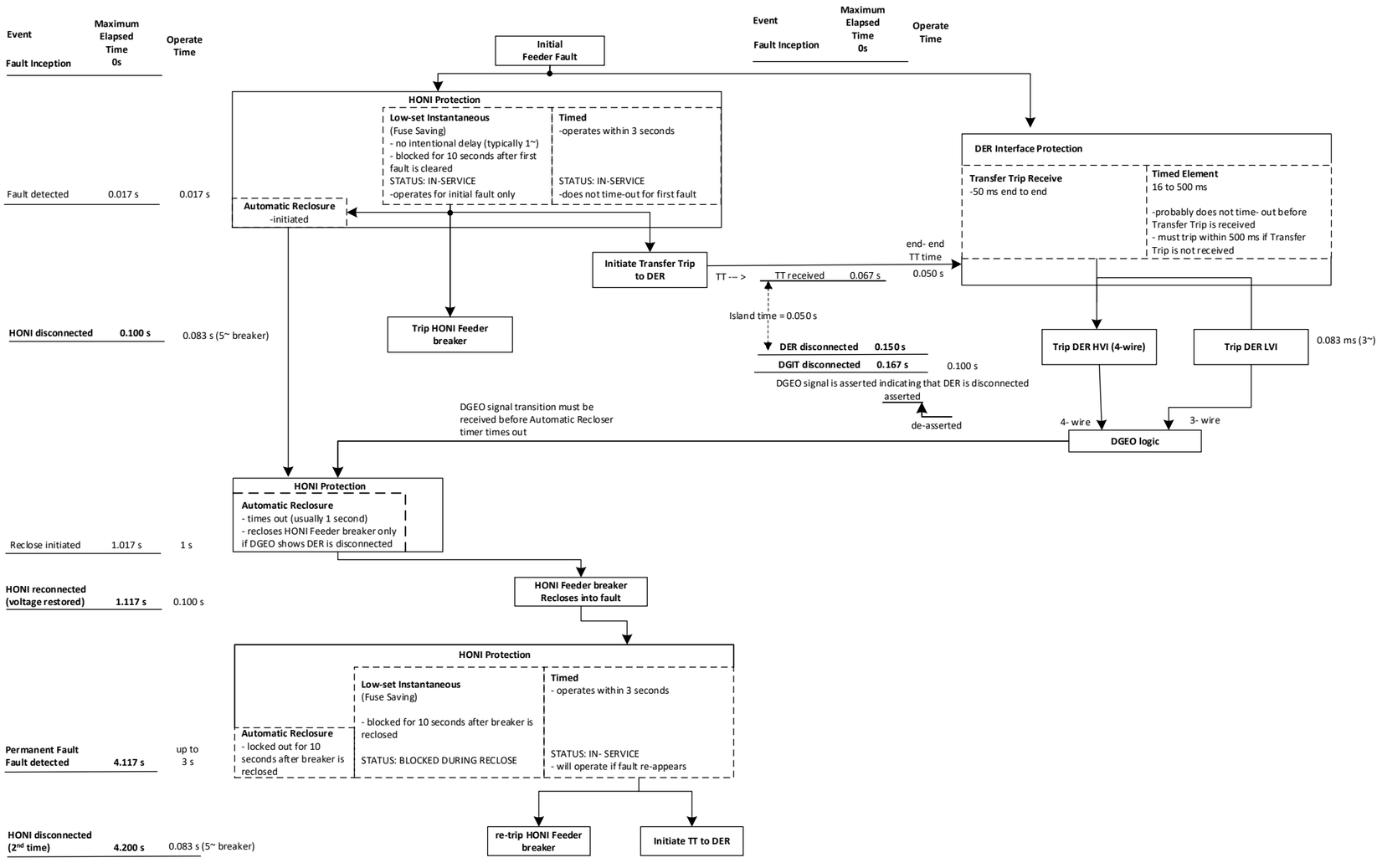


Figure 11: Sequence and Timing Diagram for Permanent Fault

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