AESO DISTRIBUTED ENERGY RESOURCES INTEGRATION PAPER

Effective Grounding

MARCH 2022

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1. Introduction

As discussed in the *AESO Distributed Energy Resources (DER) Roadmap*[1], the growth of distributed energy resources (DERs) and their integration with the Alberta interconnected electric system (AIES) will drive significant changes for the AESO, distribution facility owners (DFOs), transmission facility owners (TFOs), market participants, and consumers in Alberta. As DER penetration continues to grow, the increasing complexity and scale of power systems in Alberta may present reliability challenges concerning AIES operations and coordination of planning between the distribution and transmission systems. One of these challenges concerns the effective grounding of power systems.

Grounding is a fundamental technical issue in power system engineering that impacts protection performance, equipment ratings, system reliability, and safety. Adding a DER to an existing distribution system that traditionally serves loads in a radial connection configuration may result in unexpected reliability issues for both the distribution and transmission systems if the grounding scheme is not designed properly.

2. Background and Purpose

The AESO's legislative duties include directing the safe, reliable and economic operation of the AIES.[2] Given its central role in ensuring the reliability of the AIES, the AESO developed the *AESO DER Roadmap*, which is being advanced in collaboration with stakeholders, to explore and manage the challenges and opportunities associated with the transformation of the AIES.[3]

In July 2019, the AESO established the Technical Performance Exploration Group (TPEG), consisting of technical experts from utilities across Alberta, including DFOs and TFOs, to exchange ideas, discuss DER-related topics, and proactively prepare for a future state with higher DER penetration and potentially rapid growth in DERs. The TPEG focuses on:

- facilitating a common understanding of the overall impacts on the reliable operation and planning of the AIES due to DER integration;
- developing consensus on the future state of DER technical performance;
- proposing recommendations to close any gaps identified between the current and desired future states; and
- supporting the coordination of stakeholders' implementation of recommendations relating to the technical interconnection of DERs in Alberta.

The TPEG's scope of work excludes matters relating to policy and the regulatory framework in Alberta, the electricity market impact of DERs, and various other technical aspects related to DER integration and operation, including modelling, forecasting, and DER management systems (DERMS).

[1] *AESO Distributed Energy Resources (DER) Roadmap* (June 2020), available on the AESO website.

[2] *Electric Utilities Act* (EUA), section 17(h).

[3] AESO DER Roadmap, at PDF 5.

The AESO engaged with the TPEG to establish alignment on grounding schemes and related issues in the context of DERs connecting to the AIES, including: the impact of grounding on distribution and transmission facilities; grounding scheme design; and an implementation strategy for Alberta. The AESO also engaged a consultant, PS Technologies Inc. (PSTI), to develop a white paper titled, *White Paper on DER Effective Grounding – Screening and Study Methodology, TOV and TRV Study Methodology* (PSTI White Paper)[4], a copy of which is attached as *Appendix A*.[5] The PSTI White Paper provides an overview of relevant background, an explanation of the relevant theoretical concepts**,** a jurisdictional review, and a screening and study methodology on effective grounding and the associated concepts of temporary overvoltage (TOV) and transient recovery voltage (TRV).

This AESO DER Roadmap Integration Paper:

- provides an update to stakeholders, including DFOs, TFOs, DER owners, the Alberta Utilities Commission, and other interested parties, about the results of the TPEG's work;
- articulates the AESO's rationale for recommending the adoption of relevant industry standards and common practices regarding grounding schemes into DFOs' technical interconnection requirements; and
- sets out the AESO's recommended implementation approach, developed in collaboration with the TPEG.

This AESO DER Roadmap Integration Paper is also intended to assist interested parties in assessing the potential impacts that the AESO's recommendations may have on them, including current or planned projects, facilities, and services.

3. Objectives and Scope

One of the integration activities associated with the *AESO DER Roadmap* (DER Roadmap integration activities) is the need to address reliability concerns related to electrical protection schemes, including the grounding schemes for DERs connecting to the AIES. This AESO DER Roadmap Integration Paper, together with the appended PSTI White Paper in *Appendix A*, articulates complex grounding and other related issues associated with DERs connecting to the AIES, and provides guidance in terms of grounding scheme design.

The AESO intends to use this AESO DER Roadmap Integration Paper to establish alignment amongst the AESO, TFOs, DFOs, and the owners of DERs on the design and coordination of grounding schemes, including parties' respective roles and responsibilities as set out in *Appendix B*. Furthermore, this AESO DER Roadmap Integration Paper will recommend that DFOs implement the agreed-upon grounding requirements as part of their respective distribution interconnection requirements or guidelines.

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[4] PS Technologies Inc., *White Paper on DER Effective Grounding – Screening and Study Methodology, TOV and TRV Study Methodology* (March 23, 2021).

[5] The AESO has relied on the PSTI White Paper as a source of information in preparing this AESO DER Roadmap Integration Paper, While the AESO has made every attempt to ensure that the information relied on in this AESO DER Roadmap Integration Paper is obtained from reliable sources, the AESO is not responsible for any errors or omissions contained in the PSTI White Paper.

The following items are considered out-of-scope for this DER Roadmap integration activity:

- requirements for zero-sequence and negative-sequence impedances of DERs;
- other types of TOV, aside from ground fault overvoltage, that may be observed with a DER connection, including load rejection overvoltage; and
- the impact of DER connections at substations that are connected to the transmission system using a T-tap configuration

4. Technical Context and Grounding-related Issues associated with DER Connections

4.1 Temporary overvoltage (TOV) issues

Power system grounding is important to determine the level of ground fault current (*i.e.*, fault current to flow to ground) during an unbalanced fault event. When the circuit breaker on the transmission system side, which is commonly the circuit breaker for the distribution feeder, detects the fault and is opened, and if the ground fault current from the DER is small, the neutral point of the transformer on the DER side will be shifted causing temporary overvoltage (TOV) on the healthy phases. This overvoltage may damage electrical equipment attached to the phases between the DER transformer and the opened circuit breaker on the transmission system side. Furthermore, many existing point-of-delivery (POD) transformers in the AIES are designed to serve only downstream loads. Therefore, the primary side of the POD transformers are not necessarily effectively grounded after a downstream DER is connected to the POD. If an upstream high voltage breaker is open, the connection of a DER could potentially change the status quo in the power system, and as a result, the transmission equipment between the POD transformer and the high voltage breaker could also be at risk.

If effective grounding is not in place on the high voltage side of the DER transformer and there is a single-phase-to-ground fault on phase A of the distribution line, for example, and, in response, the feeder breaker opens, TOV could be observed on phase B and C in the electrical island formed by the DER, which could persist for a short period of time. If TOV exceeds the overvoltage rating of the distribution equipment, including surge arrestors, the fault current from the DER can flow through the equipment and could potentially cause permanent damage. For the same reason, if the winding configuration of the POD transformer does not provide effective grounding on its high voltage side, and a high voltage breaker upstream of the POD transformer opens due to a single-phase-to-ground fault on phase A of the transmission line, then the TOV will be observed on phase B and C in the electrical island (consisting in part of the distribution system and a portion of the transmission system) formed by the DER. This would put both distribution and transmission equipment at risk. If the surge arrestors at risk use porcelain insulators inside a transmission substation, the debris from a potential explosion may further damage adjacent equipment and compromise personnel safety. Therefore, to avoid the TOV issue, it is important to maintain effective grounding on the distribution system when connecting a DER. If the primary side of a POD transformer on the upstream side of the DER does not provide effective grounding, then a grounding assessment and mitigation measures on the transmission side are necessary.

Effective grounding can effectively mitigate TOV caused by a ground fault. On the other hand, effective grounding may introduce a new challenge. For example, transmission-connected generation requires effective grounding to mitigate TOV on the high voltage side of the transmission system. Effective grounding on the generation side means an additional path with appropriate zero-sequence impedance to allow an appropriate amount of zero-sequence current to flow from the generating facility to the fault so that the neutral point of the transformer will not shift to cause overvoltage. A consequence is that this may reduce fault current contribution from the transmission system side. Whereas the fault current reduction from the transmission system side does not compromise transmission line protection since the line protection scheme is installed on both ends of the transmission line, the same phenomenon may be a concern on a distribution system. Given that it is impractical to install protective relays at the end of the distribution feeder opposite the transmission substation, feeder overcurrent protection is commonly used instead. When a DER is connected, effective grounding can mitigate TOV issues while the grounding scheme allows additional ground fault current contribution from the DER and may reduce ground fault current contribution from the transmission system side below the pick-up current of feeder overcurrent protection to detect the fault. Therefore, grounding scheme design requires special attention to the potential for desensitization of the distribution feeder overcurrent protection. Overall, the grounding scheme design of a DER connection must achieve a balance between TOV mitigation and the impact on the distribution feeder protection scheme.

4.2 Issues associated with DER grounding schemes

It is noteworthy that TOV may not be fully mitigated with effective grounding. This is because the ground fault current is determined not only by the zero-sequence topology and the associated impedance resulting from the winding configuration of the transformer, but also by the zero-sequence and negative-sequence impedances of the DER and its grounding scheme. If the zero-sequence and negative-sequence impedances of the DER are very large, the ground fault current will be very small, and the neutral point of the transformer will be shifted regardless of the transformer's winding configuration. A DER, particularly inverter-based generation, can have a wide range of zero-sequence and negative-sequence impedances depending on the inverter control methodology and settings. At present, the AESO and utilities in Alberta have not established authoritative requirements regarding zero-sequence and negative-sequence impedances of DERs. As previously discussed, this AESO DER Roadmap Integration Paper does not elaborate on this topic, but the AESO may explore it in the future.

As explained earlier, there is a feeder relay desensitization issue when effective grounding is in place to mitigate TOV on a distribution feeder for a DER connection. This is a unique problem on the distribution system. Distribution feeders use overcurrent relays installed in a transmission substation to detect and clear a fault on distribution feeders. The overcurrent relays monitor phase current and zero-sequence current (which indicates ground fault current) from the transmission system side to detect the fault in a timely manner. Given that most faults are single-line-to-ground, ground fault current can achieve much quicker fault detection than phase fault current. Protection engineers thus use the overcurrent relay with zero-sequence current detection to effectively clear the unbalanced fault on distribution feeders. Adding a DER to a distribution feeder will change the fault current contribution direction from radial (from the transmission system to the fault only) to multi-directional (both from the transmission system and from the DER to the fault). Prior to the connection of the DER, distribution feeder overcurrent relays would have measured 100% of the ground fault current. After adding a new grounding source on the DER side, the overcurrent relay may measure less fault current-to-ground from the transmission system side. This is a well-known challenge for distribution feeder protection, and it is referred to as "current desensitization" or "current blinding". This protection problem is obvious in the zero-sequence impedance network for unbalanced faults.[6] As a result, the ground overcurrent protection inside the substation could suffer a loss of sensitivity and reduction of fault detection capability. Compromising feeder overcurrent protection system-wide, on many feeders with DER connections, is a concern for all market participants, particularly TFOs and DFOs from the perspective of public safety.

4.3 Transient recovery voltage (TRV) issues

Other than TOV, a change to a grounding scheme due to a DER connection could cause distribution or transmission breakers to fail to interrupt electrical current. When a circuit breaker is opening to interrupt electrical current caused by a fault, the incoming side of the breaker (transmission system side) will attempt to return to the power frequency voltage while the outgoing side of breaker (load-serving side) will experience voltage oscillation. The industry uses point-by-point voltage difference at the incoming side and at the outgoing side of the circuit breaker to indicate breaker current interruption capability during the opening process. This is referred to as the transient recovery voltage (TRV) rating of the breaker. If the voltage difference between two contacts of the circuit breaker becomes so high and so steep that it exceeds the circuit breaker's TRV rating, then electrical current could restrike between the contacts leading to a disastrous breaker failure, which may result in a significant system disturbance. For safety and reliability reasons, such system performance deterioration on both the distribution and transmission systems resulting from the connection of DERs must be avoided to the extent possible.

For example, if a DER connection does not provide effective grounding on its primary side and there is a single-phase-to-ground fault on the distribution feeder, there could be more fault current from the transmission system side than was present before the DER was connected. This would result in the circuit breaker having to interrupt higher fault current than was necessary prior to the connection of the DER. Because of this, a study would be required to confirm that there is no violation to a circuit breaker's TRV rating when interrupting this larger current associated with the DER connection with non-effective grounding. Essentially, a DER connection can add more risk to both distribution and transmission breakers in the event of a TRV issue. Ensuring that there is effective grounding in the distribution and transmission systems can reduce such risk; however, it may not guarantee avoidance of transmission TRV issues because of an increased overall fault current level associated with the DER connection.

4.4 Importance of effective grounding for DER connections

As discussed above, improperly designed DER connections on existing distribution feeders can have negative impacts on the existing grounding scheme, which impacts the reliability of both the distribution and transmission systems because of increased risks to equipment, protection performance, and public safety. Effective grounding is required on the primary side of a DER connection on both the distribution and transmission systems in order to avoid TOV and TRV. On the other hand, effective grounding may desensitize distribution feeder overcurrent relays. Therefore, to ensure TOV and feeder protection desensitization are within acceptable tolerances, and to avoid TRV, the grounding scheme design may utilize various grounding devices and designs, including transformer winding configurations, grounding transformers, and grounding reactors or resistors as required to optimize the grounding solution. Furthermore, the grounding scheme design requires coordination among the DFO owner and relevant

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[6] For balanced faults, the positive sequence current from a DER usually does not cause any current desensitization. This is because the MVA capacity of the DER is much smaller than the MVA capacity of the distribution feeder on the transmission system side.

DFO, and TFO. To assist the reader, *Appendix C* includes examples to illustrate how the grounding scheme could theoretically impact TOV, TRV, and feeder relay desensitization.

Overall, effective grounding and associated issues in DER connection projects are complicated, requiring a balance between effective grounding and feeder protection desensitization. Inverter-based generation will require the engineer's knowledge and experience in transient study rather than power flow when studying TOV and TRV. For greater insight into effective grounding and associated phenomena, the PSTI White Paper provides detailed explanations on the background of grounding schemes and related TOV and TRV issues, a review of other jurisdictions' DER interconnection requirements and guidelines relating to grounding, and an effective grounding scheme screening and study methodology. The PSTI White Paper includes detailed explanations of grounding scheme concerns.

Theoretically, a three-phase ungrounded fault with a DER that introduces any unbalanced phase to ground voltages may cause more severe TOV and TRV issues when the DER connection does not have effective grounding on its primary side. However, the three-phase ungrounded fault has a very low likelihood of occurring. It is an acceptable practice to keep a three-phase ungrounded fault out of scope when evaluating TOV and TRV.

Notably, other types of overvoltage, such as load rejection overvoltage, may be observed with a DER connection. Multiple factors could contribute to the overall TOV, all of which are equally important to consider when a DFO reviews a given DER connection. However, as previously discussed, these types of overvoltage are considered out of scope for this DER Roadmap Integration Paper because they are not attributed to grounding.

5. Current State in Alberta

Most DFOs in Alberta have their own distribution technical interconnection requirements or guidelines that apply to DERs connecting to the DFOs' respective distribution systems. The interconnection requirements or guidelines establish acceptable grounding schemes for a DER connection. However, the PSTI White Paper (see *Appendix A*) has identified the following areas that it considers may not have been addressed sufficiently or with sufficient detail:

- Some DFOs' grounding requirements or guidelines require solid grounding, instead of effective grounding.
- DFOs' grounding requirements or guidelines lack clarity on effective grounding for inverter-based DERs which, unlike machine-based DERs, do not have consistent sequence impedances.
- DFOs' grounding requirements or guidelines lack criteria for acceptable TOV and TRV.
- DFOs' grounding requirements or guidelines do not indicate the need for design coordination with TFOs even though the grounding scheme may cause TOV and TRV on both the distribution and transmission systems. As a result, DFOs may make decisions on distribution grounding scheme design without TFOs' input or agreement, which in turn can increase risks and may have negative impacts on transmission facilities.
- DFOs' grounding requirements or guidelines do not consider unbalanced current desensitization on their feeder protection.

Given these gaps and differences in existing DFO interconnection requirements or guidelines, the AESO has observed inconsistent engineering practices in proposed grounding schemes for DER connection projects. In some cases, extensive technical discussions have been required to ensure that all parties fully understand the grounding-related issues in a given project. There is a risk that the scope of work required to implement the grounding requirements necessary for a particular project could result in delays to the project schedule, potentially impacting the economic viability of the project.

With respect to project modelling, the AESO currently requires distribution modelling data for a DER project to be submitted in a Project Data Update Package (PDUP), in accordance with updated AESO Information Document #2010-001R, *Facility Modelling Data,* which relates to Section 502.15 of the ISO rules, *Reporting Facility Modelling Data*. DER transformer winding configuration and specific grounding devices will impact the zero-sequence impedance in modelling. For further clarity, the AESO plans to provide guidance in the future on how grounding devices on both transmission and distribution systems should be modelled in the project connection process.

6. Standards & Jurisdictional Review

Per IEEE C62.22-2009 – *IEEE Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems* (IEEE C62.22), the coefficient of grounding (COG) is defined as the percentage ratio of E_{LG}/E_{LL} between the sound (un-faulted) line-to-ground voltage (E_{LG}) and system nominal line-to-line voltage (E_{LL}), for unbalanced faults (*i.e.*, both single-line-to-ground (SLG) and phase-to-phase-to-ground (2LG)). To quantify a grounding scheme as being effective or not, IEEE 141-1993 – *Recommended Practice for Electric Power Distribution for Industrial Plants* (IEEE 141) defines that if COG ≤ 80%, then the grounding scheme is deemed to be effective. If a system's COG is higher than 80%, then it is non-effectively grounded. The definition of "effectively grounded" and "non-effectively grounded" is also presented in Sections 7.1 and 7.2 in IEEE C62.92.1-2016 – *Guide for the Application of Neutral Grounding in Electrical Utility Systems - PART I: Introduction* (IEEE C62.91.1). Notably, this definition applies to the electrical utility system rather than inside generating facilities, which may follow different effective grounding definitions defined in other IEEE standards.

Based on the definition above, effective grounding can keep TOV caused by an unbalanced fault within an acceptable range and keep the line-to-ground voltage of un-faulted phases less than 1.38 times[7] the nominal line-to-ground voltage during an unbalanced fault. However, DFOs may customize the range and define more stringent TOV requirements in their distribution interconnection requirements or guidelines, such as less than 1.30, 1.25 or 1.20 times the nominal line-to-ground voltage.

The PSTI White Paper (see *Appendix A*) provides an extensive jurisdictional review.[8] The review includes Canadian jurisdictions such as Hydro One, BC Hydro, and SaskPower, and U.S jurisdictions such as Fortis Central Hudson, PG&E, Xcel Energy Colorado, and Eversource Energy. Market participants are encouraged to read details in *Appendix A*. To summarize, however, all jurisdictions have effective grounding requirements for DER connections, albeit with slightly different criteria. Some jurisdictions have developed distinct grounding requirements based on the type of DER. This approach also takes into

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[7] This value is derived as follows: 1.38 pu accords with the effective grounding definition of IEEE 141-1993. That is, <= 80%*1.732 = 1.38 pu of phase voltage (line-to-ground voltage).

[8] See *Appendix A* at Section 1.4

consideration that effective grounding requires a balance between TOV and desensitization of feeder overcurrent relay.

7. AESO's Proposed Guideline

The AESO, in consultation with DFOs and TFOs, proposes the following recommendations regarding effective grounding and its related TOV, TRV, and feeder relay desensitization issues.

- The AESO shares the PSTI White Paper with DFOs, TFOs, market participants and interested stakeholders for awareness of the complexity of effective grounding and related issues associated with DER connections.

- The AESO recommends DFOs, TFOs, and market participants use the screening methodology illustrated in Section 4.4 of the PSTI White Paper in *Appendix A*.

- The AESO recommends that all generation and loads (including energy storage resources operating in both charging and discharging modes) connecting on a distribution system shall appear as being effectively grounded[9] as viewed from the transmission system. Please note that for transmission-connected generation and loads, subsection 10(3) of Section 502.1 of the ISO rules, *Aggregated Generating Facilities Technical Requirements*, subsection 11(4)(c) of Section 502.5 of the ISO rules, *Generating Unit Technical Requirements*, subsection 10(4)(c) of Section 502.13 of the ISO rules, *Battery Energy Storage Facility Technical Requirements*, and subsection 6 of Section 502.7 of the ISO rules, *Load Facility Technical Requirements* are existing authoritative requirements that require the transmission system be operated as an effectively grounded system at all times, including after the connection of a DER to an existing load facility.

    - For a distribution-connected source (including both generation and energy storage resources) equal to or greater than 5 MW, DFOs' distribution interconnection requirements or guidelines shall ensure either i) that the distribution system is operated as an effectively grounded system, or ii) effective grounding on the medium-voltage[10] side of the transformer. The AESO and TFOs will do a reasonableness check on the grounding scheme and request the grounding study report of the DER as required.

    - For a distribution connected source less than 5 MW, DFOs' distribution interconnection requirements or guidelines shall ensure either i) that the distribution system is be operated as an effectively grounded system, or ii) effective grounding on the medium-voltage side of the transformer. The AESO and TFOs will fully rely on the DFOs to assess the grounding scheme.

    - Deviation from effective grounding on the medium-voltage side of the transformer will require a detailed study to show that there is no TOV or TRV concern on either transmission or distribution equipment, or both, as applicable. In addition, the study

[9] In accordance with subsection 1(1)(bbb) of the *Electric Utilities Act*, a feeder breaker within a substation falls within the legislative definition of "transmission facility".

[10] Medium voltage ranges between 1 kV and 35 kV as per IEEE 1585-2002.

results and mitigation measures must be reviewed and approved by the relevant DFOs, TFOs, and the AESO.

- The AESO will rely on DFOs and TFOs to prevent unacceptable reliability issues, such as equipment damage or safety concerns associated with non-effective grounding or inappropriate grounding of DER connections. The AESO will include generic grounding scheme requirements to DFOs and DERs in the AESO functional specification documents for DER projects, requiring that the distribution system operate as an effectively grounded system following the connection of the DER to the distribution system. This requirement shall effectively mitigate incremental risk to change the grounding effectiveness on the transmission system. The AESO must be notified if a DFO seeks exceptions. The AESO can also request the grounding study report from the DFOs or perform reasonableness checks on grounding through PDUP modeling review as required.

- The AESO recommends that DFOs review, and if necessary revise, their technical interconnection requirements or guidelines relating to effective grounding, TOV, TRV, and feeder relay desensitization to address the reliability and safety concerns outlined in this document.

- The AESO recommends that TFOs and DFOs inform the AESO about their best engineering practices to deal with effective grounding, TOV, TRV, and feeder relay desensitization by publishing or sharing their technical documents.

- The AESO may consider revising effective grounding requirements in various ISO rules for the transmission system. Should the AESO determine that AESO requirements are necessary in the future, these will be addressed through the applicable processes for developing ISO rules and Alberta reliability standards.

- The AESO proposes a RACI table to identify roles and responsibilities of different entities regarding grounding, TOV, TRV, and feeder relay desensitization (see *Appendix B*). Determining the appropriate grounding for a DER connection will be a joint effort requiring coordination amongst the DER owner, DFO, TFO, and the AESO.

- With respect to effective grounding and feeder relay desensitization:

    - For a DER connection transformer with a winding configuration such Dyg[11], the AESO recommends that DFOs mandate an overvoltage study report from the DER owner to demonstrate that overvoltage is lower than the relevant DFO's requirements.

    - For a DER connection transformer with a winding configuration such as YGyg or YGygD[12], the AESO recommends that DFOs mandate an overvoltage study report from the DER owner to demonstrate that overvoltage is lower than the relevant DFO's requirements, particularly for inverter-based generation.

    - For a DER connection transformer using a winding configuration such as YGd, the AESO recommends that DFOs approve such configuration from the viewpoint of effective

[11] Uppercase lettering indicates primary winding whereas lowercase lettering indicates secondary winding. "YG" means grounded Y.

[12] "D" refers to tertiary winding.

grounding. However, given the corresponding risks associated with zero-sequence current desensitization on the feeder breaker, the DER owner needs to receive approval from the DFO in consultation with the TFO, having regard for protection considerations.

- With respect to TOV:
    - In general, TOV at the distribution system level may propagate to the transmission system level via load transformers in transmission substations. The AESO recommends that DFOs, in consultation with TFOs, ensure the TOV is within an acceptable level so that the connection of DERs does not compromise the reliability of existing transmission facilities.
- With respect to TRV:
    - The AESO recommends that an assessment study be conducted for TRV ratings of circuit breakers, particularly on the transmission side and sometimes on the distribution side, that may be exceeded as a result of altered voltage characteristics and a change to the grounding scheme following a DER connection. Once the study is reviewed by the relevant DFOs or TFOs, the AESO recommends that DER owners resolve any concerns and align on the mitigation measures with the DFOs or TFOs during the scoping stage of the project.

8. AESO's Proposed Implementation Approach

Effective grounding is one of the technical requirements included in a DFO's distribution connection technical requirements or guidelines. The AESO relies on DFOs to implement and enforce this requirement with DER owners when connecting their DERs to the DFOs' respective distribution systems. If a DFO determines that the proposed DER requires AESO engagement (*i.e.*, the DER has maximum authorized real power greater than 5 MW or the size of the DER is sufficiently large to trigger the requirement for a system access service agreement with the AESO), a system access service request will be initiated with the AESO in accordance with the AESO Connection Process.[13] The AESO will perform a reasonableness check on the effective grounding, and if necessary, will facilitate a technical discussion amongst DFOs or TFOs to resolve any questions or concerns. The subsections below provide an overview of the AESO's current effective grounding check process.

8.1 Technical Requirement Alignment

The AESO intends to use this AESO DER Roadmap Integration Paper to align all DFOs and TFOs in Alberta on their understanding of effective grounding requirements and assessment practice. Each DFO and TFO is responsible for defining its acceptance criteria for effective grounding based on its respective equipment ratings and technical practices. The AESO plans to engage with the DFOs and TFOs to better understand their effective grounding requirements and assessment approaches.

8.2 Industry Practice

[13] An overview of the AESO Connection Process is available on the AESO website.

Alberta's DFOs and TFOs are the first line of defense for ensuring effective grounding for all new DER connection projects. For those DER connection projects that proceed through the AESO Connection Process, the AESO performs a reasonableness check on effective grounding as described in this AESO DER Roadmap Integration Paper. In addition, the AESO requires grounding study coordination amongst the DER owner, DFO, and TFO in the DER project's functional specification. The DER owner, DFO, and TFO may be required to submit an effective grounding study report. Furthermore, the agreed sequence data is submitted to the AESO in PDUPs as part of the DER connection process.

8.3 Inverter-based generation

Inverter-based generation has a wide range of negative- and zero-sequence impedance of generation, which creates additional complexity and technical challenges in assessing effective grounding. To alleviate this issue, the DER owner is responsible for providing the necessary data and information to the DFO to complete the grounding assessment and adjust the inverter control algorithm or settings, as required, in order to meet the DFO's effective grounding requirement. If the generation connection has an impact on a transmission facility, then the TFO and the AESO can request the study report and modeling information from the DER owner and DFO.

Appendix A – PSTI White Paper on Effective Grounding, TOV, and TRV

The AESO engaged PSTI to develop the enclosed white paper, including the following sub-topics.

- Theory of effective grounding
- Literature review on industry common practice in grounding scheme
- Review of transformer winding, grounding device, and relay desensitization
- Effective grounding screening methodology
- Effective grounding study methodology
- TOV study methodology
- TRV study methodology

Appendix B – Roles and Responsibilities

A – Accountable; **R** – Responsible; **C** – Consult; **I** – Inform

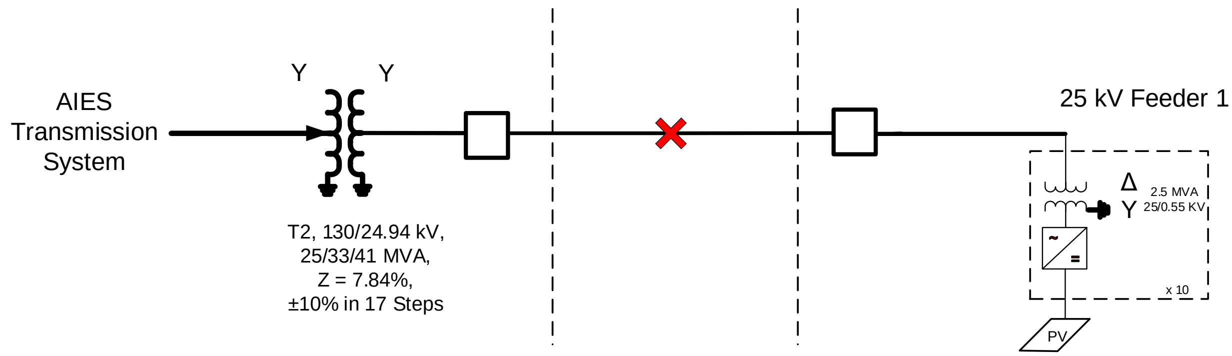
System	Topic	Task	AESO	TFO	DFO	DER Owner
Transmission	**Effective Grounding**	Rule/Requirements	A, R	C	I	I
		Study	C	C	C	A, R
		Approval	C	A, R	I	I
	TOV	Rule/Requirements	C	A, R	I	I
		Study	C	C	C	A, R
		Acceptance	C	A, R	I	I
	TRV (feeder breaker is transmission asset)	Rule/Requirements	C	A, R	I	I
		Study	C	C	C	A, R
		Approval	C	A, R	I	I
Distribution	**Effective Grounding**	Rule/Requirements	C	C	A, R	I
		Study	C	C	C	A, R
		Approval	I	C	A, R	I
	TOV	Rule/Requirements	C	C	A, R	I
		Study	C	C	C	A, R
		Approval	I	C	A, R	I
	TRV	Rule/Requirements	C	C	A, R	I
		Study	C	C	C	A, R
		Approval	I	C	A, R	I
	Feeder O/C Desensitization	Rule/Requirements	C	C	A, R	I
		Study	C	C	C	A, R
		Approval	I	C	A, R	I

For transmission facilities, the AESO is accountable and responsible for having a requirement for effective grounding in the ISO rules. If effective grounding on the transmission side is not assured with the connection of a DER, the DER owner will be accountable and responsible to conduct a study and share the results with the TFO and the AESO. Non-effective grounding may result in TOV risk to surge arrestors owned by TFOs. DER connection and non-effective grounding may also result in TRV risk to circuit breakers owned by TFOs. The AESO will rely on the relevant TFO, as the equipment owner, to decide whether to accept or reject the risk based on a DER owner’s study results. The equipment risk may create AIES reliability concerns. The TFO will consult the AESO if there is a risk to TFO equipment that could adversely impact the safe and reliability operation of the AIES.

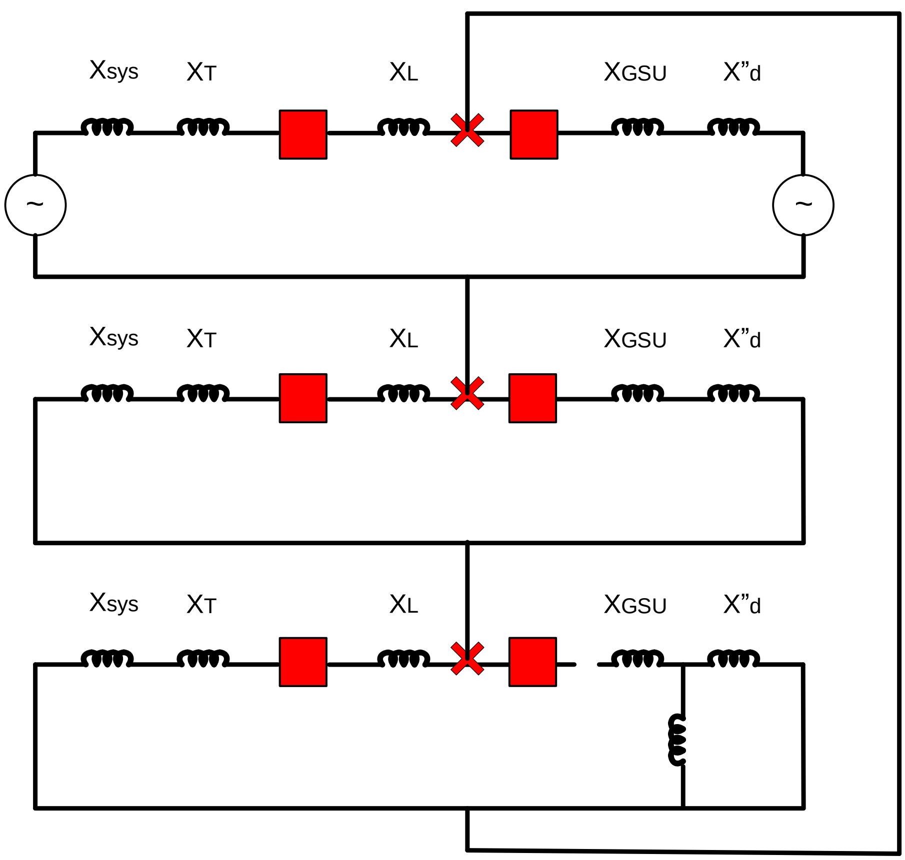
For distribution facilities, DFOs are accountable for any connection and operational requirements on the distribution system, including effective grounding, acceptable TOV, and TRV. If there are no requirements in place, a DFO is responsible for developing these distribution requirements in consultation with the relevant TFOs and the AESO. The DER owner is accountable and responsible for any studies on effective grounding, TOV, TRV, and feeder overcurrent relay desensitization. The TOV, TRV and feeder overcurrent relay desensitization issues on the distribution system may directly impact distribution equipment owned by the DFO and feeder breaker or feeder relays owned by the TFO. Given the possibility that TOV and TRV may occur on the transmission system, although the DFO is accountable and responsible for deciding whether to accept or require mitigation of the risks based on the DER owner’s study results, the DFO must always consult with the relevant TFO to address any concerns regarding effective grounding, TOV, and TRV from the transmission perspective. The AESO shall be informed by both the DFO and TFO if there is any significant risk to transmission facilities or transmission reliability.

Appendix C – Sequence Models for Illustration

B1 – An inverter-based DER connection with non-effective grounding on its primary side. Apply a single-phase-to-ground fault on phase A of the distribution feeder.



B2 – Sequence model before the feeder breaker is open. It shows potential TRV issue on the feeder breaker on all phases since the fault current from system side is larger than without the DER.



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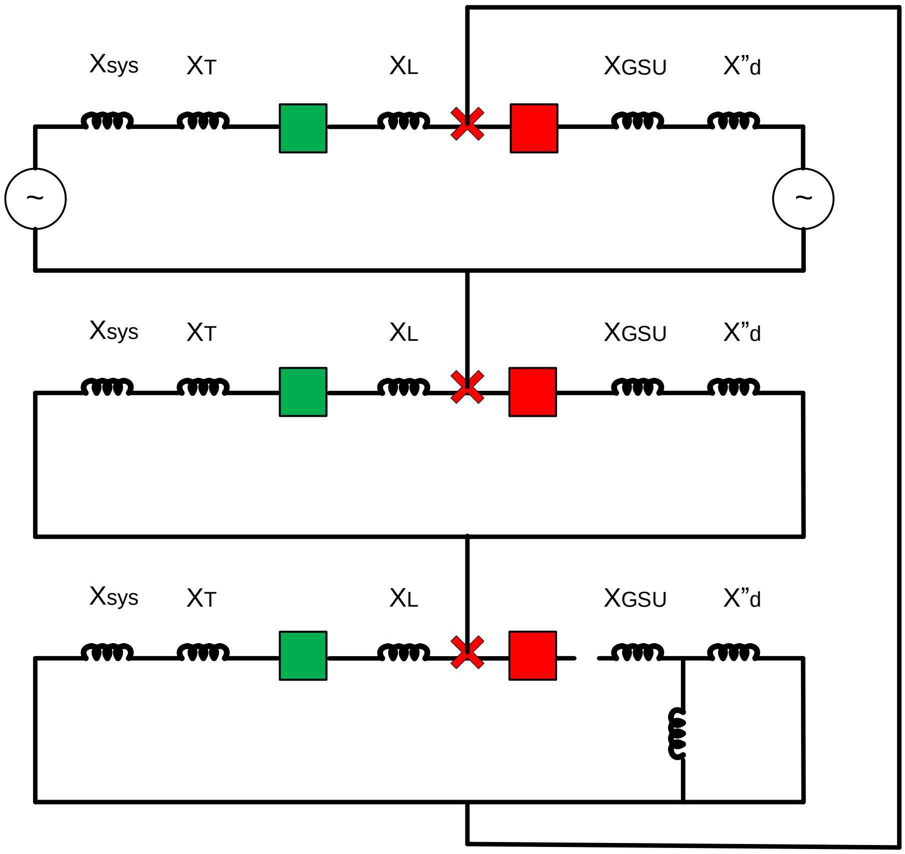
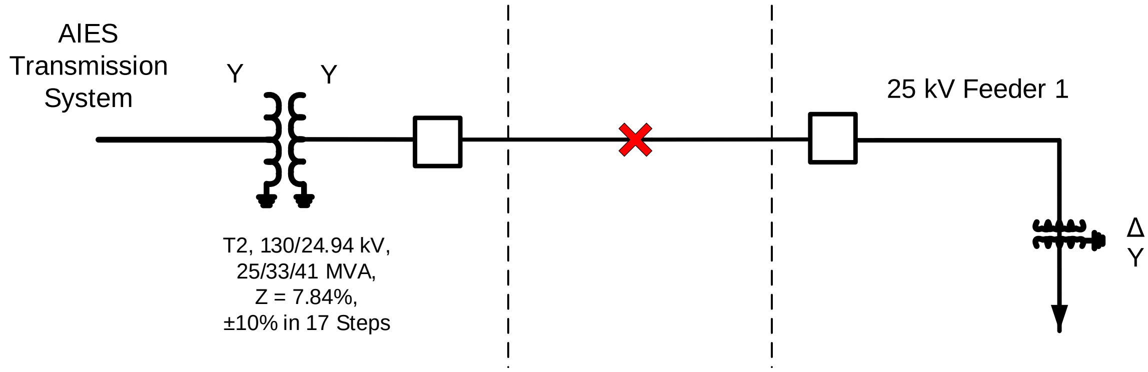
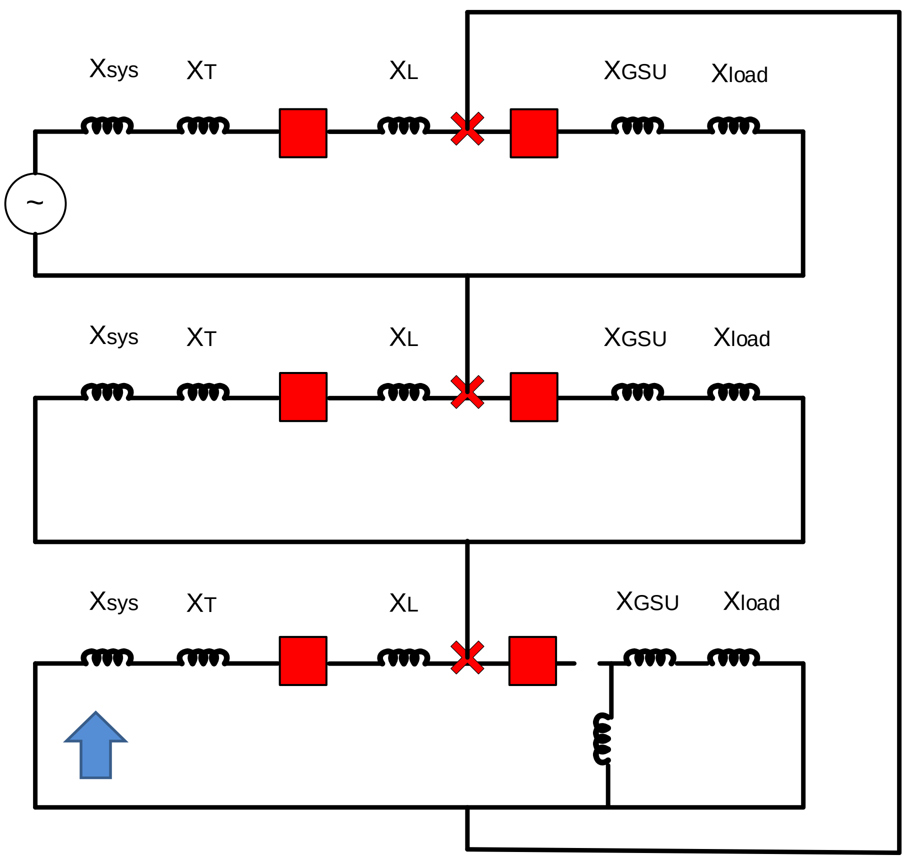
B3 – Sequence model after the feeder breaker is open. It shows potential TOV issue on phase B and C between the primary side of DER transformer and the opened feeder breaker.



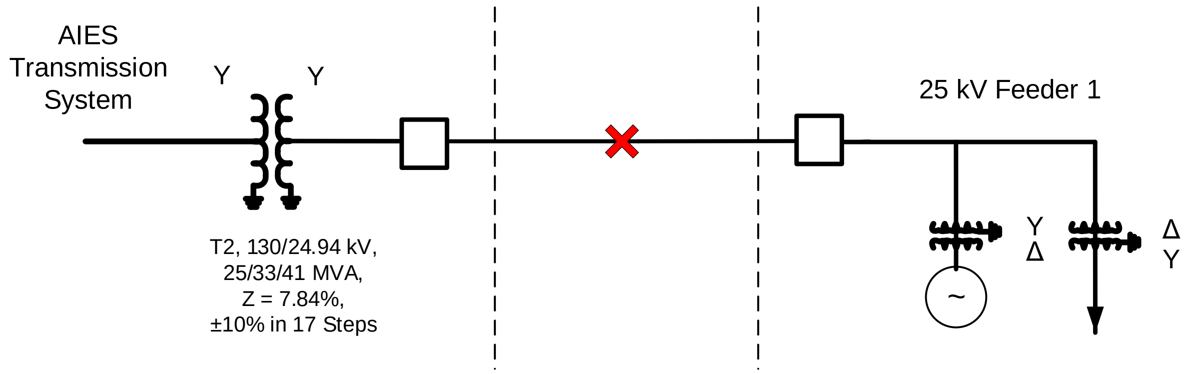
B4 – A distribution feeder connecting to a load only. Apply a single-phase-to-ground fault on phase A on the distribution feeder.



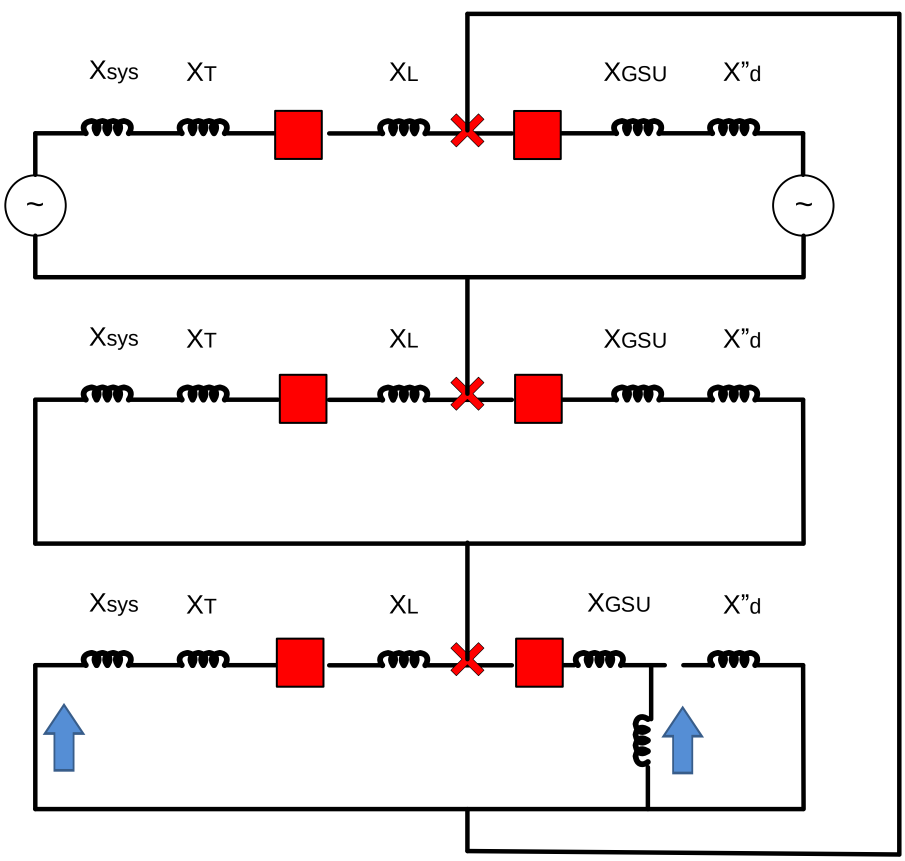
B5 – Sequence model before the feeder breaker is opened. All zero-sequence current flows from system side.



B6 – Add a machine-based DER with effective grounding on its primary side. Apply a single-phase-to-ground fault on phase A on the distribution feeder.



B7 – Sequence model before the feeder breaker is opened. Smaller zero-sequence current flows from system side. It illustrates the desensitization on feeder overcurrent relay.



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