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Recommendations for the configuration of breakers in power substations to isolate feeder circuits of Photovoltaic Solar Plants

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NORDEN Energy Inc. NORDEN Energy Inc. (NORDEN) is an engineering services company based in Calgary, Alberta, and Utah, USA; dedicated to the development, delivery and integration of power and energy facilities in Canada and internationally.

NORDEN's team includes a combined *experience of more than 50 years on transmission and substation projects related to Utilities and Oil and Gas Projects.* .

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NORDEN’s experience includes projects ranging from 138kV to 500kV in locations including:

- Western Canada and BC,
- Northwest Territories,
- Mexico,
- USA,
- The Caribbean and Central America.
- Australia
- United Kingdom
- France

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The company services include:

- transmission and substation designs,
- electrical studies including solar PV systems,
- electromechanical design,
- structural work,
- project engineering and construction management.

In addition, NORDEN has supported clients on various renewable energy projects and procurement processes, including solar energy procurements in Alberta and Saskatchewan.

THE PROJECT

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THE PROJECT

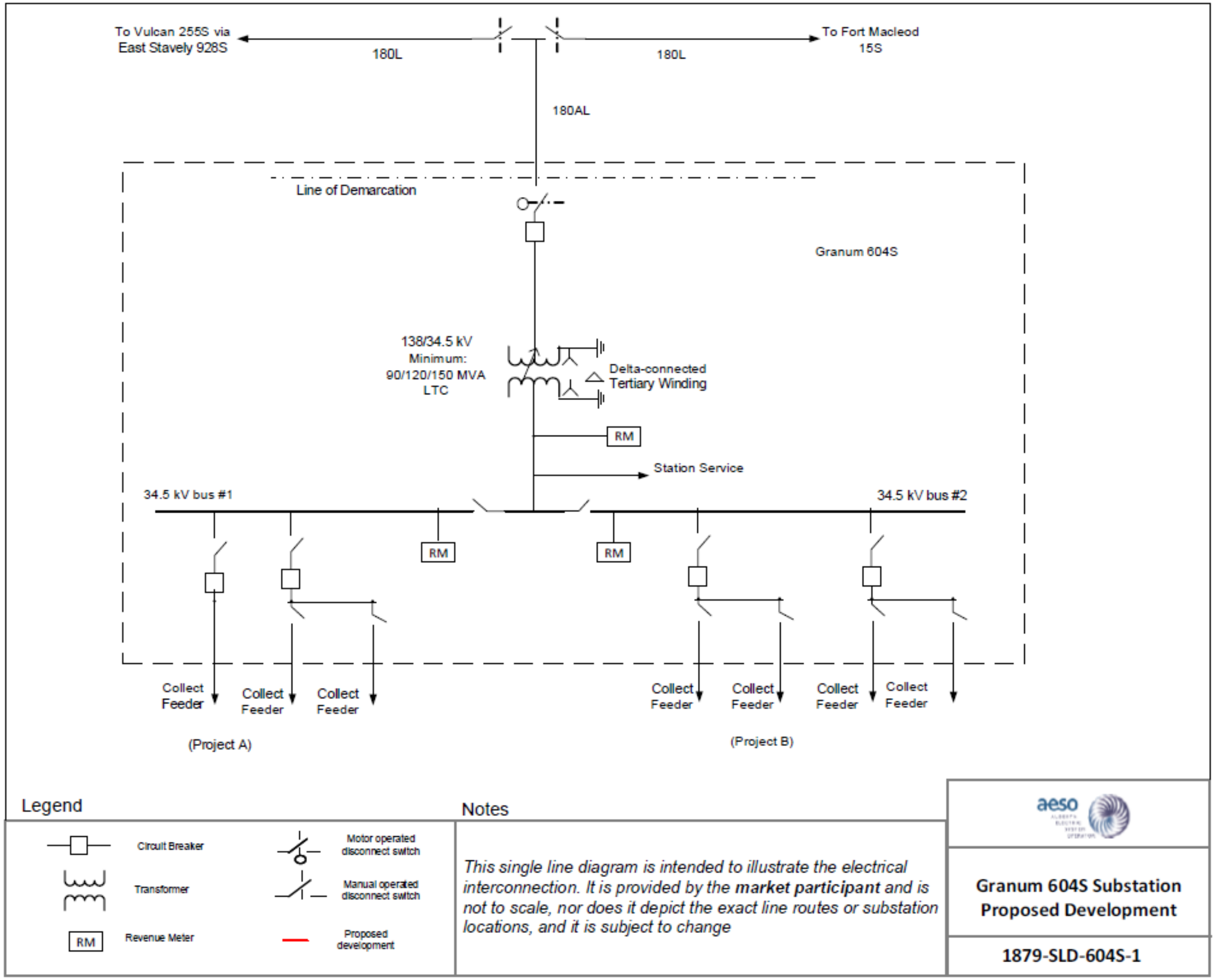
Aerial view

604S Granum 138kV, 130MWaC

Description

- The new 604S Granum substation provides interconnection of the Claresholm Solar photovoltaic plant with a capacity of 130MWac to the transmission system in Alberta, Canada.
- The configuration of this substation includes one (1) three-phase transformer 138/34.5 kV, 90/120/150 MVA, a split bar in 34.5kV, 4x34.5kV breakers and 7 incoming feeders of the photovoltaic solar plant.
- The 604S Granum substation is interconnected to the 138 KV 180L transmission line, via a T-tap connection.

THE PROJECT



Notes

*This single line diagram is intended to illustrate the electrical interconnection. It is provided by the **market participant** and is not to scale, nor does it depict the exact line routes or substation locations, and it is subject to change*

Granum 604S Substation
Proposed Development

1879-SLD-604S-1

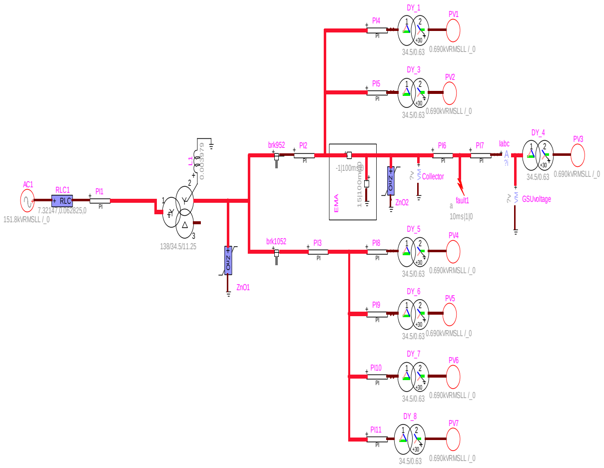
THE PROJECT

ELECTRICAL STUDY

The Issue

- If the voltage is allowed to rise excessively then surge arresters at the substation and at the ends of the 34.5 kV cable runs may be subject to overvoltage failure.
- The generator controllers may also be subject to overvoltage failure. It's essential to keep the voltage down to the withstand limits of the surge arresters and the generator controllers.

ELECTRICAL STUDY

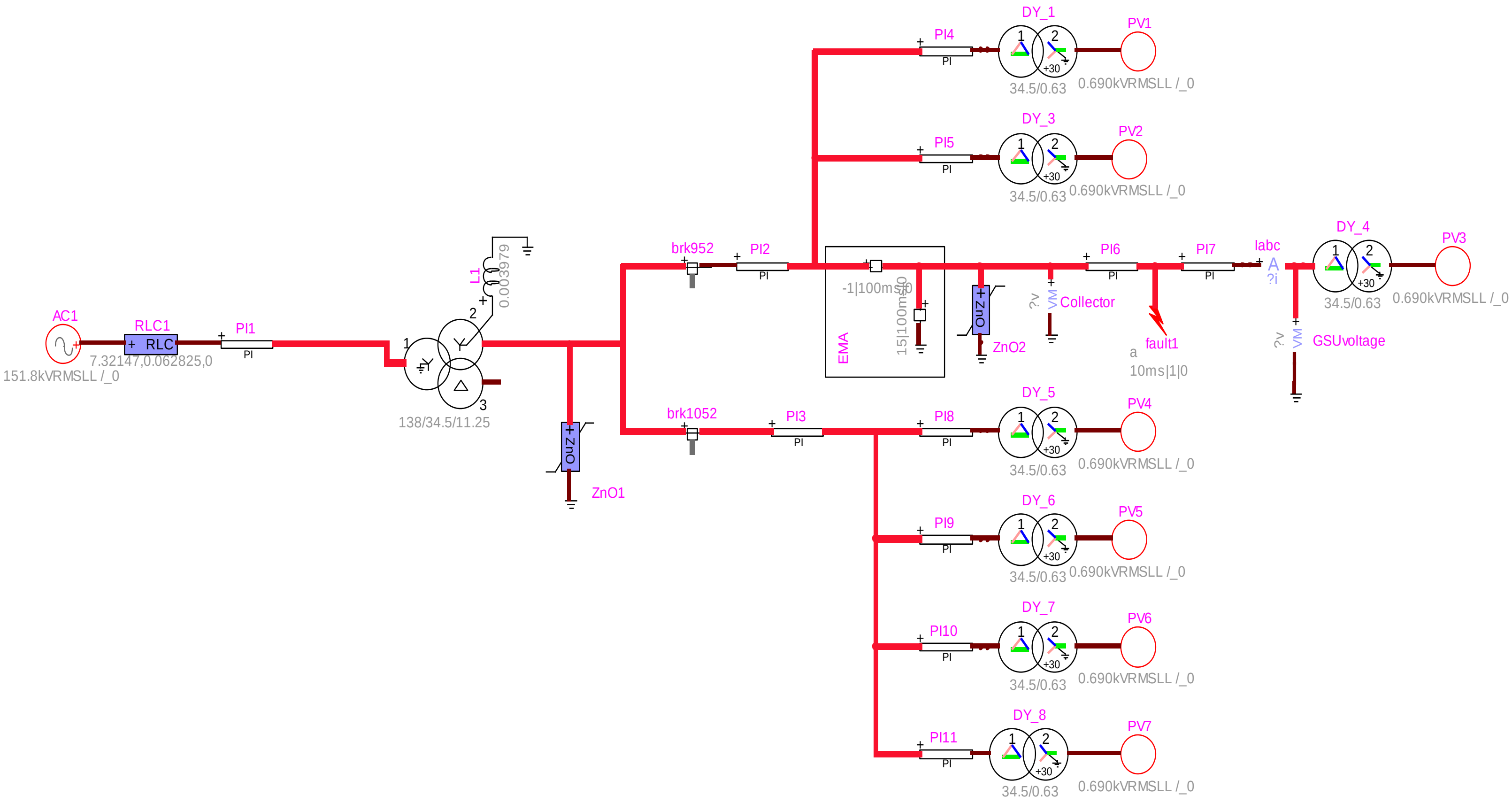


Electric modeling in PSCAD

Objectives

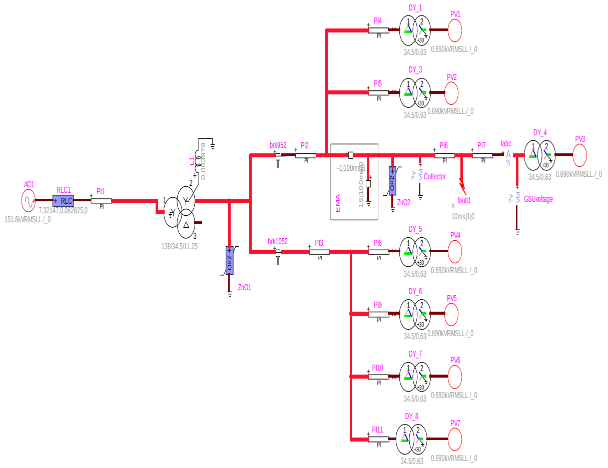
- Identification of maximum transient overvoltage (TOV) for the Medium Voltage (MV) collector system.
- Identification of strategies for TOV suppression.
- This type of studies are typically used in wind farms, but the experience is relatively new for large-scale solar plants.
- NORDEN participated in the detailed design of the complete substation, material review and monitoring of the energization.

ELECTRICAL STUDY



Electric modeling in PSCAD

ELECTRICAL STUDY



Electric modeling in PSCAD

Configuration of Electrical Model

- The 34.5 kV busbar system consists of two bars A and B: one with three feeders and the second one with four feeders. Each bar has an approximate installed generation capacity of 69.3 and 88.2 MVA from a group of 22 and 28 photovoltaic units respectively .
- Simulations for the feeders calculate the worst voltage condition that can appear in the MV equipment, once the system is isolated under failure. PSCAD software was used to calculate the TOV based on technical parameters of Generator Step-Up (GSU) transformers, collector systems, surge arresters, breakers, cable configurations, main transformer and 138kV network equivalent.
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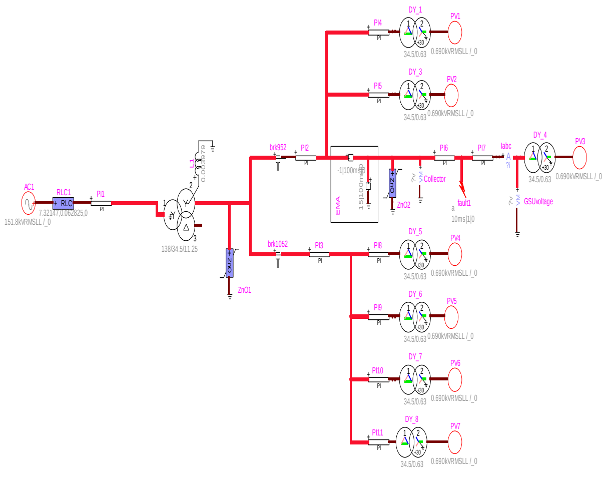
ELECTRICAL STUDY



Electric modeling in PSCAD

Configuration of Electrical Model

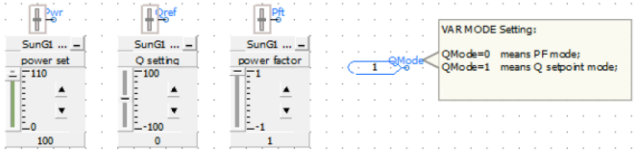
- **Breaker:** A three-pole breaker was used during the simulation. The switching angle for phase A considers a deterministic variation to compute the Inrush Current at all voltage waveforms.

- For phase B and phase C, the operation time of the breaker has a Gaussian distribution to consider the deviations in the circuit breaker mechanical closing time and the effects of prestrike. Standard deviation value for the Gaussian distribution was computed with equations (1) and (2).

- $$\frac{T}{4} = 3\sigma_s \qquad \textbf{(1)}$$

- $$\sigma_s = \frac{1}{12f} = 1.389\ ms \qquad (2)$$

ELECTRICAL STUDY



VAR MODE Setting:

QMode=0 means PF mode;
QMode=1 means Q setpoint mode;

Interface for User Application

Configuration of Electrical Model

- **Inverter:** The inverter SG3150U model was developed in PSCAD software through FORTRAN coded modules in accordance with the logic supplied by Sungrow.
- The following performance of the SG3150U inverter was included:
  1. Low Voltage Ride Through
  2. High Voltage Ride Through
  3. Reactive Power Control
  4. Frequency support
  5. Protection.

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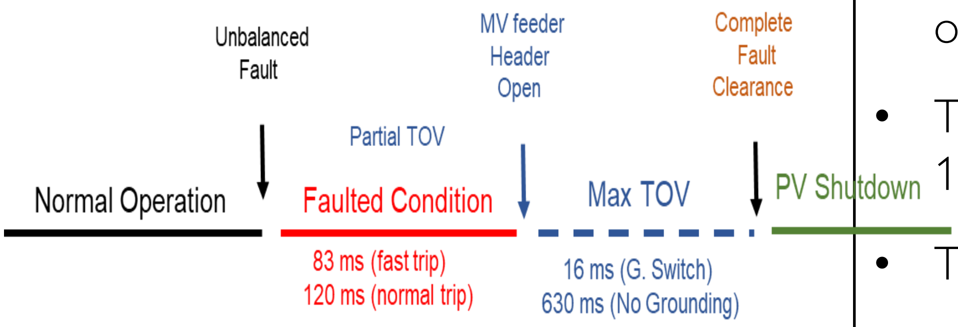
ELECTRICAL STUDY



Sequence of events

Methodology

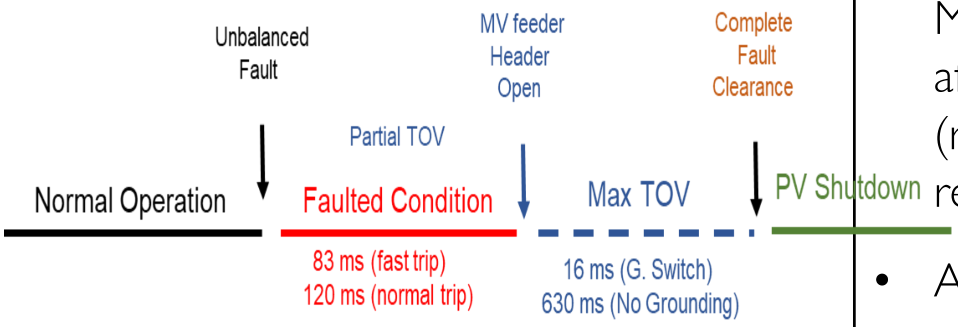
- The electrical model was built in PSCAD according to modeling criteria by the IEC 60071-4:2004 standard Technical report: Part 4 - Computational guide to insulation co-ordination and modelling of electrical networks.

- The maximum allowable voltage is 1.1 pu at the 138kV voltage level.

- TOV simulations consider the following stages:

  1. normal operation,
  2. an unbalanced failure,
  3. successful isolation of main feeder failures, and finally,
  4. a complete shutdown of the PV plant after internal response from the inverter protections.

ELECTRICAL STUDY



Unbalanced Fault

Partial TOV

MV feeder Header Open

Complete Fault Clearance

Normal Operation

Faulted Condition

Max TOV

PV Shutdown

83 ms (fast trip)
120 ms (normal trip)

16 ms (G. Switch)
630 ms (No Grounding)

Sequence of events

Methodology

- For the specific case of Granum 604S, the simulation began with the normal operation of the PV plant, once an unbalanced fault in the MV feeder is detected, the protection in the affected collector would react between 5 cycles (rapid response) and 7.5 cycles (normal response).
- After that, the collector system is isolated.
- Finally, the PV plant is turned off. The time that surge arresters and equipment are stressed with these transient surges depends on the type of technology and configuration of the switches for fault elimination.

SIMULATION SCENARIOS

SIMULATION SCENARIOS

Overhead connection to metalclad breaker

Considerations

- Maximum voltage surges under fault conditions may require considerable magnitudes of energy to be absorbed by the surge arresters.
- This absorbed energy by the surge arrester could exceed its maximum limits if proper TOV suppression is not installed.
- This study evaluates the response with fast and normal trip breakers per feeder in addition to the use of zig-zag transformers.
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SIMULATION SCENARIOS

Overhead connection to metalclad switch

Scenario 1:	Normal trip breaker (40-50ms) by feeder- No grounding
Scenario 2:	Fast trip breaker (<16ms) by feeder - No grounding
Scenario 3:	Normal trip breaker & Grounding Transformer (zig-zag) on each feeder
Scenario 3b:	Normal trip breaker for each 34.5kV busbar combined with a failure in the feeder switch and grounding transformer (zig-zag) for each feeder
Scenario 4:	Fast trip breaker (EMA) – with grounding
Scenario 5:	Fast trip breaker (EMA) on each 34.5kV busbar, grounding transformer (zig-zag) on each 34.5kV busbar, combined with a failure in the feeder breaker and grounding transformer (zig-zag) on each feeder

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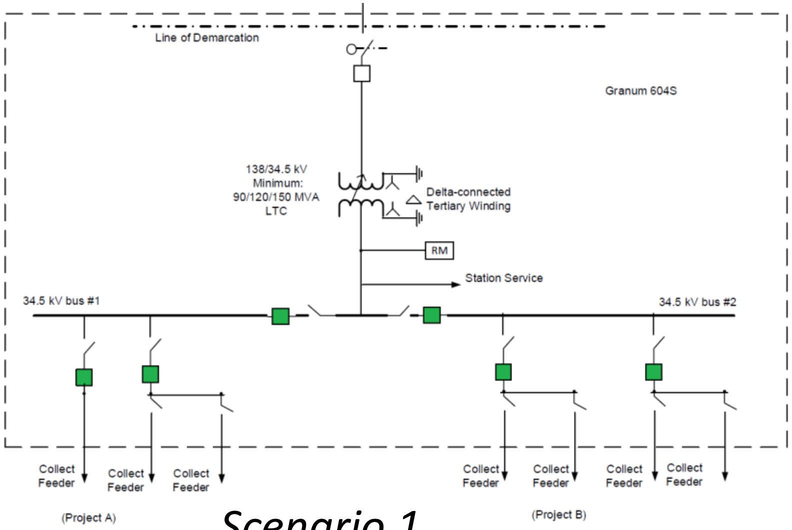
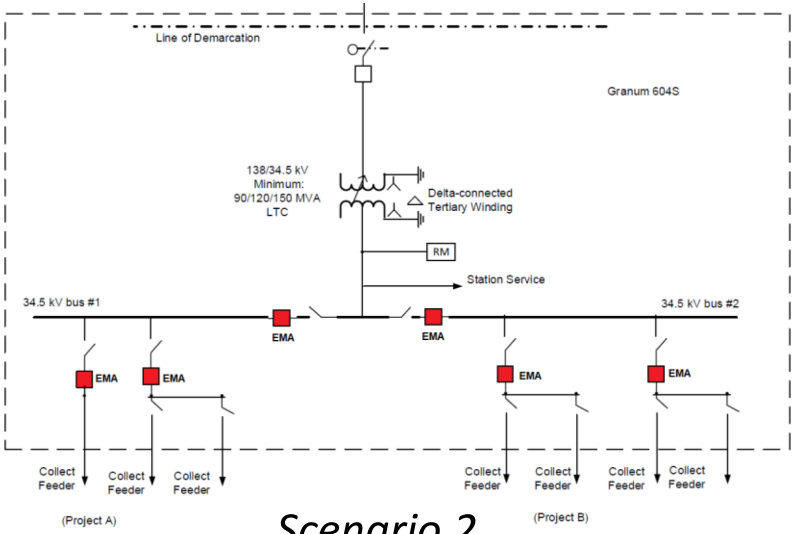
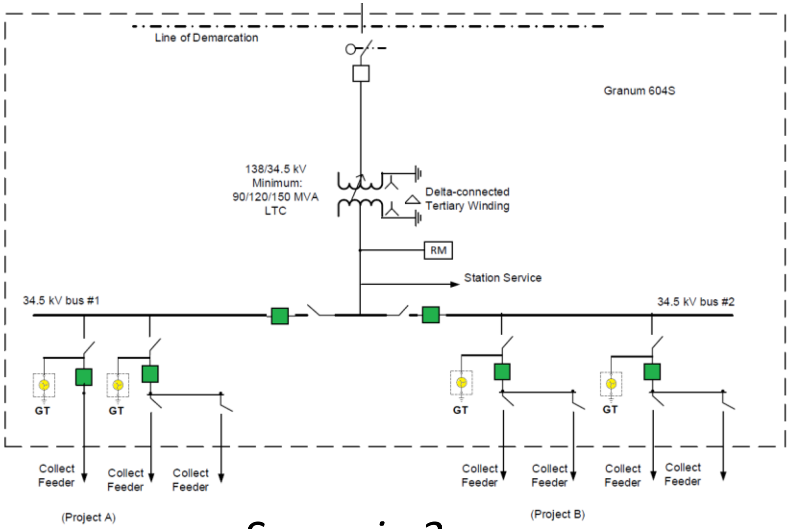
SIMULATION SCENARIOS



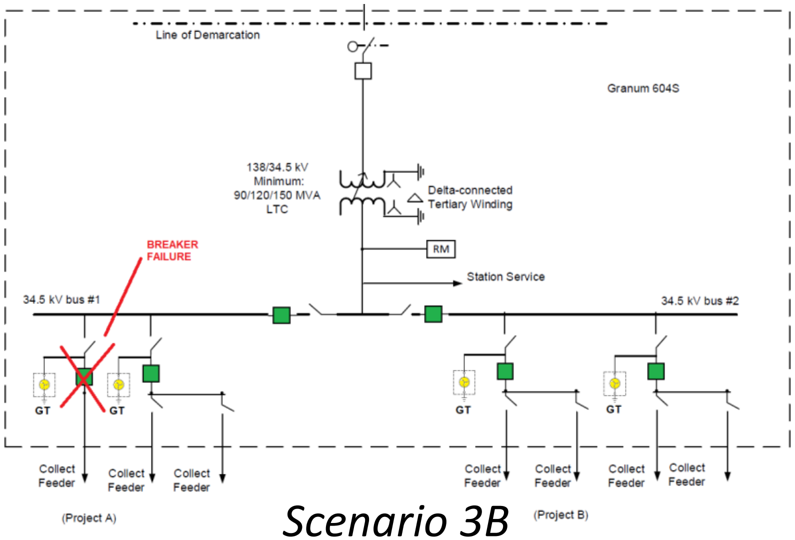
Scenario 1



Scenario 2

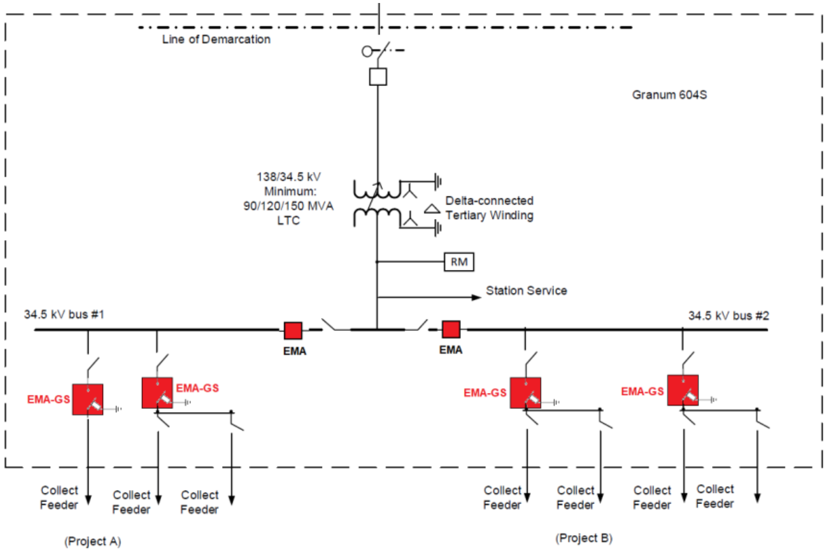


Scenario 3

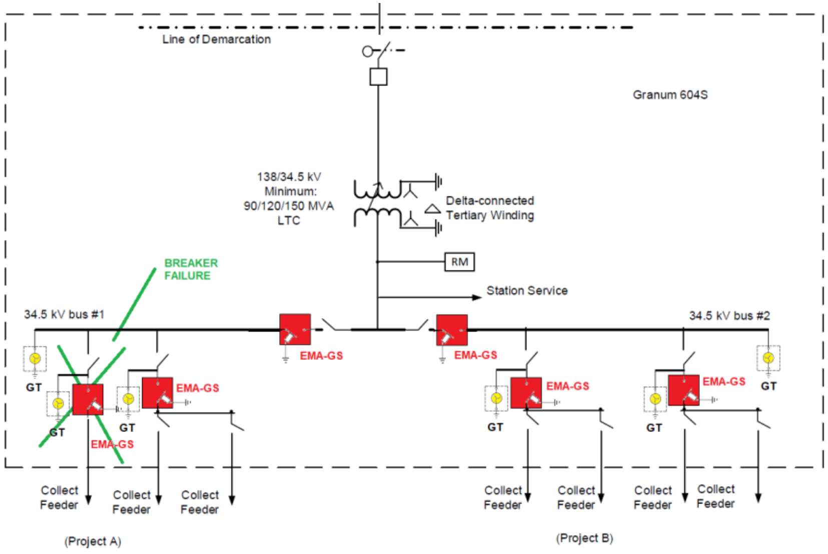


Scenario 3B

SIMULATION SCENARIOS

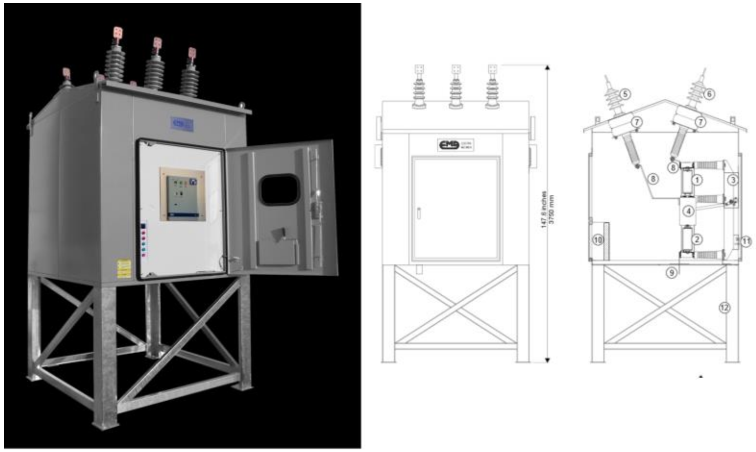


Scenario 4



Scenario 5

SIMULATION SCENARIOS



EMA: Fast trip breaker (<16ms)

Advantages:

- Less equipment to install
- Eliminates a potential source of oil spills / contamination / fire hazard from installations
- Lower power losses (kW)
- This type of equipment can be effectively used for generation curtailing schemes

Grounding transformer (zig-zag)

Advantages:

- Lower KVA's requirement than a delta-star transformer for the same fault current

RESULTS & CONCLUSIONS

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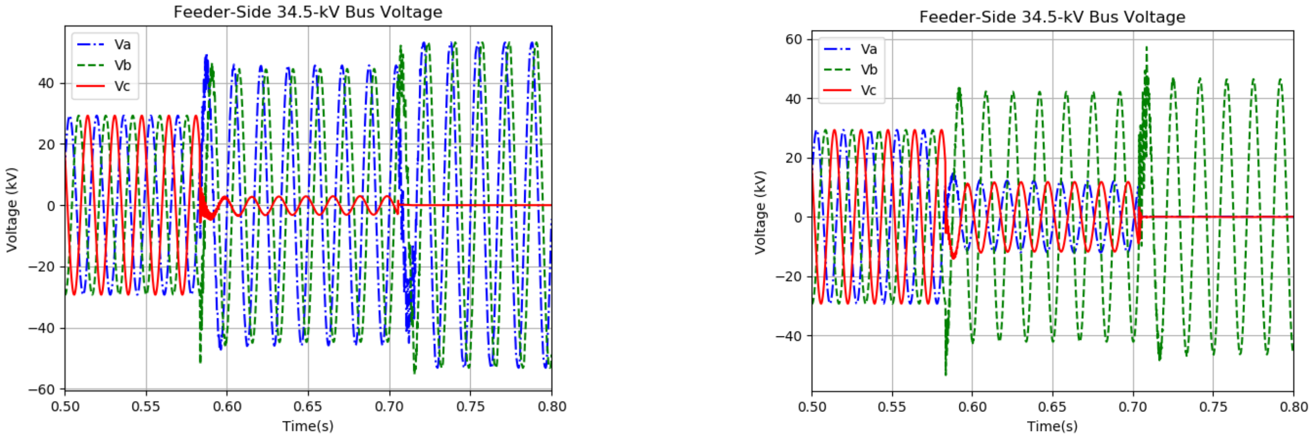
RESULTS

- Scenarios 1 and 2: The energy absorbed by the surge arrester exceeded its limit at 440 ms after the switch operation.
- Scenarios 3 and 4: overvoltage and energy for the surge arrester is within normal limits for grounding technologies.
- Scenarios 3b and 5: with a longer fault clearance time (370ms), energy of the surge arresters is shown within normal limits; confirming the convenience on using zig-zag transformer.

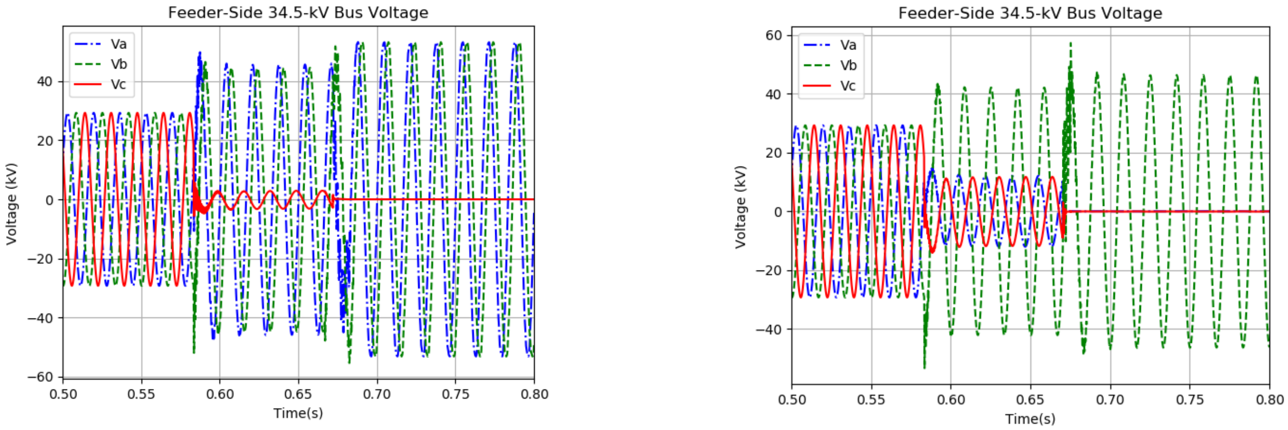
Case	Scenario	Fault	34.5 kV Collector Vmax [pu]	34.5 kV GSU Vmax [pu]	Arrester Emax (<150kJ) [kJ]
1	**1**	**SLG**	**1.96**	**1.96**	**223.29**
2	1	DLG	2.03	2.04	1.73
3	**2**	**SLG**	**1.97**	**1.97**	**219.91**
4	2	DLG	2.03	2.03	1.74
5	3	SLG	2.01	2.018	10.87
6	3	DLG	1.91	1.91	0.49
7	4	SLG	1.97	1.97	2.88
8	4	DLG	2.03	2.03	1.67
9	3b	SLG*	1.94	1.93	10.40
10	5	SLG*	1.94	1.94	10.64
	Fault SLG: Single Line to Ground DLG: Double Line to Ground * Scenarios 3b and 5 were tested with a faulted condition of 370 ms to simulate a breaker failure				

RESULTS


Feeder-Side 34.5-kV Bus Voltage

Feeder-Side 34.5-kV Bus Voltage

Figure 1. Surge arrester voltage under SLG (left) and DLG (right) considering the normal trip breaker and no grounding (scenario 1)


Feeder-Side 34.5-kV Bus Voltage

Feeder-Side 34.5-kV Bus Voltage

Figure 2. Surge arrester voltage under SLG (left) and DLG (right) considering fast trip breaker and no grounding (scenario 2)

RESULTS

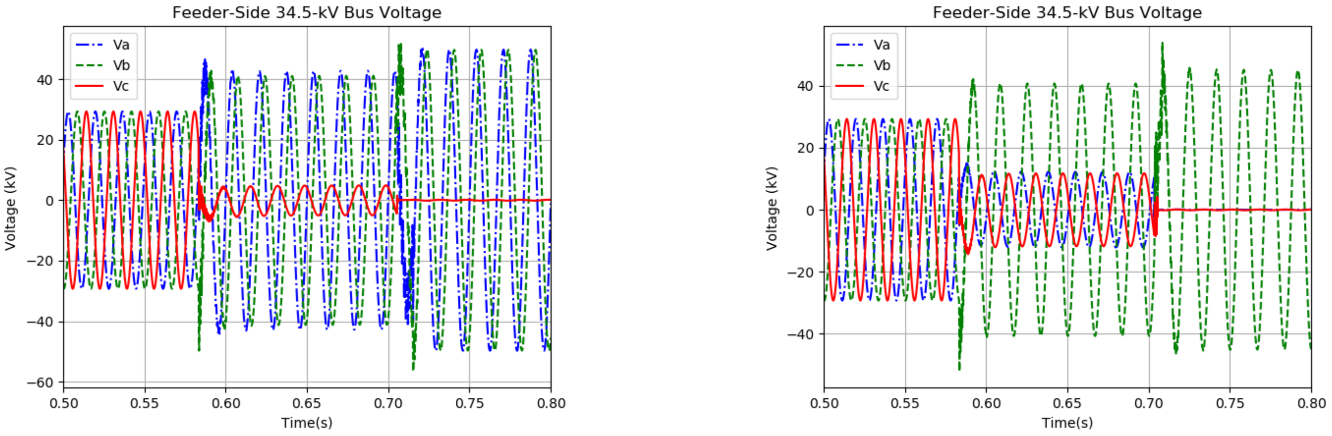


Figure 3. Surge arrester voltage under SLG (left) and DLG (right) considering normal trip breaker and grounding transformer (scenario 3)

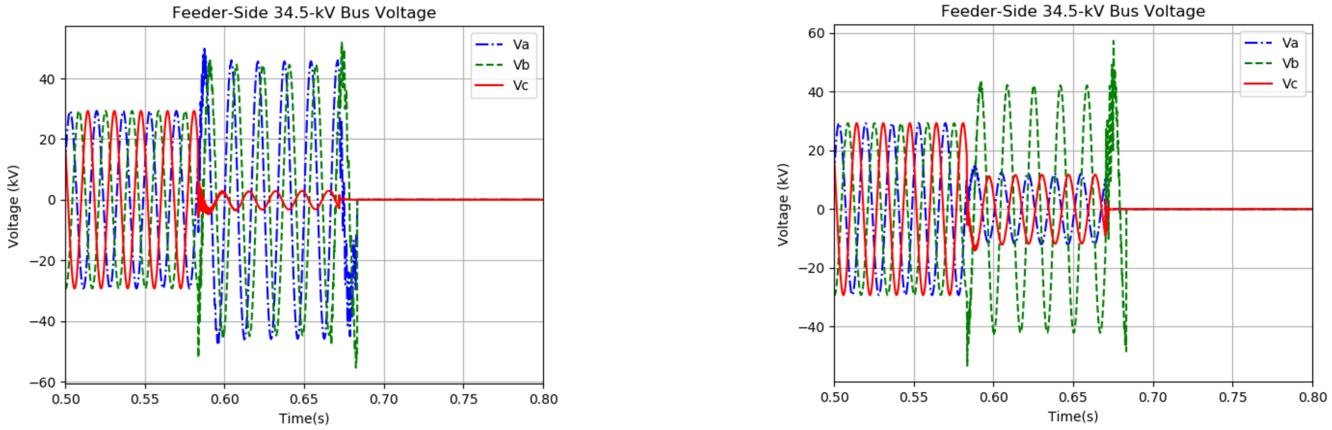


Figure 4. Surge arrester voltage under SLG (left) and DLG (right) considering fast trip breaker and grounding switch (scenario 4)

RESULTS

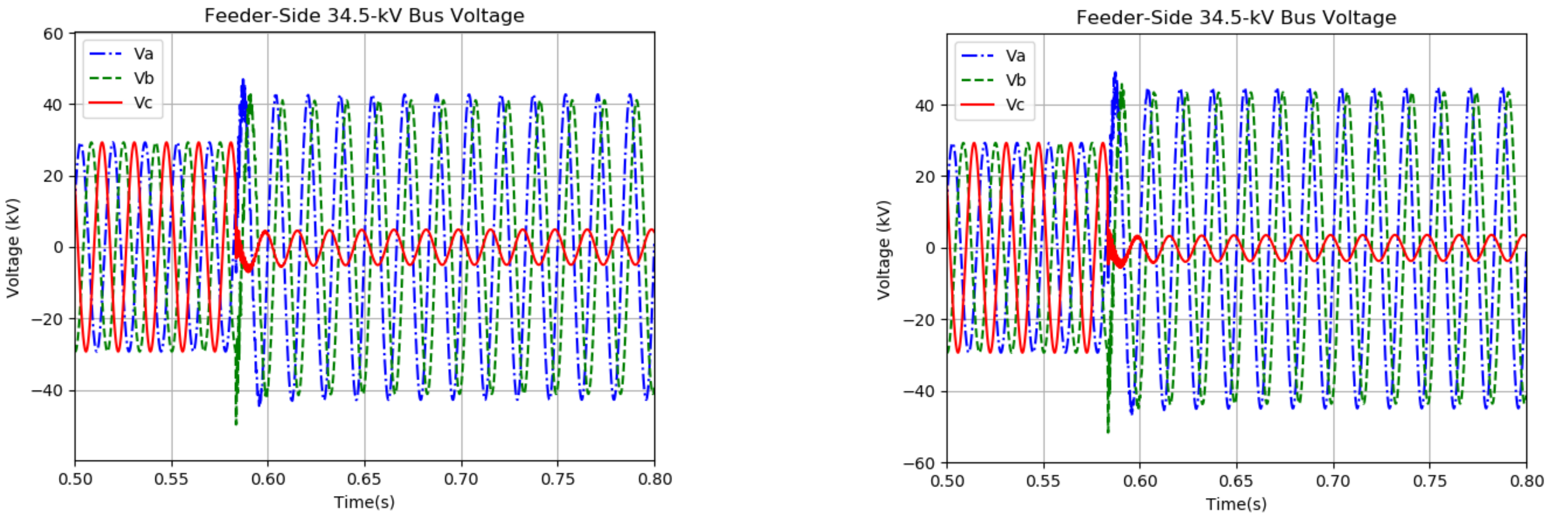


Figure 5. Surge arrester voltaje including breaker failure mode: scenario 3b (left) and scenario 5 (right)

CONCLUSIONS

Substation is currently on operaticon since January 2021

- Based on the simulation results, the configuration for fast or normal trip breakers without the grounding switch *is not recommended* as a strategy to suppress TOV in the installation of PV plants.
- Scenarios 3 and 4 provide acceptable performance for TOV suppression. *The preferred option for PV plants is to install fast trip breakers– with grounding switch* on each collector feeder and on the main bus bar. Alternatively, it is also acceptable to install normal trip breakers with a grounding transformer on each feeder for TOV suppression.
- The breaker short circuit capacity for scenarios 3 and 4 should be confirmed based on a short circuit study.

CONCLUSIONS

Substation is currently on operaticon since January 2021

- For scenarios 3b and 5, if fast trip switches are considered to isolate bars A and B, in the event of a breaker failure in the feeders, grounding transformers in similar size to those used for feeders should be included to provide TOV suppression .
- Finally, it was found that the fault current contribution for unbalanced failures in the NGR transformer is reduced when grounding transformers are included in the system.
- Grounding transformers must be sized according to IEEE C57.32-2015 IEEE Standard For Requirements, Terminology, And Test Procedures For Neutral Grounding Devices.

Annex: Grounding transformer

- The single-phase short-circuit current is 5.9 KA.
- SLG current (Zig-zag): 1000 A,
- Fault duration: 10 s, IEEE Standard C57.32-2015.
- A fault current value of 1000 A is assumed, taking into account that this value can be satisfactorily detected by the protections and does not cause unnecessary efforts in the transformer that deteriorate its useful life.
- The current per phase in failure is:
- Ifp = I000/3= 333.3 A.

Annex: Grounding transformer

- The zero-sequence impedance of the Zo transformer is given by:
  - ➢ $Sf = 3 * Ifp * U = 19918.6$ kVA, where Sf is the transformer fault power
  - ➢ $Zo = U^2/Sf = 19.92\ \Omega$, where U is the line to ground voltage.

- Finally, the homopolar impedance per phase is given by:
  - ➢ $Z0/phase = 3*Z0 = 59.76\ \Omega$ / phase

Annex: Grounding transformer

- According to IEEE Standard C57.32-2015, the ratio between the direct current Ic and the current per phase Iff during the fault, for a duration of the fault of 10 s, is 3%.

- Therefore:
  - ➢ Ic = Fc * Ifp =10 A.

- Continuous power Sc of the transformer (electrical kVA):
  - ➢ Sc = 3 * Ic * U = 598 kVA

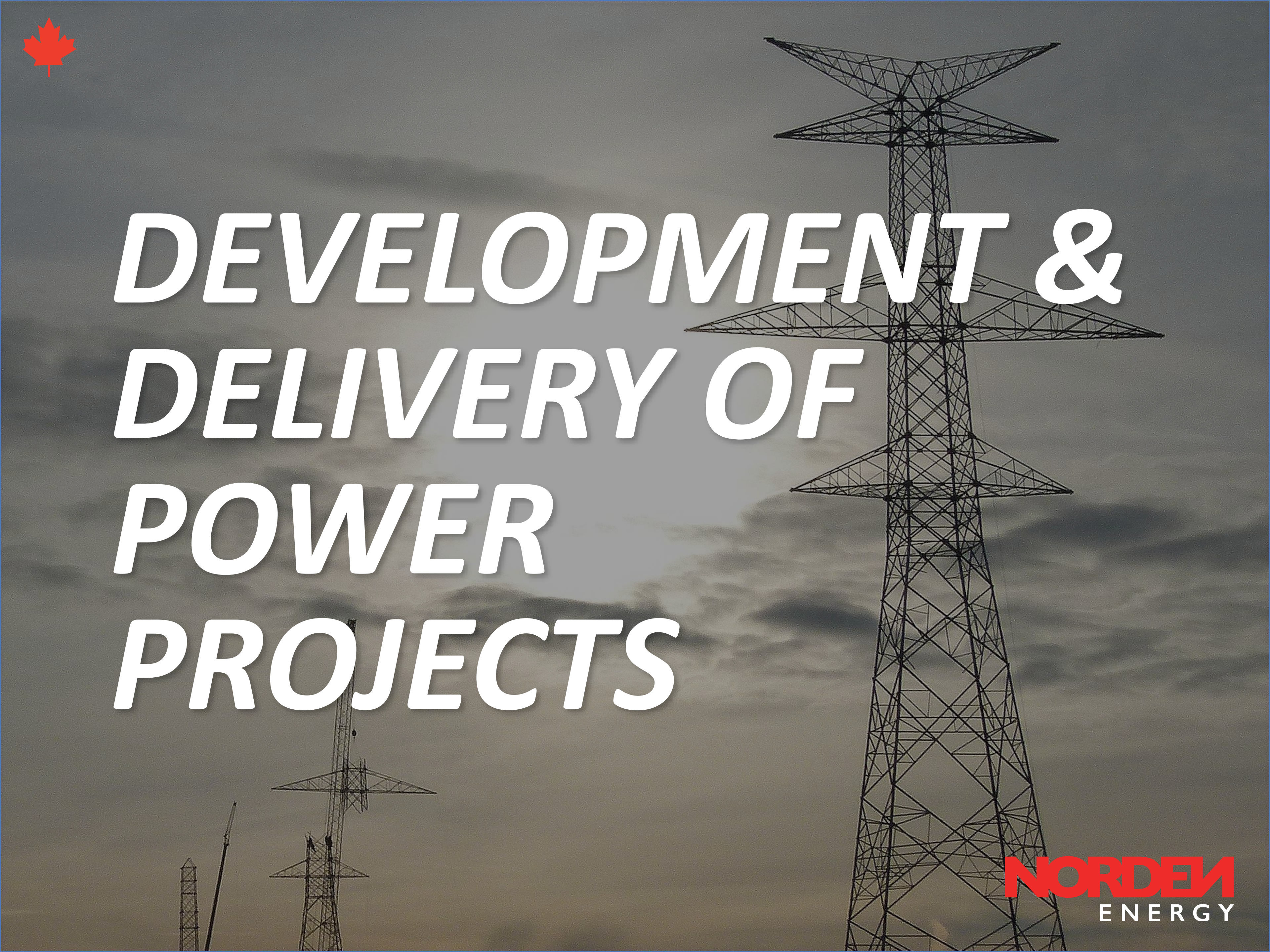
Annex: Grounding transformer

- For a zigzag grounding transformer, since both windings are active in the primary circuit and all coils are identical, (IEEE C62.92.4-2014 appendix A, equation A.2) it can be rated at one-third of the system voltage (34.5kV / 3). Therefore, the physical kVA of the unit will be:

  ➢ Sc = 11.5 kV * 10 A * 3 = 345 kVA

- A transformer with a nominal power of 345 kVA and a zero-sequence impedance of 59.76 Ω / phase, which ensures a fault current of 1000 A.

Thanks!



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