A Proposed Scheme to Protect Transformer Bank and Arc Suppression Coil in Compensated-Grounded Distribution System

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GE Grid Solutions

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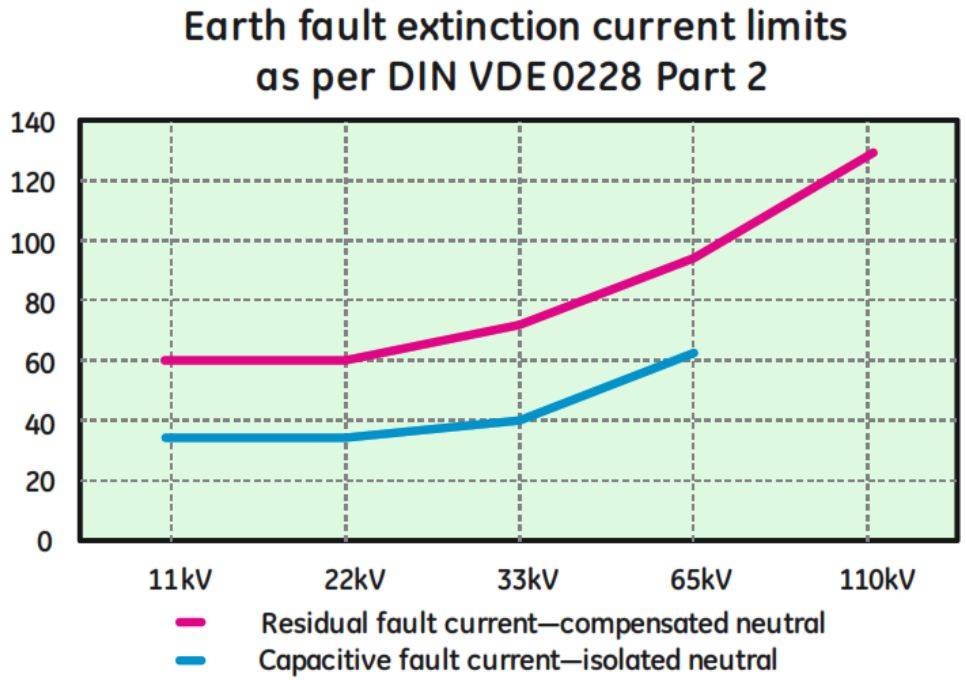
Outline

- Introduction
- Study System Grounding Scheme
- Protection Schemes Used in the Study System
- Operating Modes of the Grounding Schemes
- Hardware-in-the-Loop (HIL) Testing
- Test Results
- Conclusions

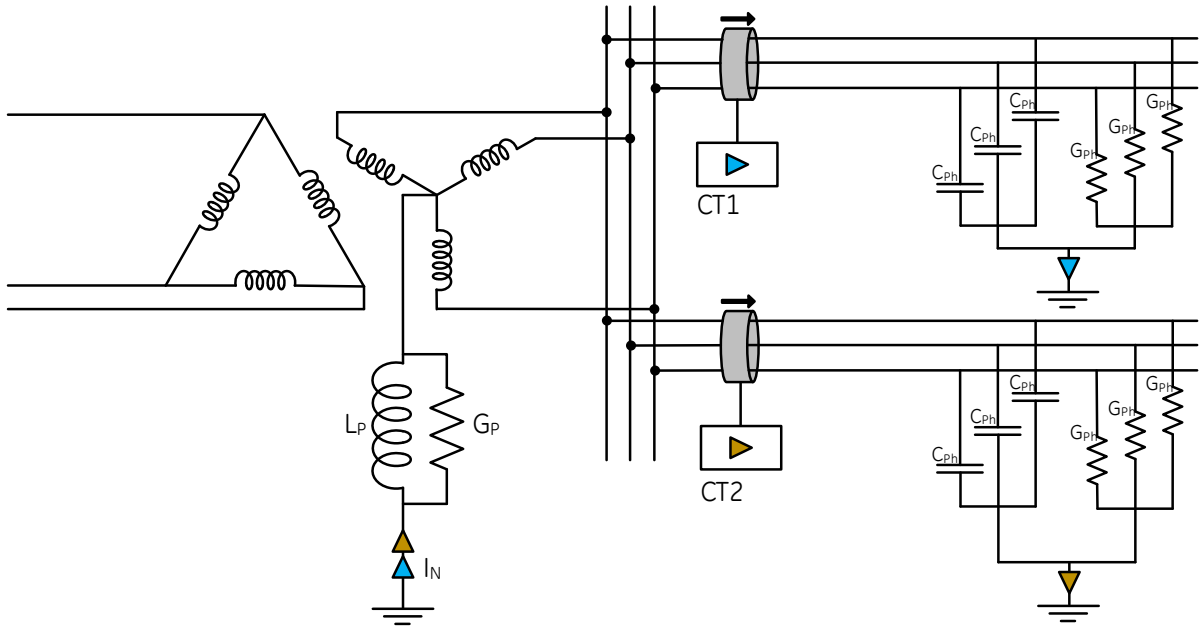
Introduction

- Ground faults can potentially cause fire ignition
- Association of German Electrical Engineers Standard (DIN VDE0228 – Part 2) has specified the maximum fault current per voltage level to ensure self-extinguishing arc.
- Limit ground fault current to prevent fire ignition due to a ground fault



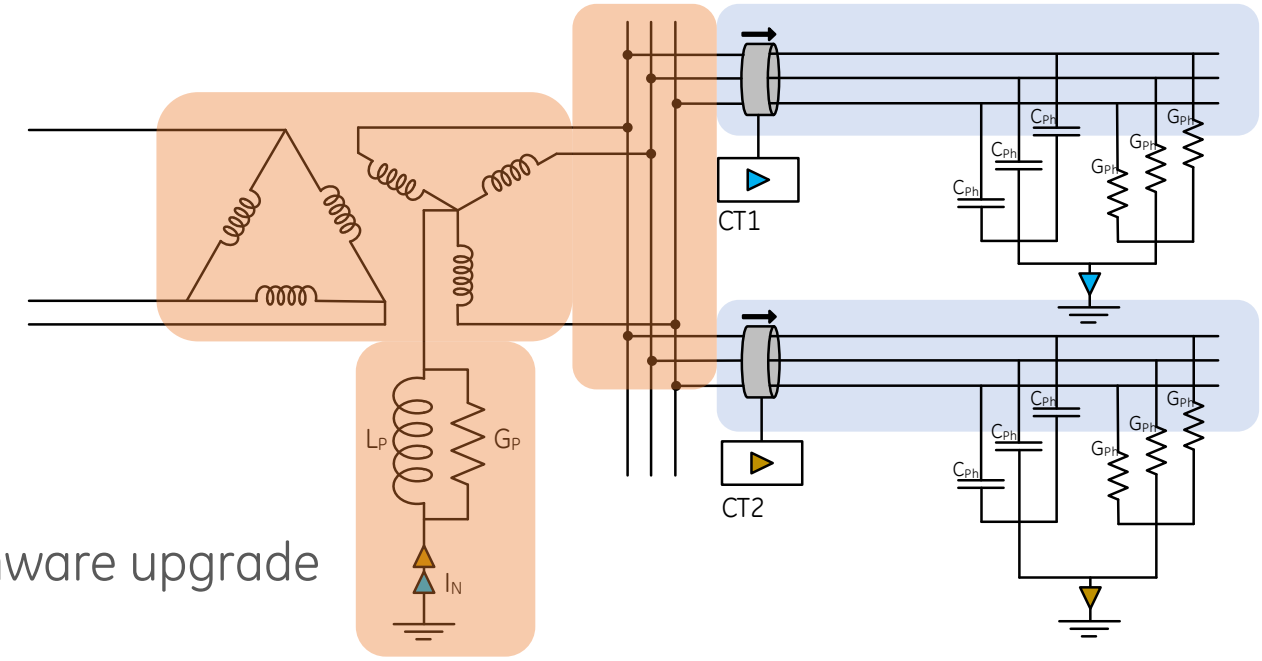
Introduction

- Power system grounding scheme impacts ground fault currents:
- Compensated-Grounded system
  - Under-Compensated - Capacitive fault current
  - Over-Compensated – Inductive fault current
  - Resonant grounded – Resistive fault current – Small fault current



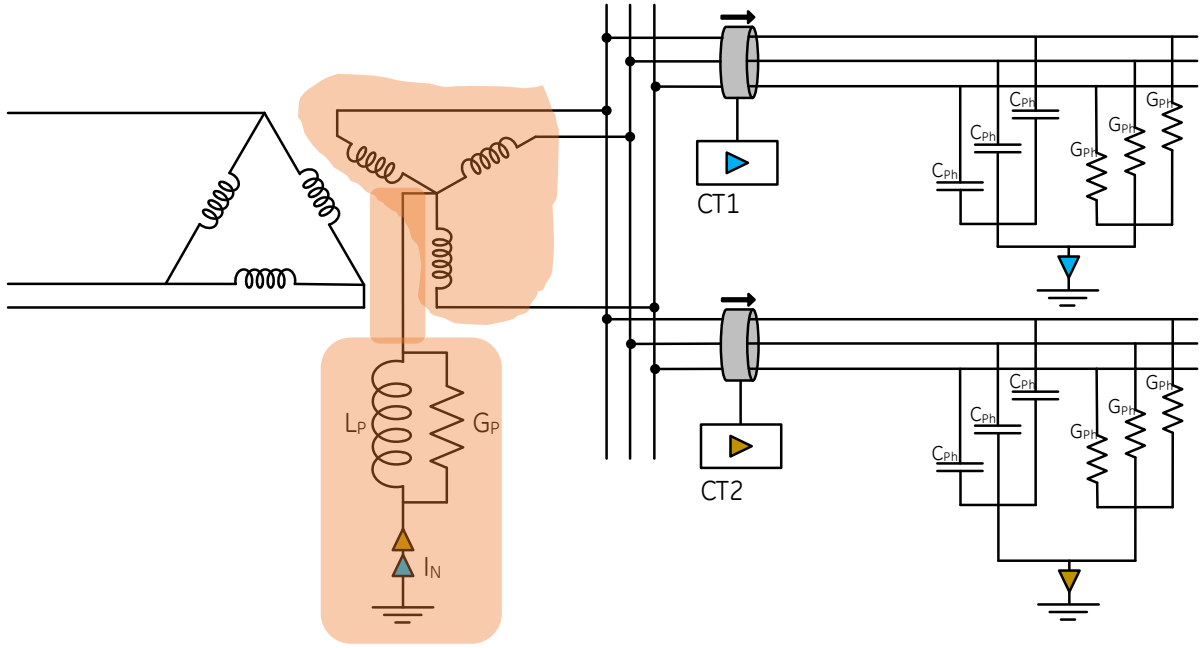
Transient Ground Fault Detection (TGFD)

- TGFD is a patented algorithm that identifies faulty feeder in non-solidly grounded systems
- It operates based on ground fault signature at higher frequencies
  - ✓ 264Hz for 60-Hz systems
  - ✓ 220Hz for 50-Hz systems
- TGFD features:
  1. No need for special equipment
  2. No need for high sampling rate
  3. Inter-harmonic measurements
  4. Can be added to the relay with a firmware upgrade



Challenge

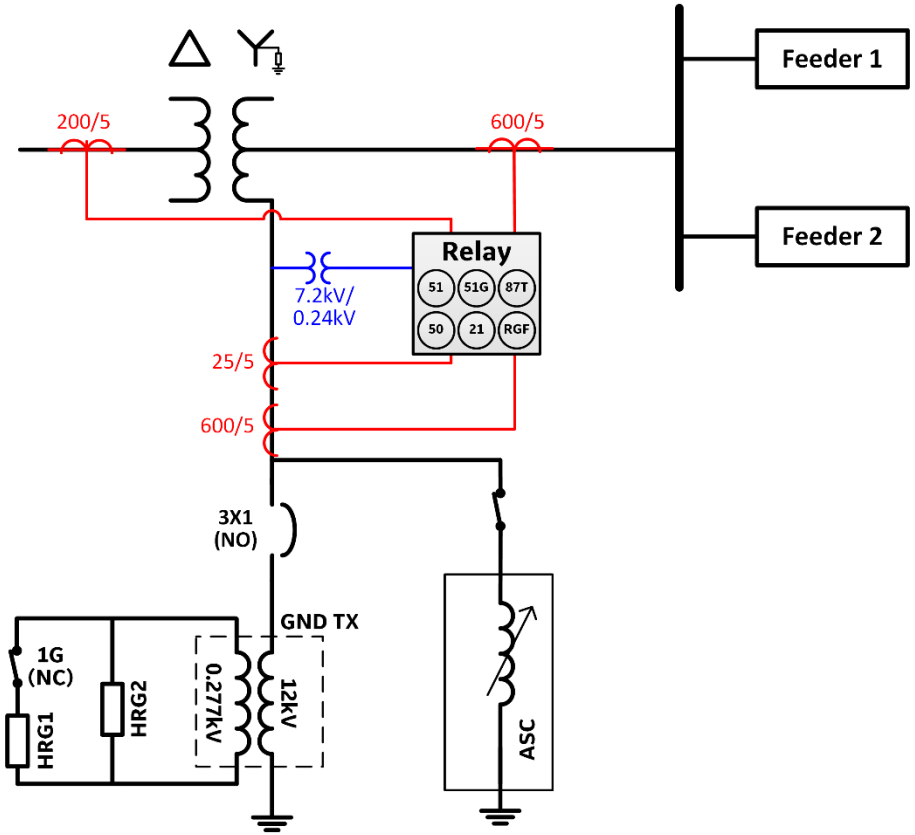
- Detecting ground faults on the secondary of the transformer bank and within the protection zone of differential function (87T)
- Detecting Neutral-to-Ground (NG) and Open-Neutral (OpneN) faults
- Protecting the Arc Suppression Coil (ASC)



Study System Grounding Scheme

Grounding system parameters :

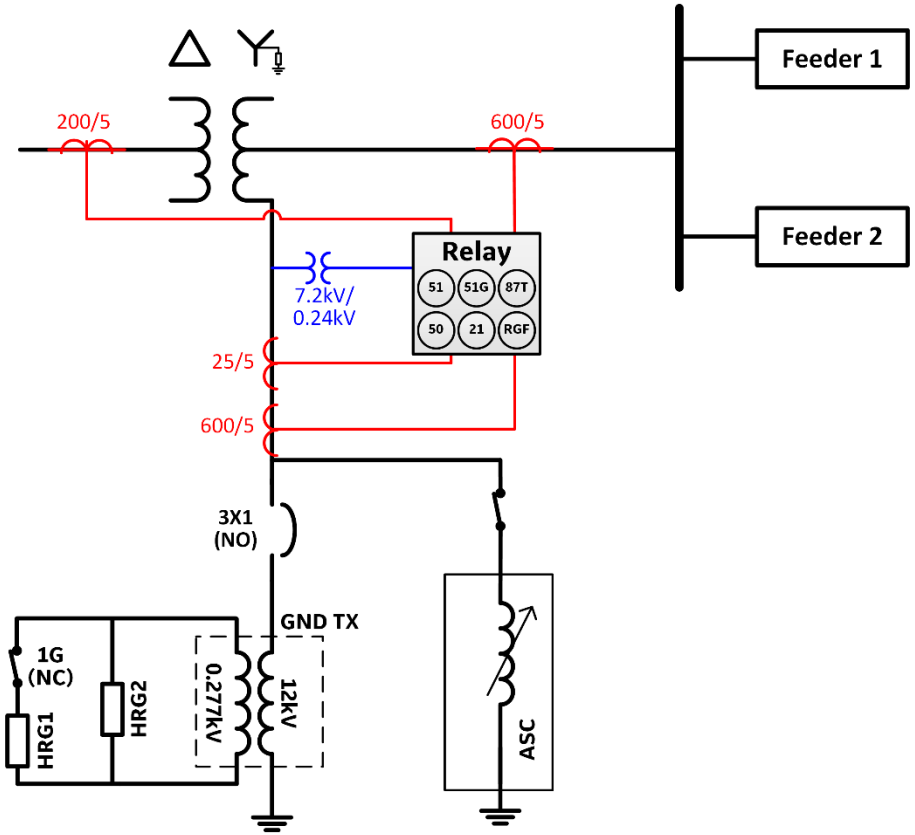
- Grounding transformer: Single phase 12 kV/0.277 kV
- HRG1 resistor: 0.0588Ω at the LV side of the grounding transformer
- HRG2 resistor: 19.2Ω at the LV side of the grounding transformer
- ASC impedance: 376.2∠ 88.3˚Ω at resonance condition and at the HV side of the grounding transformer, 0.5A-40A current range on a 12.47kV system



Protection Philosophy

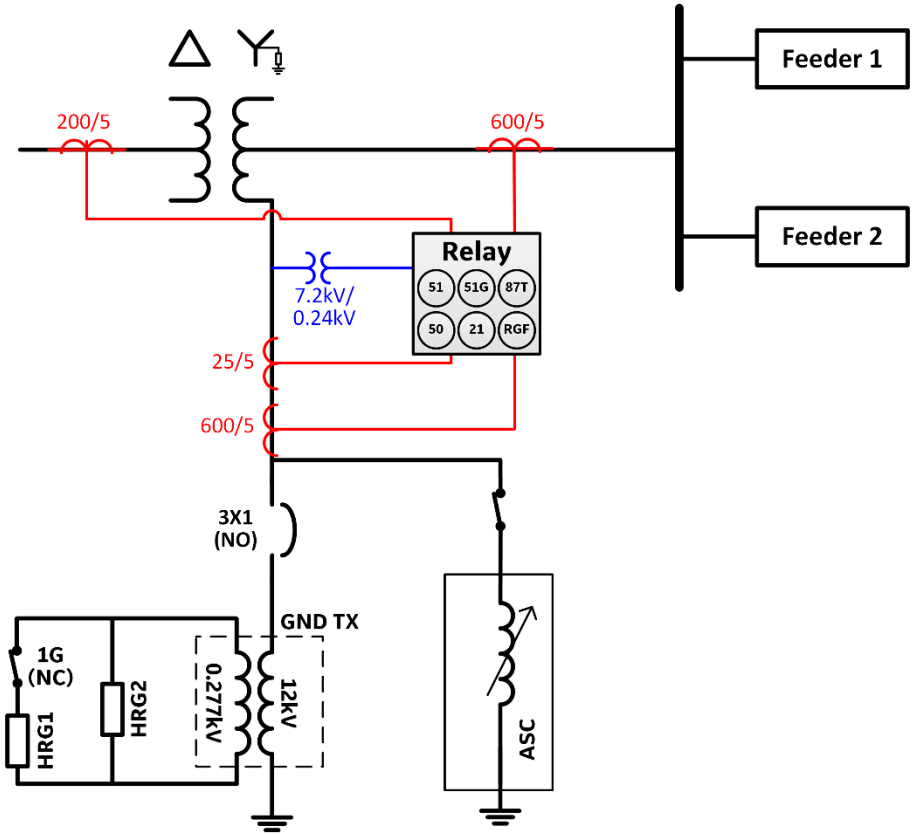
Protection elements:

- Transformer differential protection (87T), HV-side faults
- Restricted Ground Fault Protection (87RGF), LV-side ground faults, operates only after 3X1 breaker is closed
- Phase instantaneous and timed overcurrent protections (50P and 51P)
- Ground instantaneous and timed overcurrent protections (50G and 51G) – provide protection for N-1 contingency
- Neutral over-voltage protection (59G), backup protection after 5s
- Impedance-based ASC protection



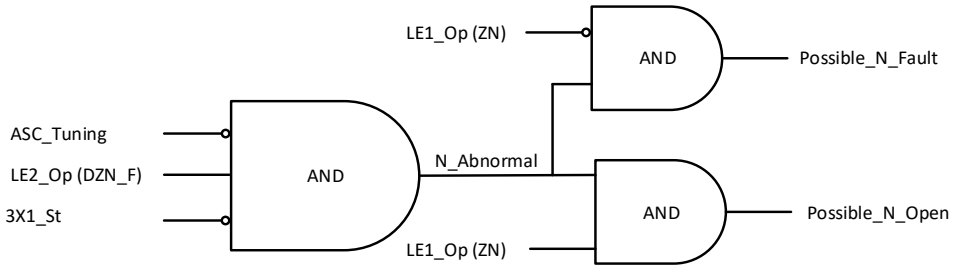
Impedance-based ASC Protection

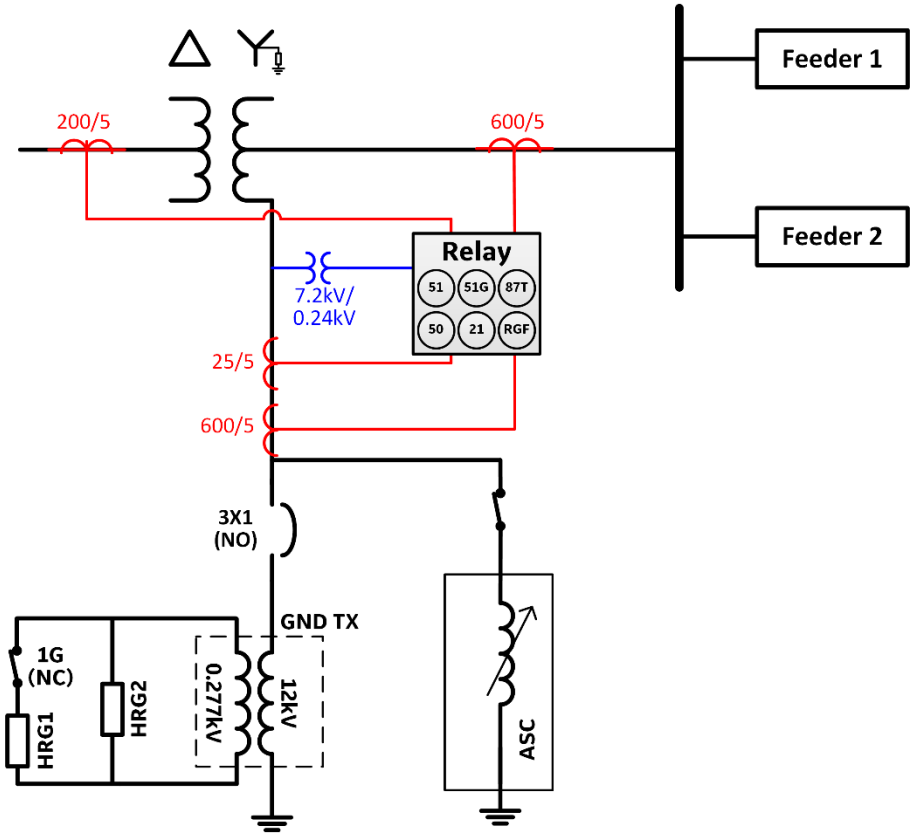
- The transformer protection relay has a built-in distance function (21)
- Neutral current and voltage are fed to the relay and the impedance of the grounding scheme is measured by the relay
- Logic processing capability of the relay is utilized to implement the following
  - ✓ LE1: a circular impedance zone with 0.12pu radius on the CT/VT secondary side corresponding to 34.56 Ω primary
  - ✓ LE2: a change of neutral impedance flag equal to 0.3pu on the CT/VT secondary side corresponding to 86.4Ω primary



Impedance-based ASC Protection

- The impedance-based ASC protection is blocked if the tuning controller is actively adjusting the impedance of the coil
- The impedance-based ASC protection is blocked if the 3X1 breaker is closed
- A change of impedance larger than 0.3 pu in the grounding system is identified as abnormal condition





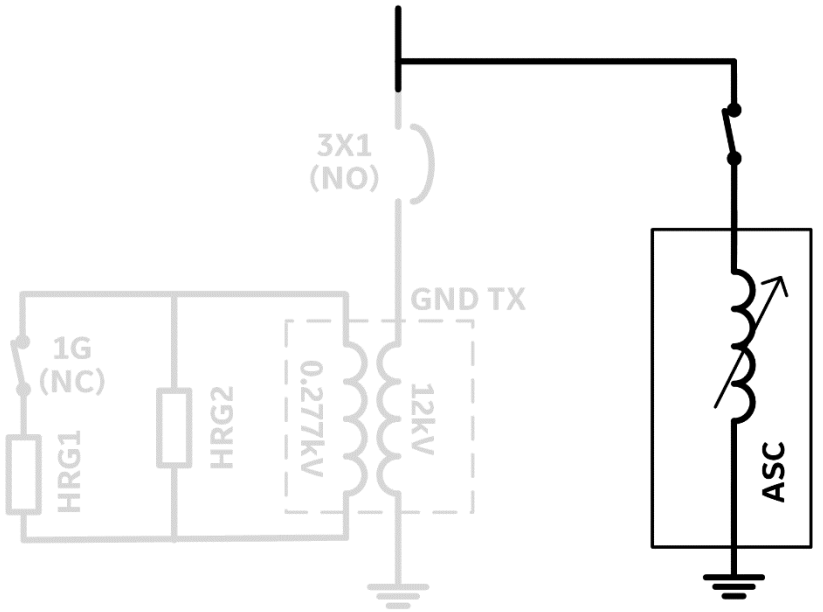
Grounding Scheme Operating Mode 1

- Pre-fault

$Zmin = 173 \angle 88^\circ$

$Zmax = 13860 \angle 88^\circ$

$ZNormal = 376 \angle 88^\circ$



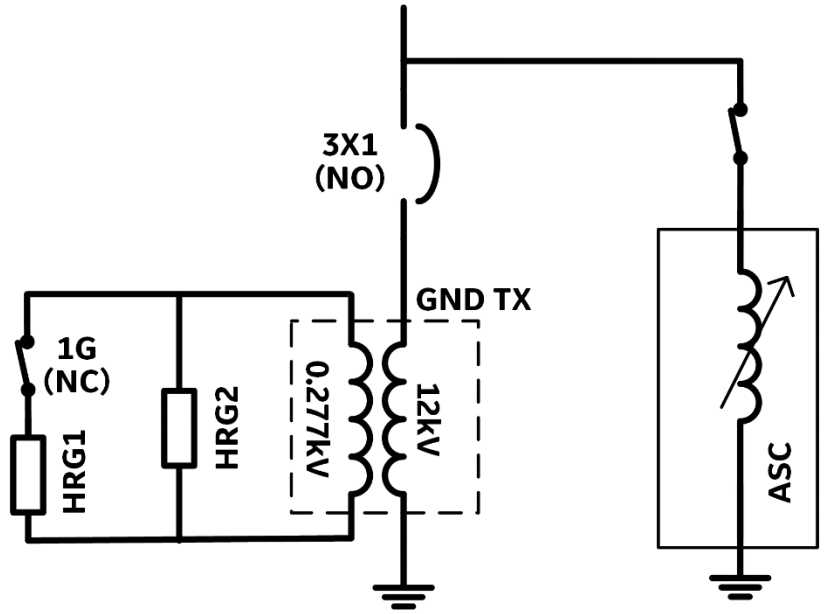
Grounding Scheme Operating Mode 2

- 0.5s after inception of a ground fault

$Zmin = 92 \angle 32^\circ$

$Zmax = 110 \angle 0.5^\circ$

$ZNormal = 104 \angle 16^\circ$



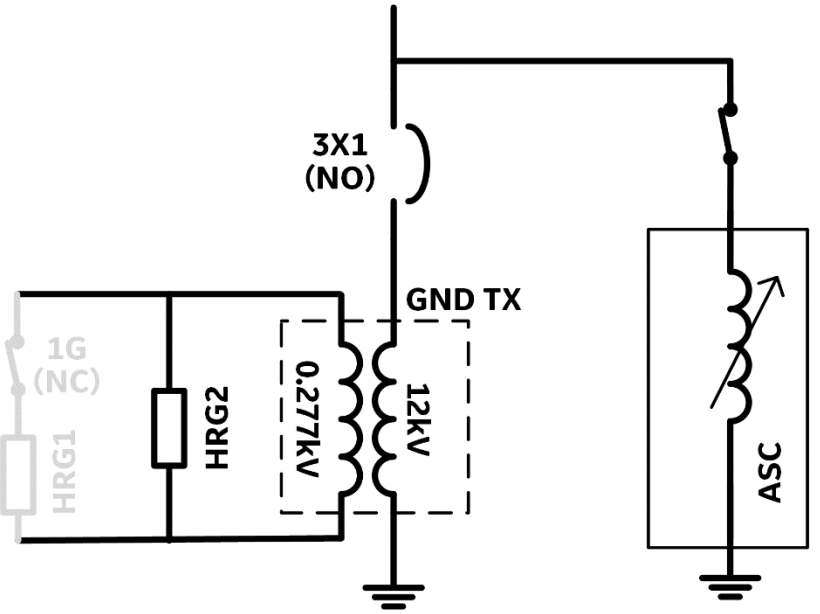
Grounding Scheme Operating Mode 3

- 2s after inception of a ground fault

$Zmin = 173 \angle 88^\circ$

$Zmax = 12809 \angle 67^\circ$

$ZNormal = 376 \angle 88^\circ$



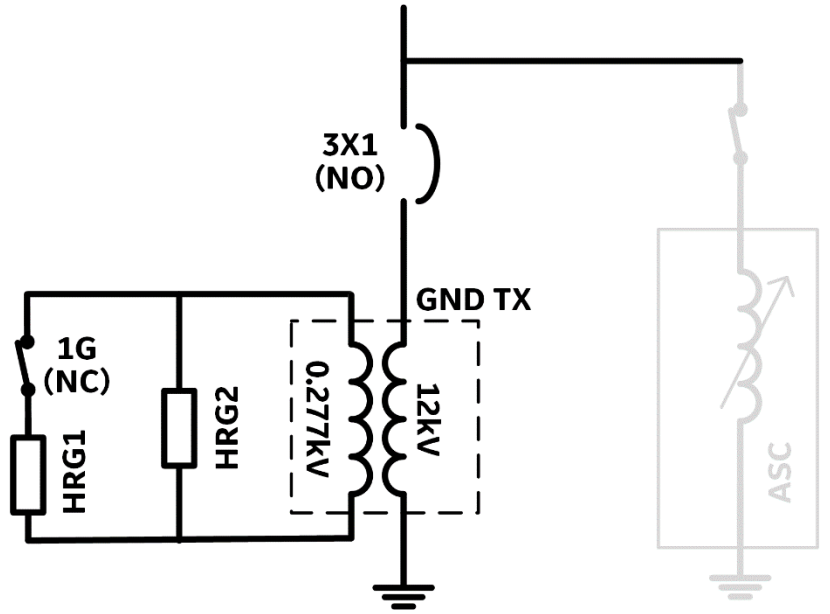
Grounding Scheme Operating Mode 4

- ASC out – 1G closed

$Zmin = 110 \angle 0^{\circ}$

$Zmax = 110 \angle 0^{\circ}$

$ZNormal = 110 \angle 0^{\circ}$



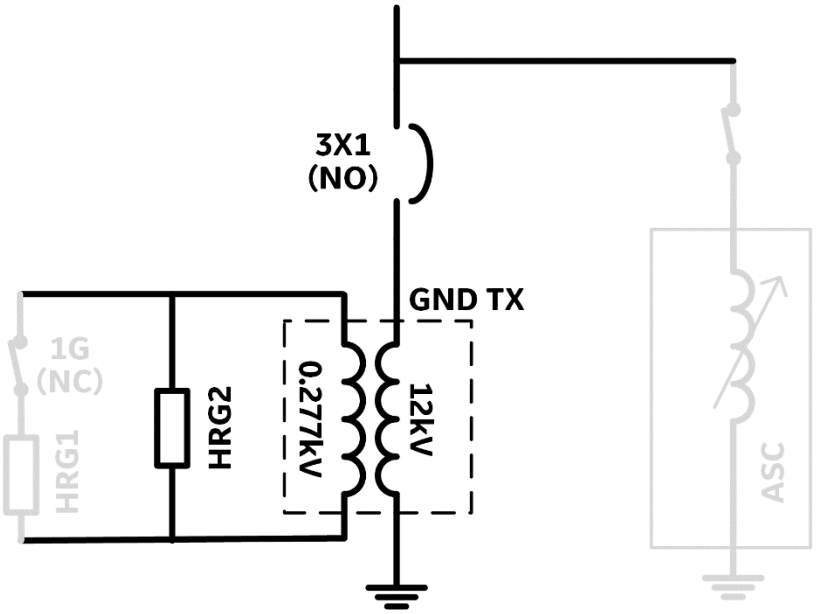
Grounding Scheme Operating Mode 5

- ASC out – 1G open

Zmin = 36033 ∠ 0°

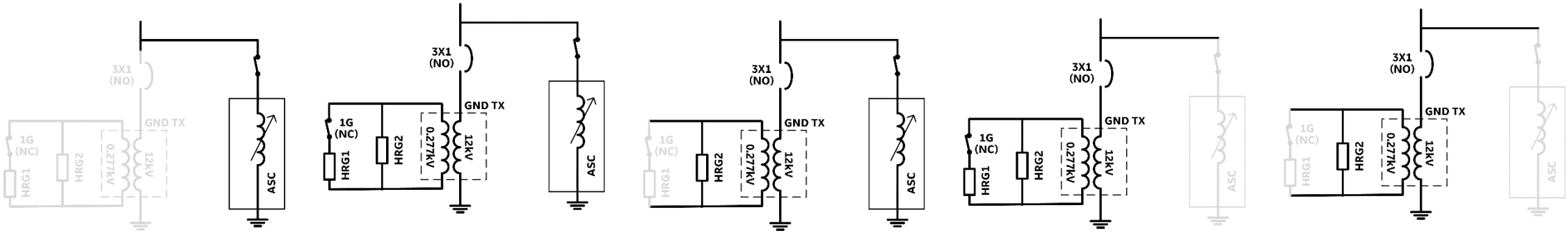
Zmax = 36033 ∠ 0°

ZNormal = 36033 ∠ 0°



Grounding Scheme Impedance Range

Mode	Condition description	Normal Impedance			Minimum Impedance			Maximum Impedance		
		Pri (Ω)	Sec (Ω)	Angle (˚)	Pri (Ω)	Sec (Ω)	Angle (˚)	Pri (Ω)	Sec (Ω)	Angle (˚)
1	ASC only 3X1: Open	376.2	62.7	88.3	173.25	28.9	88.3	13860	2310	88.3
2	ASC || HRG1 || HRG2 376 ∠ 88.3˚ || 36033 || 110 3X1: Closed 1G: Closed	104.4	17.4	16.1	91.7	15.3	31.9	110.0	18.3	0.5
3	ASC || HRG2 376 ∠ 88.3˚ || 36033 3X1: Closed 1G: Open	376.1	62.7	87.7	173.2	28.9	88.0	12809.3	2134.9	67.5
4	HRG1 || HRG2 1G: Closed	110.0	18.3	0.0	110.0	18.3	0.0	110.0	18.3	0.0
5	HRG2 only 1G: Open	36033.0	6005.5	0.0	36033.0	6005.5	0.0	36033.0	6005.5	0.0

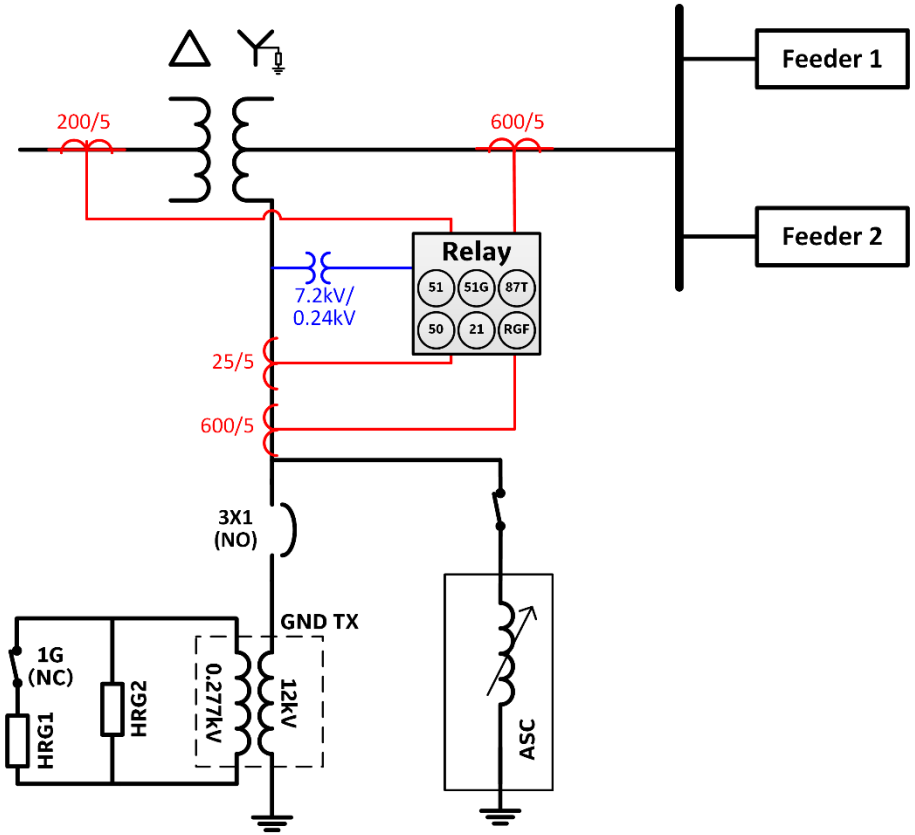


Hardware-In-the-Loop (HIL) Testing

- Real-Time Digital Simulation (RTDS) is used to model the system of the study
- The RTDS is interfaced with the transformer protection relay using amplifiers
- Relay trip signal and internal variables are communicated back to the RTDS using IEC61850 GOOSE message for monitoring and capturing
- A comprehensive sets of tests is conducted in different conditions (different fault types and locations, neutral open conductor, compensation level, and etc)

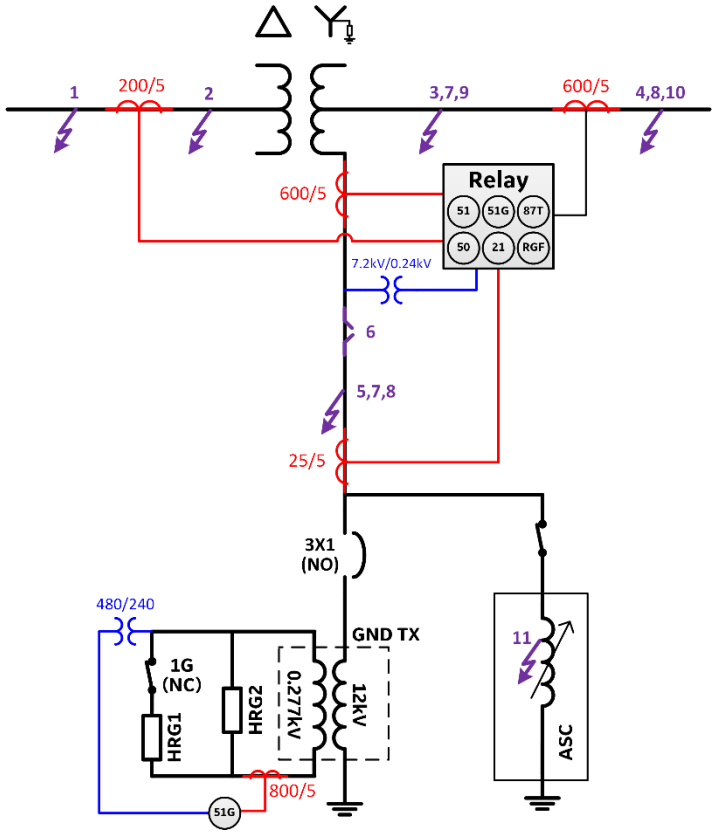
Challenge

- Initially, the 25:5 neutral CT in conjunction with a 600:5 phase CT was used for the RGF
- RGF mis-operated for high-current out of zone ground fault
- The 25:5 neutral CT was saturated due to the high current while the 600:5 phase CT was not
- Solution:
  - ✓ The 600:5 neutral and phase CTs were used for RGF



Test Cases

- 79 test cases
- Based on fault location, fault type, compensation level
- Compensation levels:
  - ✓ Under-compensated (92%)
  - ✓ Full compensation – Resonance (100%)
  - ✓ Over-compensated (120%)
- Additional two compensation levels are also considered – min and max reactive current from ASC



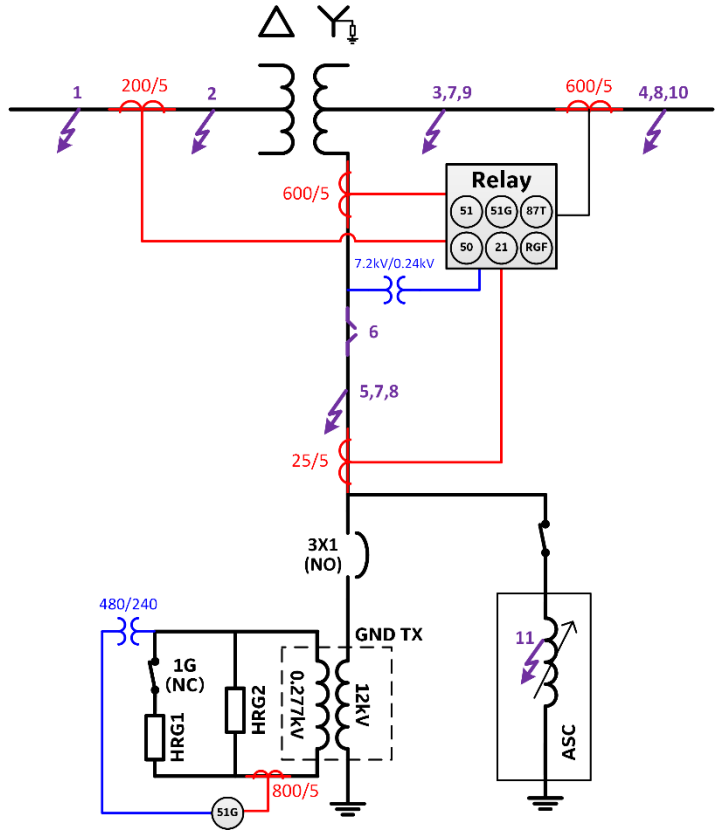
Test Cases

Full compensation test cases

Case ID	Fault Location ID	R_f (Ohm)	Fault Type
1001	1	0	AG
1002	1	0	ABG
1003	1	0	ABCG
1004	2	30	AG
1005	2	30	ABG
1006	2	30	ABCG
1007	3	3	AG
1008	3	3	ABG
1009	3	3	ABCG
1010	4	3	AG
1011	4	3	ABG
1012	4	3	ABCG
1013	5	0	NG
1014	6	0	OpenN
1015	7	3	NG->AG
1016	8	3	NG->AG
1017	9	3	AG->ABG
1018	10	0	AG->ABG
1019	11	0	TG90
1020	11	0	TG75
1021	11	0	TG50
1022	11	0	TG25
1023	11	0	TG10

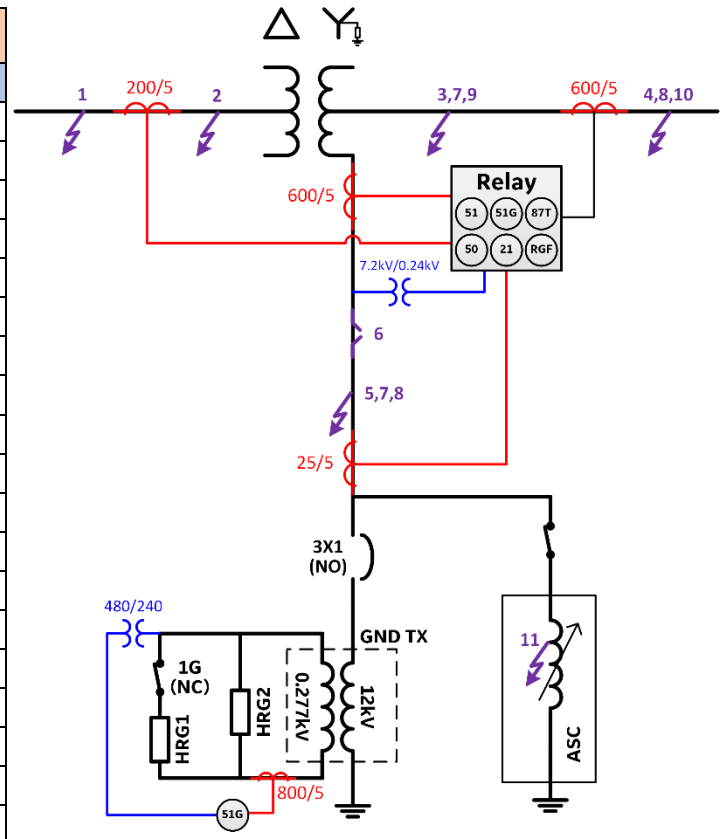
Miscellaneous test cases

Case ID	Fault Location ID	R_f (Ohm)	Fault Type	ASC
1301	11	0	TG90	MAX
1302	11	0	TG75	MAX
1303	11	0	TG50	MAX
1304	11	0	TG25	MAX
1305	11	0	TG90	MIN
1306	11	0	TG75	MIN
1307	11	0	TG50	MIN
1308	11	0	TG25	MIN
1309	11	0	TG10	MIN
1310	11	0	TG10	MAX



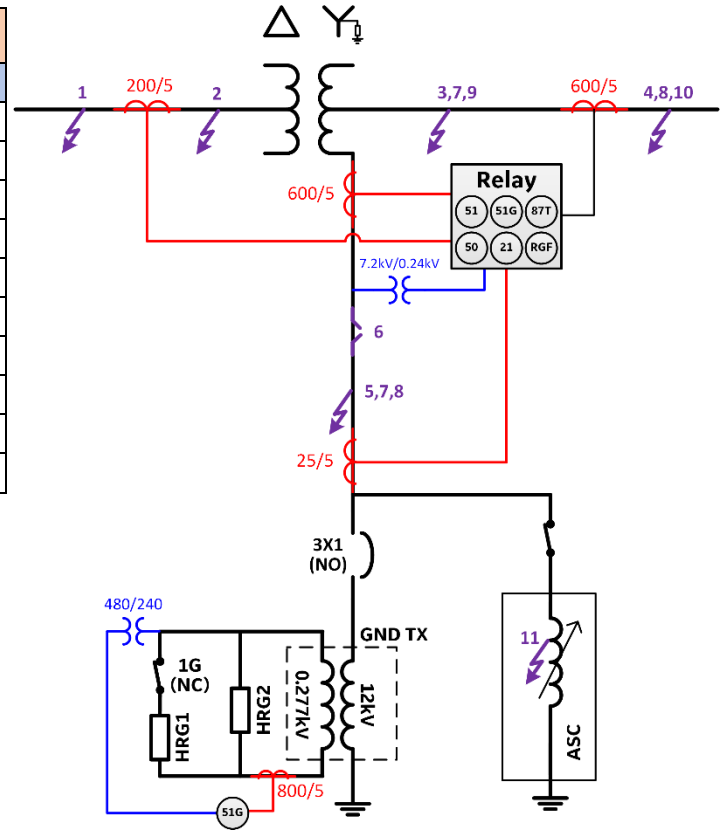
Test Results

T60 Test Results - SCE - Full Compensated												
CaseID	FltLocID	Rf	FltType	ASC	87T	RGF	51G	Ph_TOC	Ph_IOC	N_Abnormal	N_Open	N_Fault
1001	1	0	AG	RES	0	0	0	0	0	0	0	0
1002	1	0	ABG	RES	0	0	0	0	0	0	0	0
1003	1	0	ABCG	RES	0	0	0	0	0	0	0	0
1004	2	30	AG	RES	0.02545	0	0	4.36485	0	0	0	0
1005	2	30	ABG	RES	0.0364	0	0	4.201	0	0	0	0
1006	2	30	ABCG	RES	0.0307	0	0	4.2997	0	0	0	0
1007	3	3	AG	RES	0	0.5276	0	0	0	0	0	0
1008	3	3	ABG	RES	0.0298	0.5361	0	4.4324	0	0	0	0
1009	3	3	ABCG	RES	0.0255	0	0	4.4255	0	0	0	0
1010	4	3	AG	RES	0	0	0	0	0	0	0	0
1011	4	3	ABG	RES	0	0	0	4.429	0	0	0	0
1012	4	3	ABCG	RES	0	0	0	4.42885	0	0	0	0
1013	5	0	NG	RES	0	0	0	0	0	10.75825	10.75825	15.26665
1014	6	0	OpenN	RES	0	0	0	0	0	0.52405	0.54055	0.52405
1015	7	3	NGAG	RES	0.03385	0.01515	0.1071	0	0	0	0	0
1016	8	3	NGAG	RES	0	0	0.1129	0.1129	0	0	0	0
1017	9	3	AGABG	RES	0.02555	0	0	4.43	0	0	0	0
1018	10	3	AGABG	RES	0	0	0	4.425	0	0	0	0
1019	11	0	TG90	RES	0	0	0	0	0	0.524	0	0.524
1020	11	0	TG75	RES	0	0	0	0	0	0.66925	0	0.66925
1021	11	0	TG50	RES	0	0	0	0	0	0.7071	0	0.7071
1022	11	0	TG25	RES	0	0	0	0	0	0.81445	0	0.81445
1023	11	0	TG10	RES	0	0	0	0	0	0	0	0



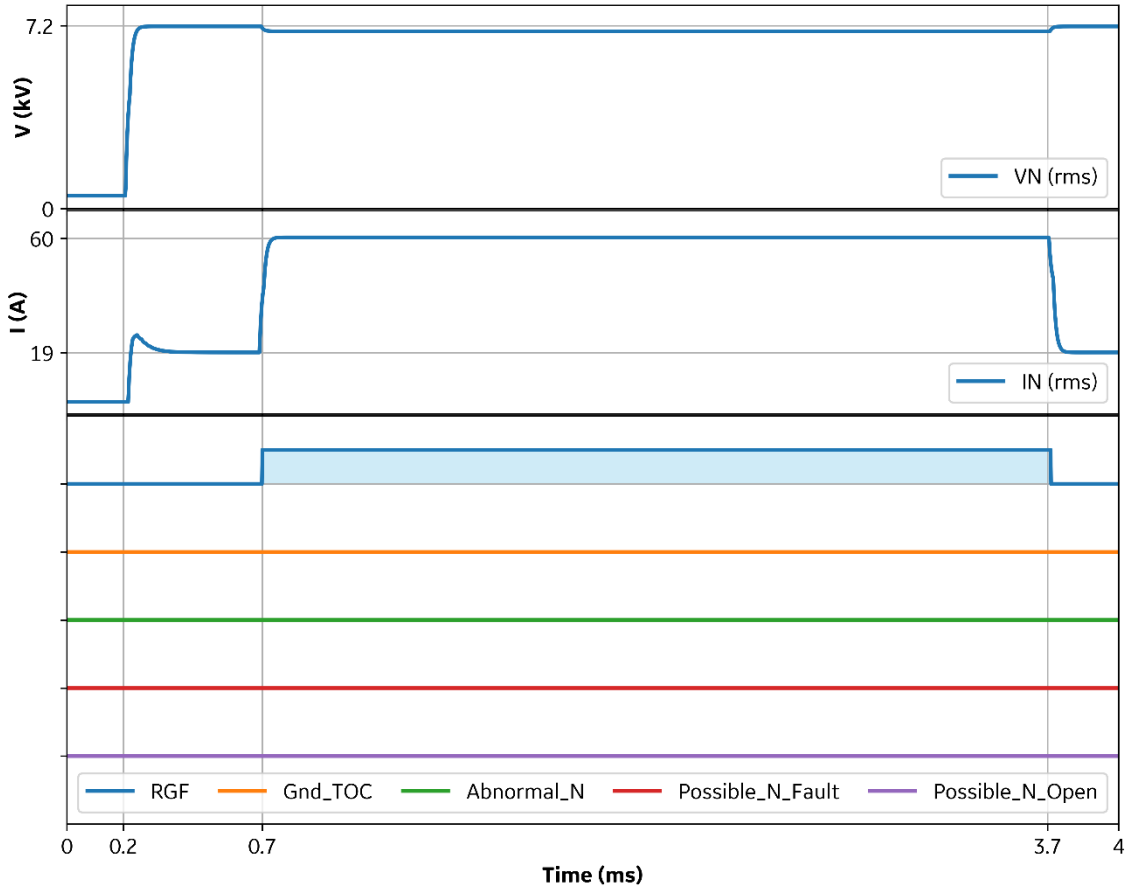
Test Results

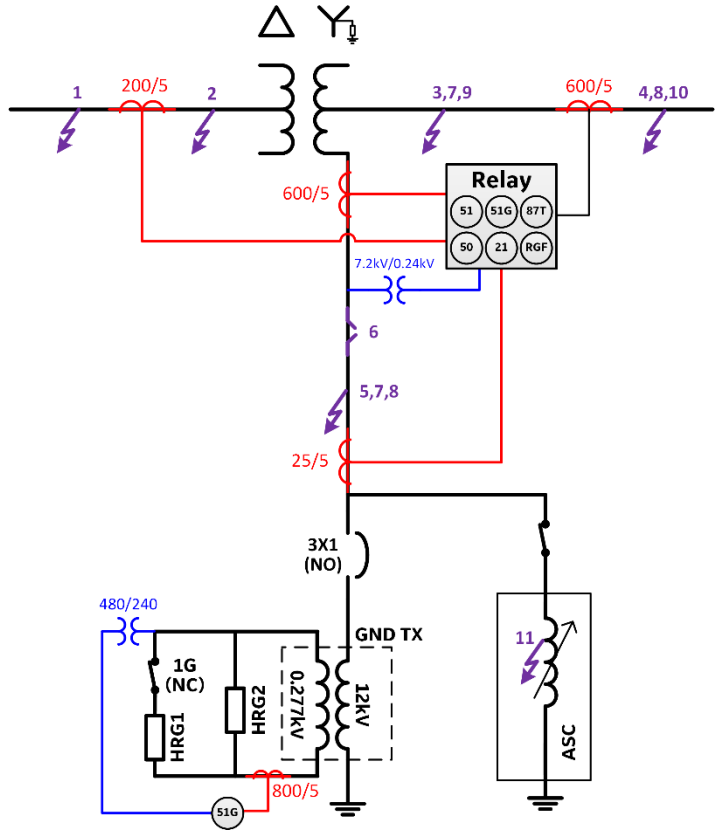
T60 Test Results - SCE - Miscellaneous												
CaseID	FltLocID	Rf	FltType	ASC	87T	RGF	51G	Ph_TOC	Ph_IOC	N_Abnormal	N_Open	N_Fault
1301	11	0	TG90	MAX	0	0	0	0	0	0	0	0
1302	11	0	TG75	MAX	0	0	0	0	0	0	0	0
1303	11	0	TG50	MAX	0	0	0	0	0	0	0	0
1304	11	0	TG25	MAX	0	0	0	0	0	0	0	0
1310	11	0	TG10	MAX	0	0	0	0	0	0	0	0
1305	11	0	TG90	MIN	0	0	0	0	0	0.5228	0.5311	0.5228
1306	11	0	TG75	MIN	0	0	0	0	0	0.52035	0	0.52035
1307	11	0	TG50	MIN	0	0	0	0	0	0	0	0
1308	11	0	TG25	MIN	0	0	0	0	0	0	0	0
1309	11	0	TG10	MIN	0	0	0	0	0	0	0	0



Results Analysis – Case 1007

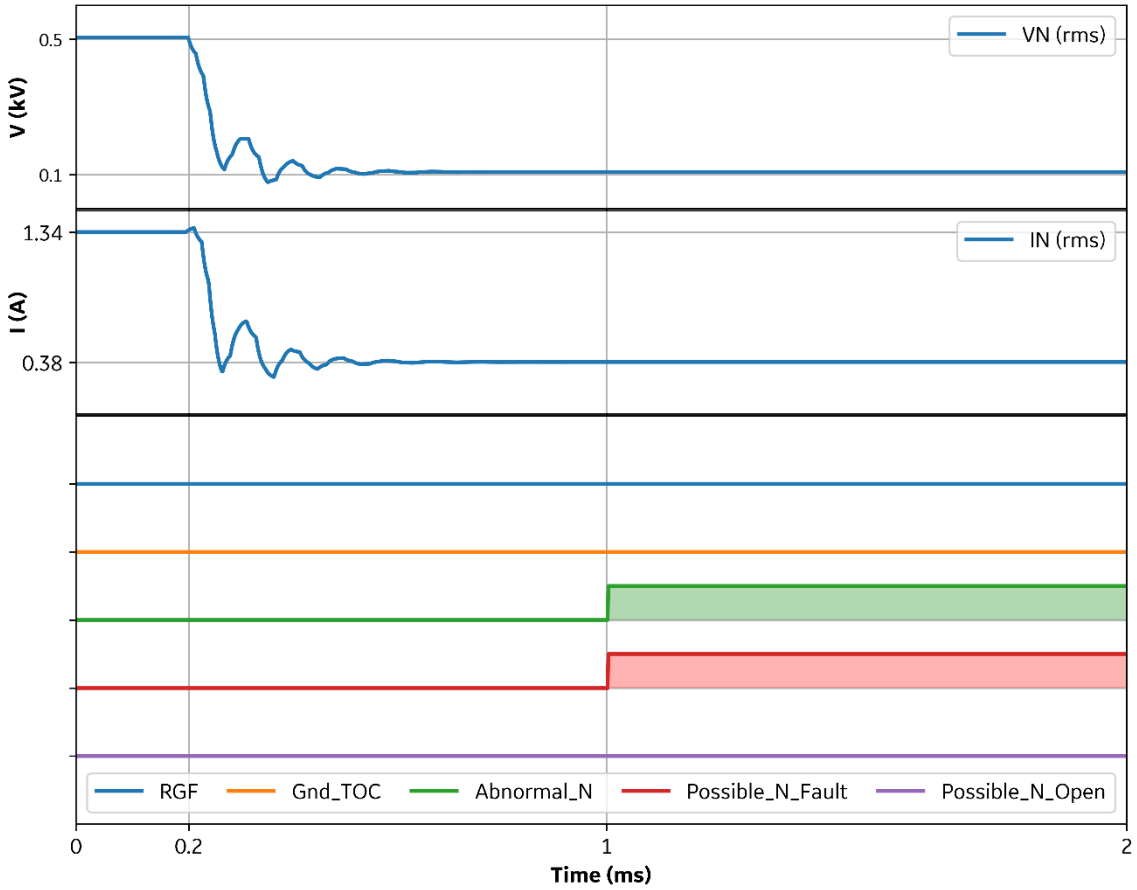
- Full compensation, Location 3, AG fault

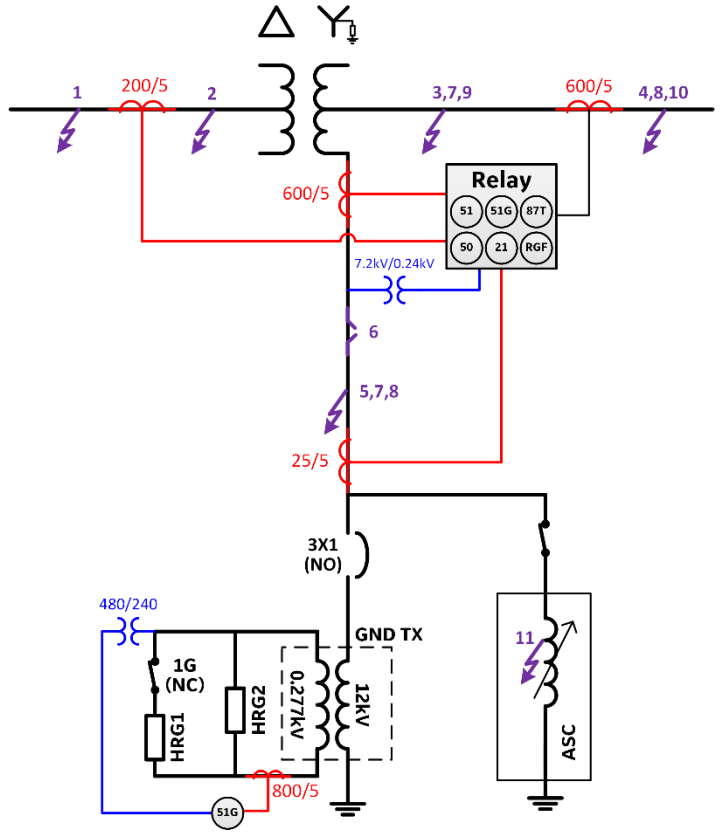




Results Analysis – Case 1022

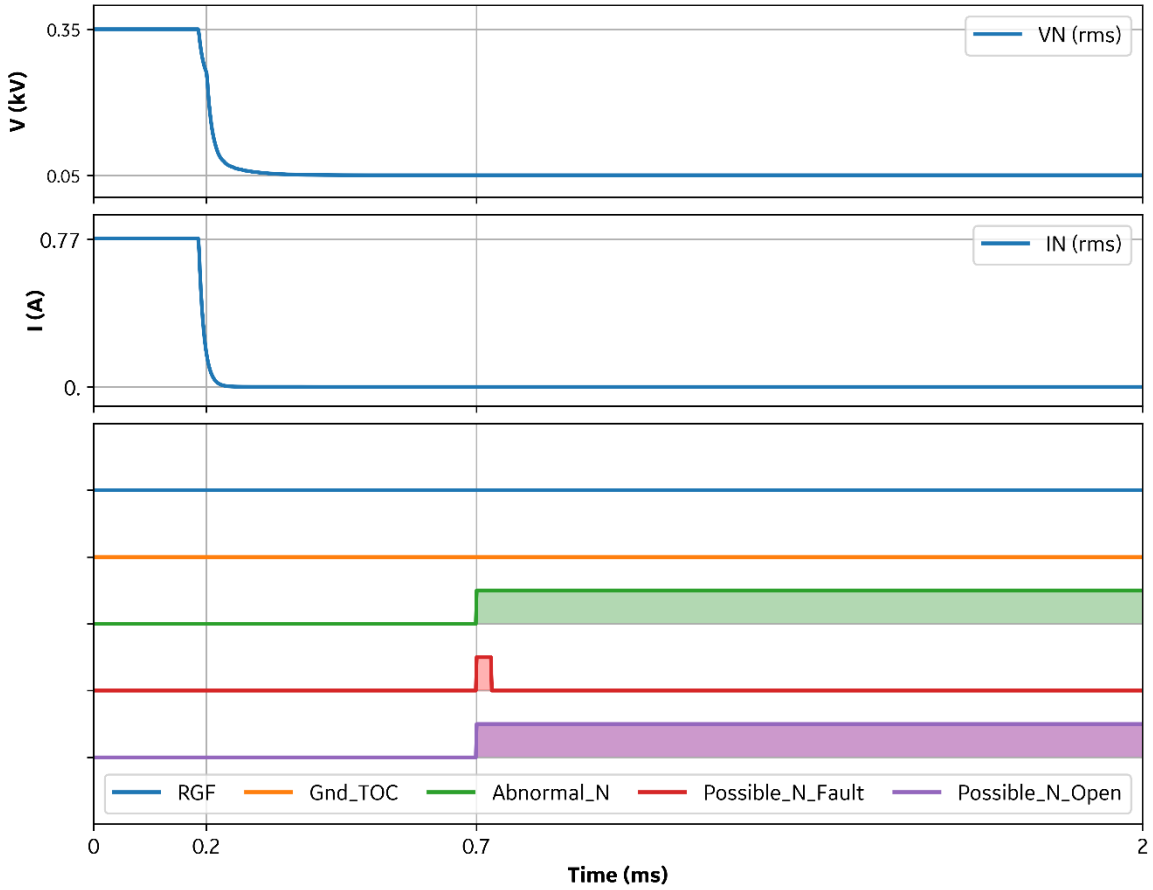
- Full compensation, Location 11, TG25 fault

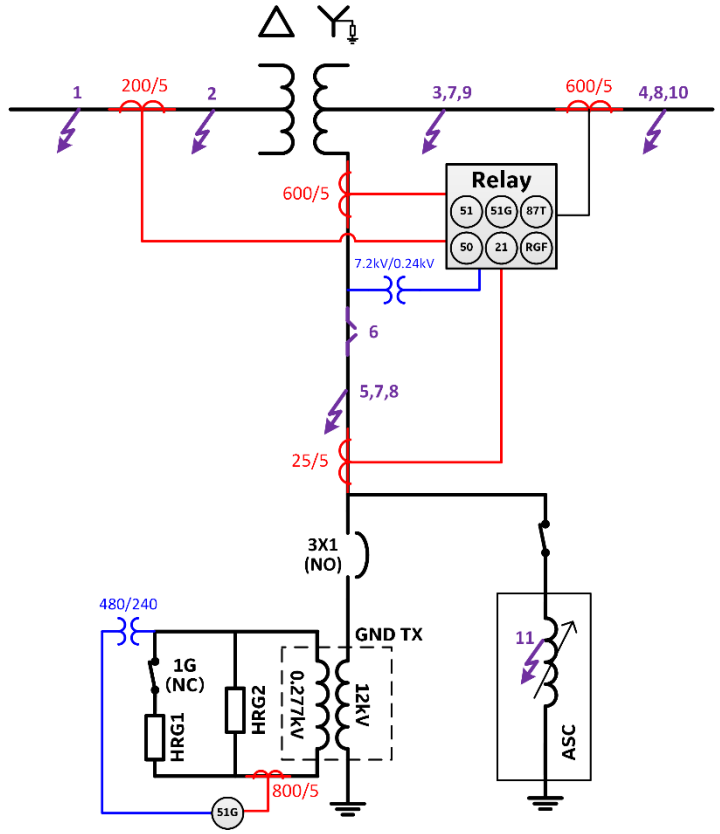




Results Analysis – Case 1214

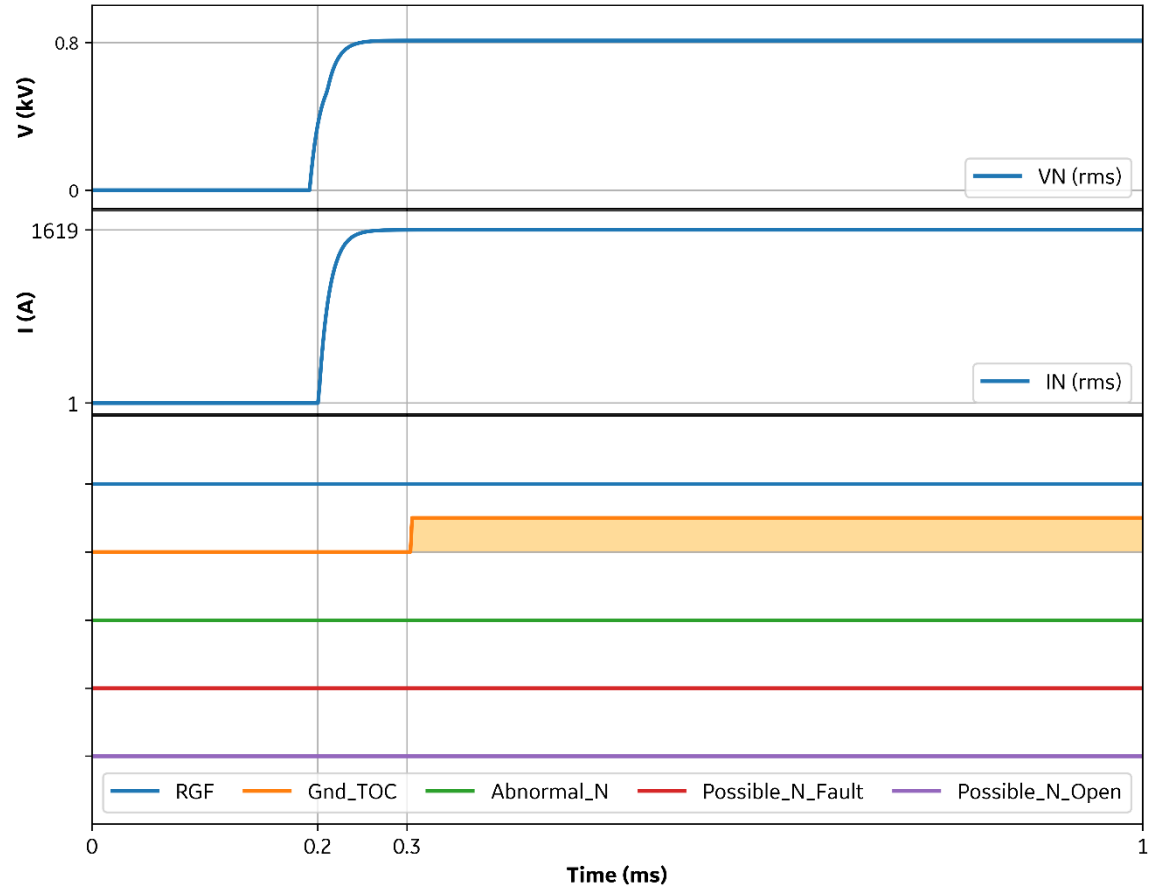
- Over-compensated, Location 6, OpenN fault

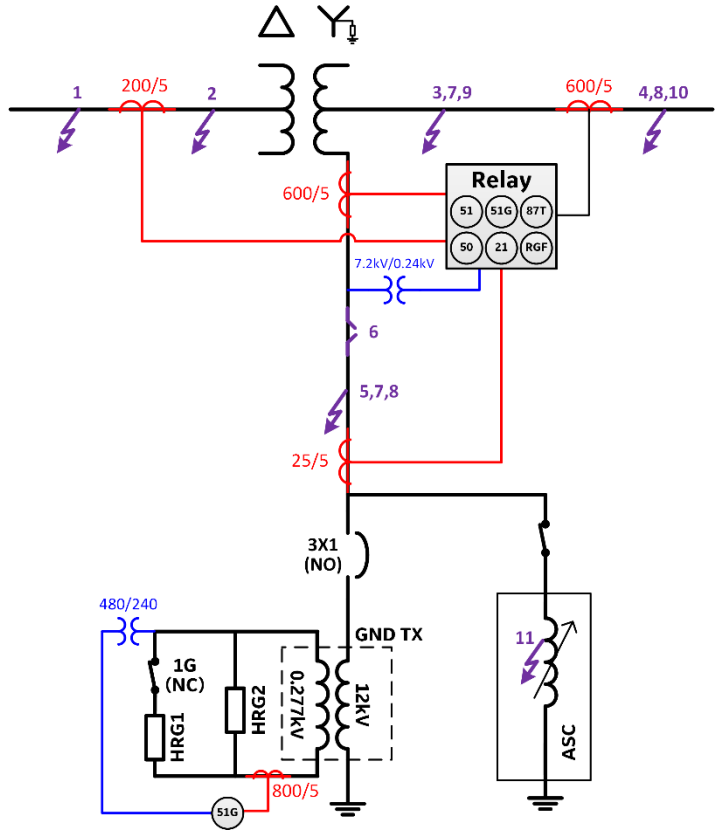




Results Analysis – Case 1216

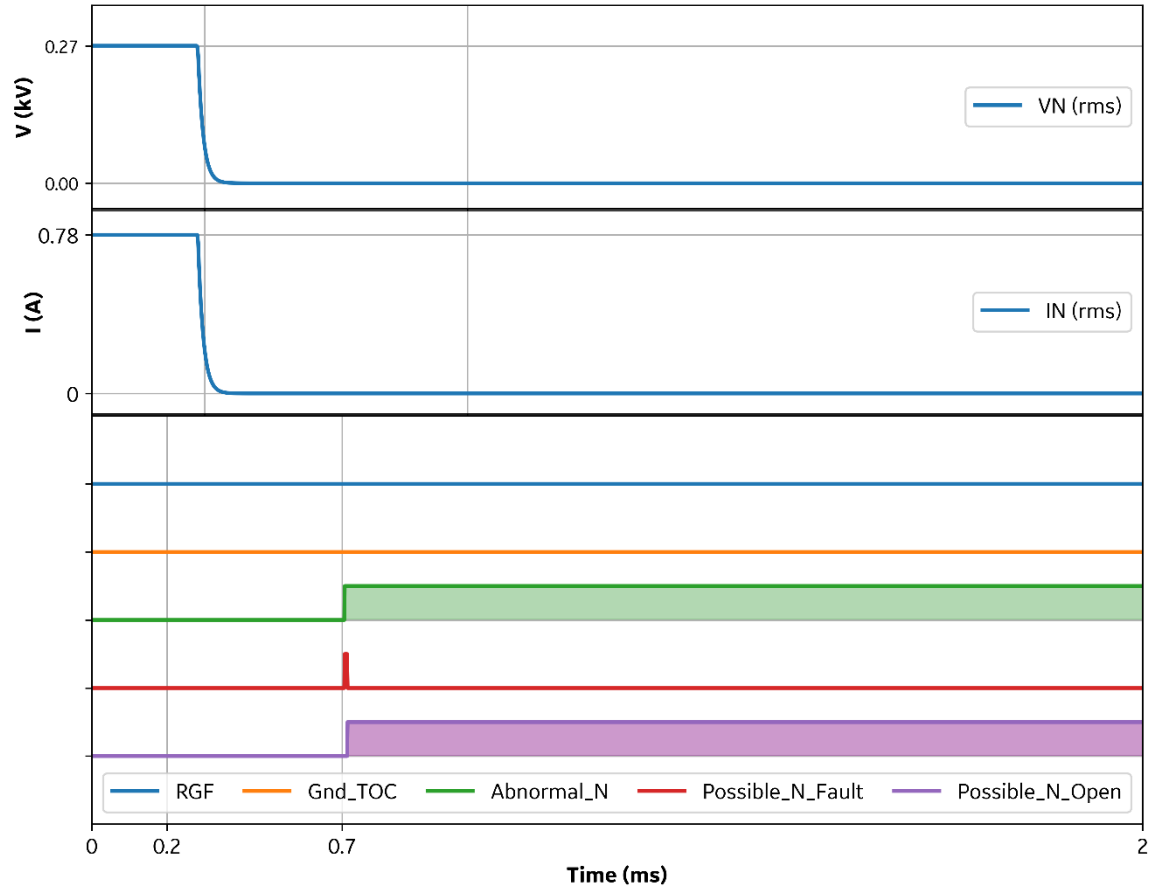
- Over-compensated, Location 8, NG fault missed → AG fault

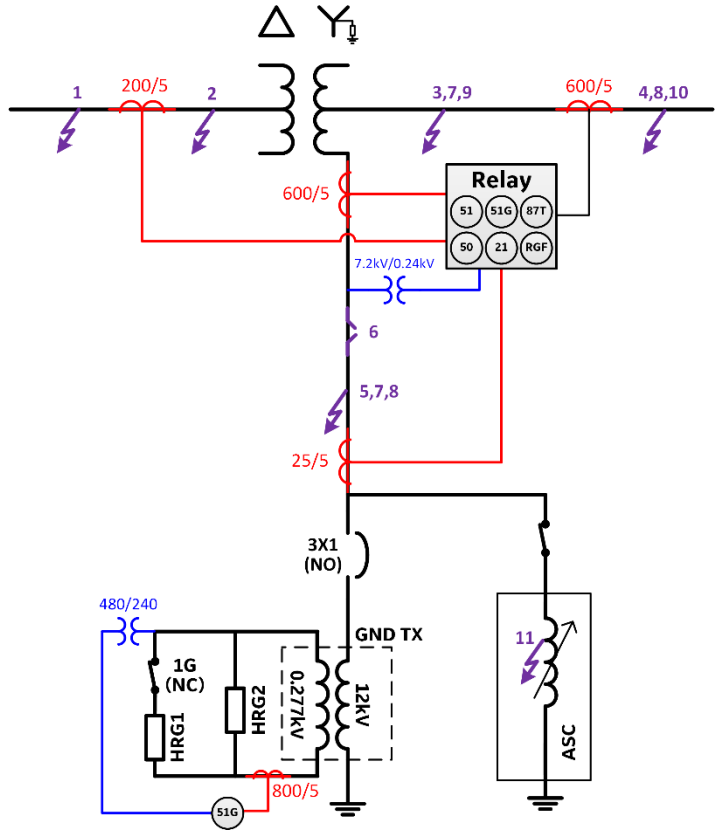




Results Analysis – Case 1113

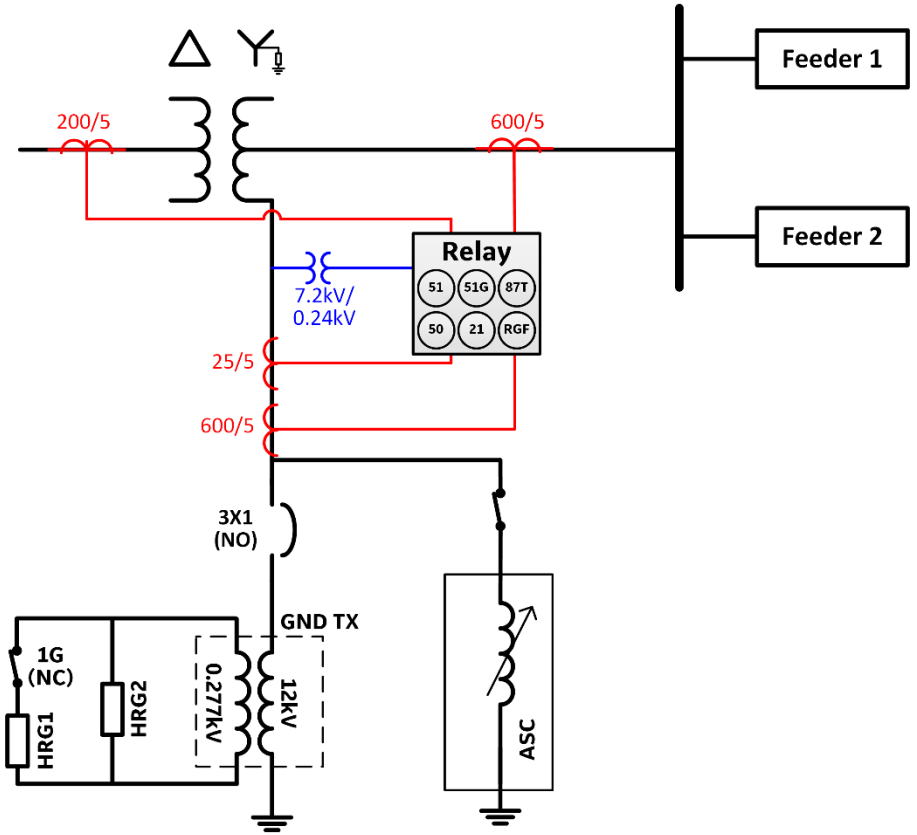
- Under-compensated, Location 11, TG25 fault





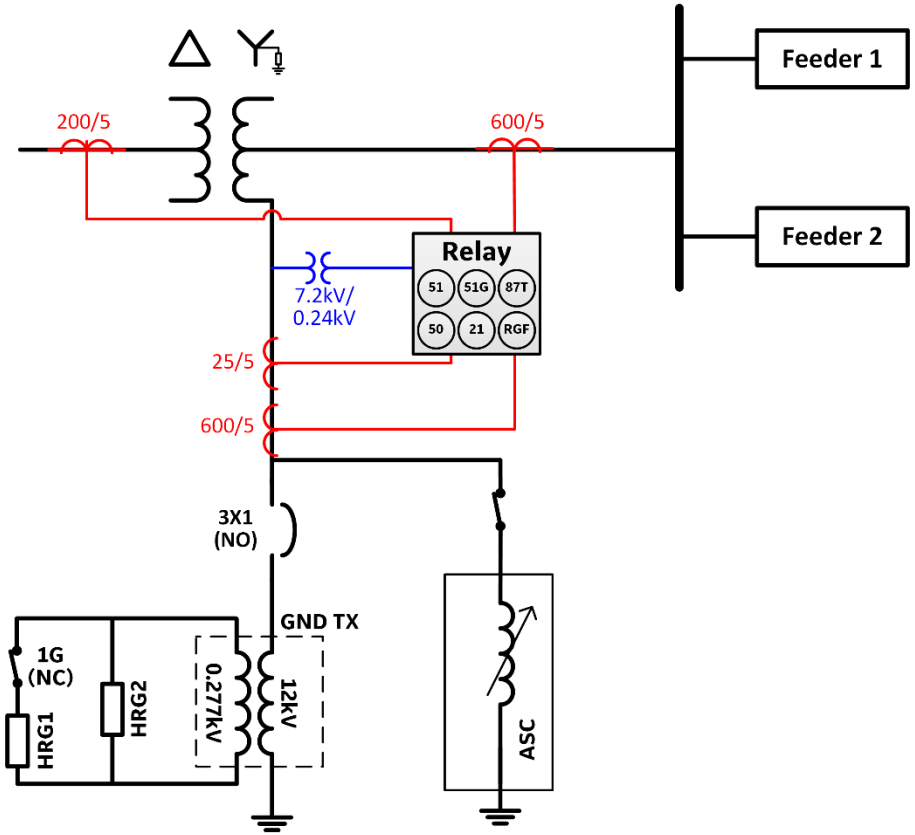
Conclusions

- The protection scheme operated properly for all cases
- RGF CTs should have the same characteristics
- 87T is not able to detect the SLG faults on the LV side – the fault current is too small
- The RGF operates after sensitive ground scheme is switched in
- The impedance-based ASC protection identifies abnormal condition in the neutral
- The impedance-based ASC protection detects TG fault that short minimum 25% of the ASC winding



Recommendations

- The CTs used for RGF should have the same ratio
- Let through current of the sensitive grounding scheme should be above the pickup level of the RGF
- Lower neutral VT can enhance the operation of the impedance-based ASC protection function



Acknowledgement

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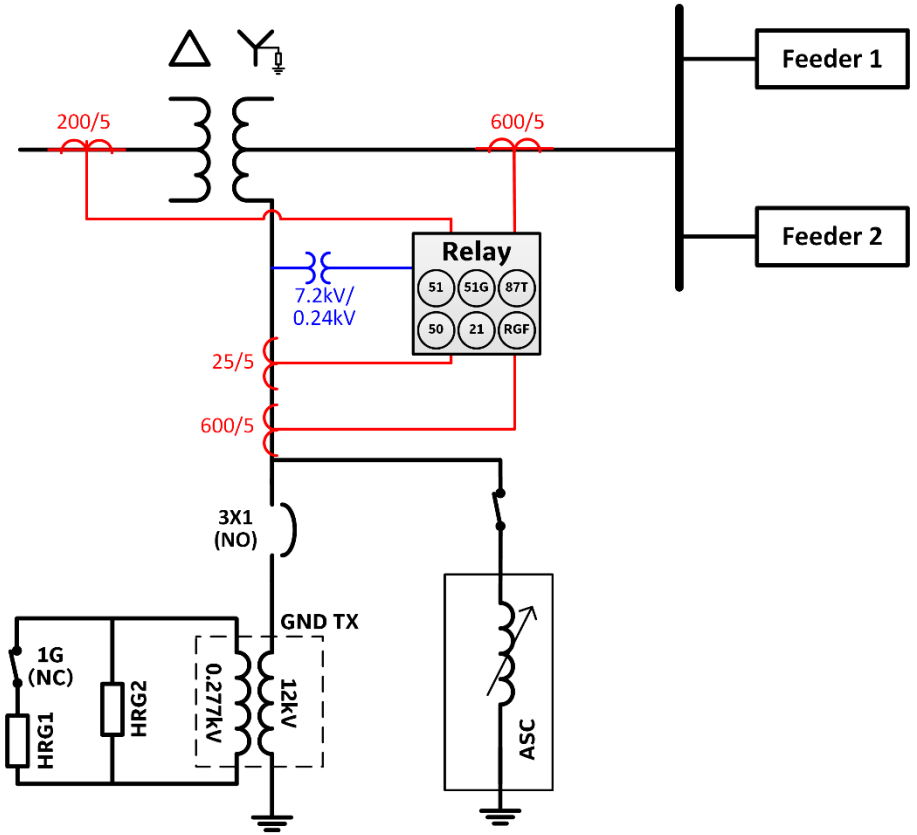
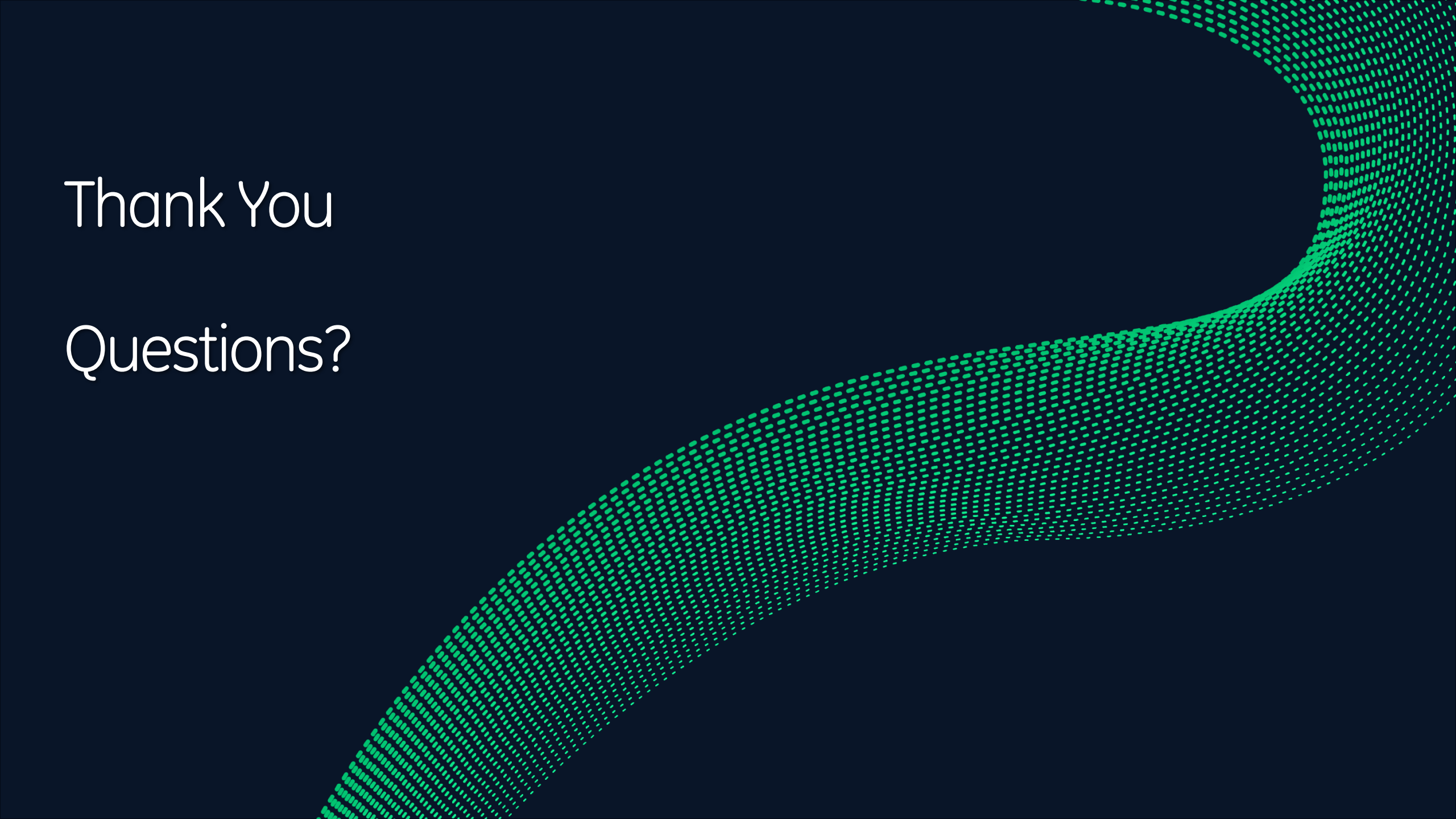


Thank You

Questions?