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Enhancing Power System Resilience: An Analysis of Novel Arc Suppression Device Technology in Mitigating Single Line to Ground Faults

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Introduction

- Electricity network is the foundation of modern civilization, with cables crucial for distribution systems.
- Cables are prone to faults, including single line to ground (SLG) faults, compromising performance and reliability.
- Insulation deterioration often causes SLG faults, creating a conductive path between the phase conductor and the ground.
- SLG faults can lead to overvoltage in unfaulted phases and high ground-fault current, damaging cable insulation and causing more faults.
- Overvoltage can affect other equipment like transformers, generators, and motors.
- In industrial settings, high temporary voltage after a fault can degrade cables, requiring strategies to reduce SLG fault impacts.
- Mitigation includes grounding cables with a grounding transformer or neutral grounding resistor, limiting ground-fault current and reducing overvoltage.

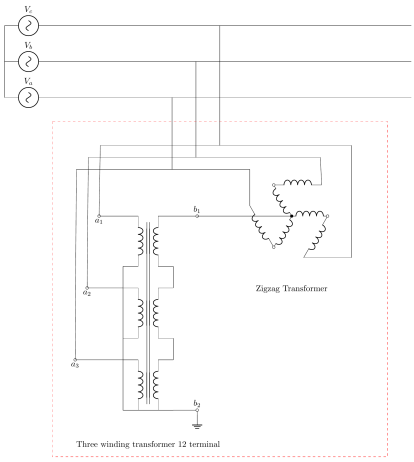
Main Contributions

- Evaluates the effectiveness of AASD technology in mitigating SLG faults in power cables connected between two delta side transformers.
- increasing the power system resilience by automated control logic for the AASD device.
- Utilizes MATLAB Simulink simulations for a comparative analysis of system performance with and without AASD implementation.
- Discusses the benefits and potential limitations of AASD technology, emphasizing its implications for power system protection and reliability.

Agenda

Arc Suppression Device I

- The power industry employs symmetrical components for the analysis of unbalanced three-phase systems. The zero sequence component plays a pivotal role in fault detection and diagnosis.
- An innovative device is proposed that uses the zero sequence component for the suppression of SLG faults.
- The device is comprised of two parts: a zigzag transformer and a three-phase transformer.
- The device combines features of both active and passive arc suppression techniques.



Arc Suppression Device II

The function of each part of the device consists of:

- Zigzag transformer for cases without a real ground point or ungrounded systems.
- Three-phase transformer designed to extract the zero voltage component.

For the three-phase transformer, the voltage is calculated according to the following equation:

$$v_{\text{open}\Delta} = v_a + v_b + v_c = 3v_o \tag{1}$$

The zero sequence voltage is calculated according to the following equation:

$$v_0 = \frac{1}{3}(v_a + v_b + v_c) \tag{2}$$

Arc Suppression Device III

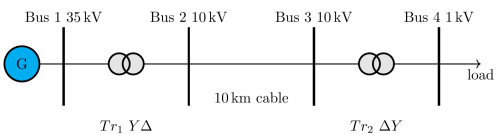
For the zigzag transformer, the neutral point is calculated according to the following equation:

$$v_{n\ \text{zigzag}} \begin{cases} I_g * 3 * Z_{zigzag} & \text{Case 1} \\ v_{\text{open}\Delta} & \text{Case 2} \end{cases} \tag{3}$$

The two cases are: if the system's neutral point is connected to the ground (Case 1) or if the neutral point is connected to the open delta (Case 2).

System Overview

- Source feeds first bus (35 kV), star-delta transformer 35/10 kV, and cable.
- Second bus connected to transformer's secondary side and beginning of the cable.
- Third bus as primary side of delta-star transformer and the end of the cable, the transformer is steps down voltage to 1 kV and connects to fourth bus.
- Fourth bus connected to load.



10 km Cable Parameters Configuration 606

R (Ω/km):

	Phase A	Phase B	Phase C
Phase A	0.4960	0.1983	0.1770
Phase B	0.1983	0.4903	0.1983
Phase C	0.1770	0.1983	0.4960

L (H/km):

	Phase A	Phase B	Phase C
Phase A	0.7356	0.0541	0.0236
Phase B	0.0541	0.6661	0.0541
Phase C	0.0236	0.0541	0.7356

C (F/km):

	Phase A	Phase B	Phase C
Phase A	0.3194	1.3063e-6	1.3063e-6
Phase B	1.3063e-6	0.3194	1.3063e-6
Phase C	1.3063e-6	1.3063e-6	0.3194

Transformers Data

	Transformer 1 $Y\Delta$:
Nominal power and frequency	[10e6 VA, 50 Hz]
Winding 1 parameters	[35,000 V Ph-Ph, 0.245 Ω, 0.031194 H]
Winding 2 parameters	[10,000 V Ph-Ph, 0.06 Ω, 0.0076394 H]
Magnetization resistance	61,250 Ω
Magnetization inductance	194.96 H

	Transformer 2 ΔY:
Nominal power and frequency	[10e6 VA, 50 Hz]
Winding 1 parameters	[10,000 V Ph-Ph, 0.06 Ω, 0.0076394 H]
Winding 2 parameters	[1,000 V Ph-Ph, 0.0002 Ω, 2.5465e-05 H]
Magnetization resistance	15,000 Ω
Magnetization inductance	47.746 H

Load Parameters

	Phase A	Phase B	Phase C
Active power (kW)	485	485	485
Reactive power (kvar)	190	190	190

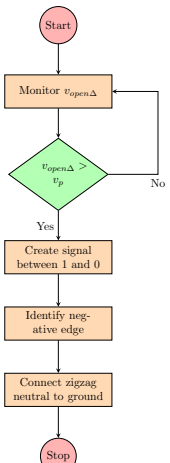
Load Flow Analysis

Bus	Phase A (pu deg.)	Phase B (pu deg.)	Phase C (pu deg.)
1	1.0000 0.00	1.0000 -120.0000	1.0000 120.0000
2	0.9878 -31.4430	0.9886 -151.4730	0.9887 88.5842
3	0.9241 -32.0681	0.9294 -152.1210	0.9252 87.5295
4	0.9159 -3.5646	0.9178 -123.9295	0.9116 116.1323

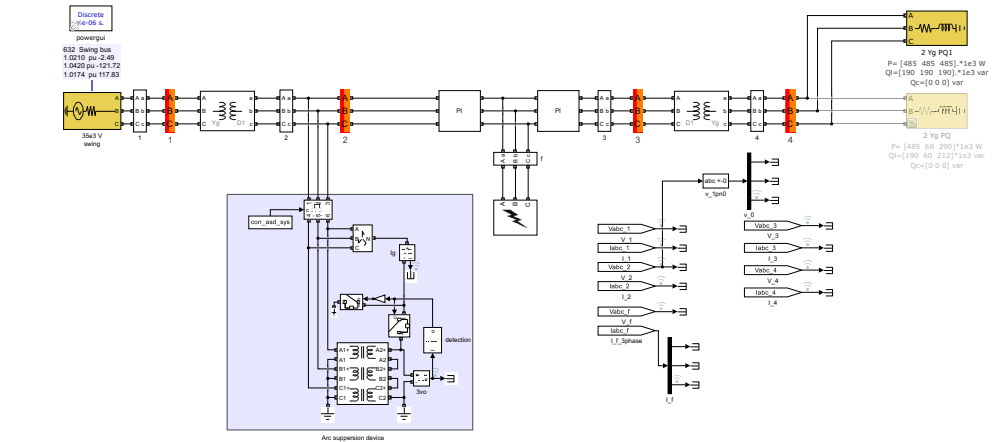
Theory

The AASD device can be automated with a control logic to regulate its operation. The control logic monitors the neutral point voltage $v_{open\Delta}$ and, if it exceeds a threshold, triggers a fault identification process. An industrial technique identifies the fault's end, and a signal connects the zigzag neutral to the ground.

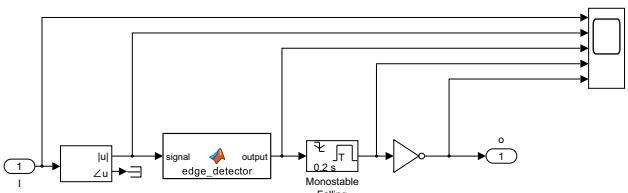
1. Identify fault by monitoring neutral point voltage when zigzag is connected to open delta.
2. Detect fault end using an industrial technique.
3. Connect zigzag neutral to ground to mitigate fault.

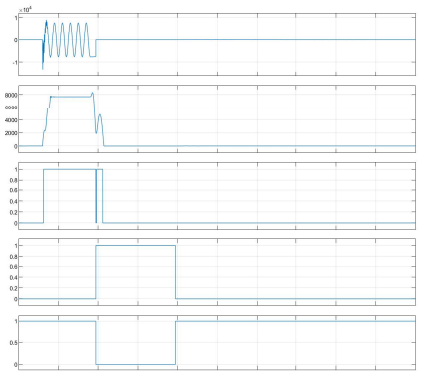


Implementation I



Implementation II

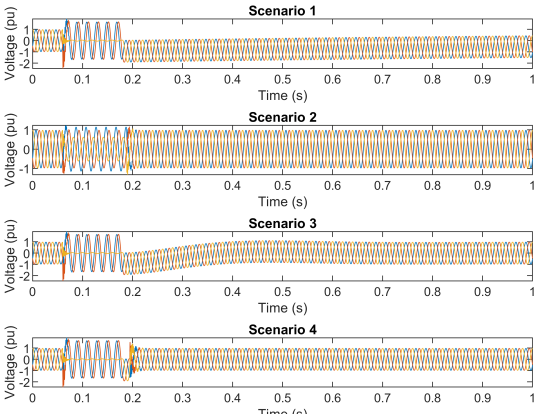




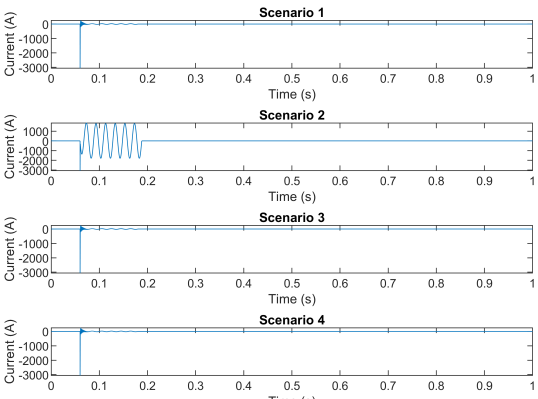
Operational Scenarios

Scenario No	Description
1	The zone between the two transformers is not grounded.
2	This zone is grounded by a zigzag transformer (the neutral point of the zigzag is solidly grounded
3	An AASD device is added to this zone (the neutral point of the zigzag is connected to the open delta side of the transformer
4	The control logic is used in the system operation (the neutral point of the zigzag is connected to the ground after the fault).

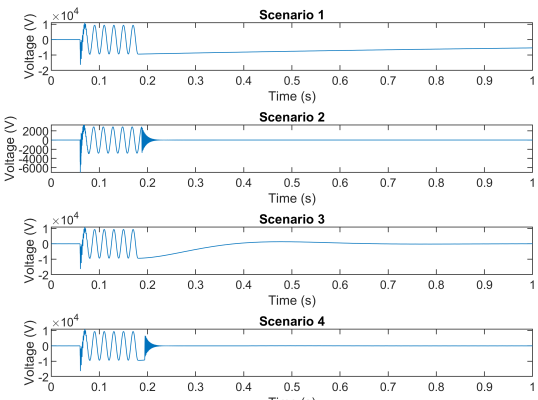
- Figure shows voltage at bus 2, output of Delta side of Tr_1.
- Controlled-AASD device improves system by preserving isolation and quickly restoring healthy conduction.



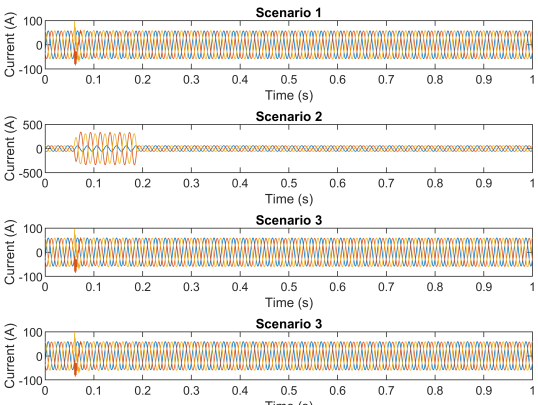
- The controlled-AASD device reduces the SLG fault current to around zero.



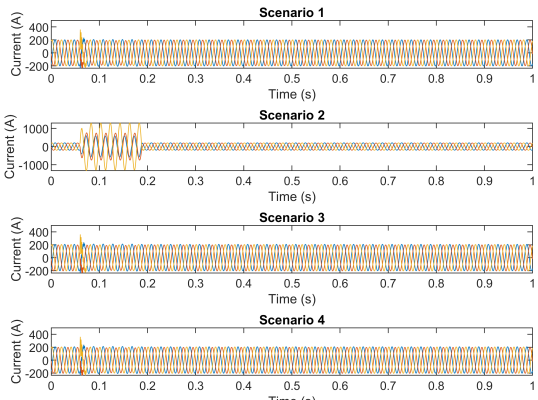
- An SLG fault significantly increases the zero voltage component.
- The delta transformer eliminates this zero voltage but takes time, causing overheating and reducing its lifespan.
- The controlled-AASD device immediately eliminates this zero voltage component, preserving the transformer's lifespan.



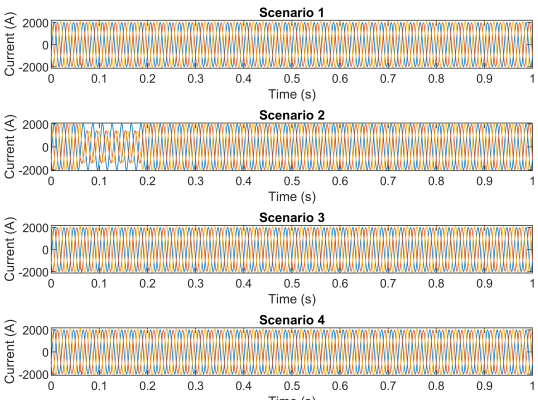
- In scenario 3 (using an AASD device), no current is drawn from the source.
- This means the AASD device maintains system isolation during a fault.
- The controlled-AASD device identifies faults using control logic based on the open delta voltage.
- Scenario 4 shows the device current is high for less than 0.01 seconds.



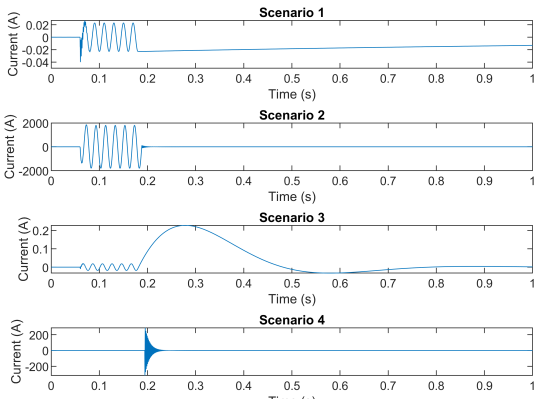
- In scenario 2 (grounding with zigzag), an SLG fault in cable zone causes high current draw in two phases on grid side (bus 1), leading to voltage and rotor angle stability problems in grid.
- Adding an AASD device does not introduce this problem.



- Using the AASD or controlled-AASD, the load still receives high-quality power, similar to an ungrounded system, compared to the grounded system.



- This figure shows the ground current for the four scenarios. It's clear that the controlled-AASD device reduces the ground current to around zero, with a current spike for less than 0.01 seconds.



Conclusions

- The system was simulated using Simulink and M-files in MATLAB, testing four scenarios.
- The AASD device effectively maintained power quality and stability, especially when controlled.
- This method enhances power system reliability and decreases maintenance costs by extending cable and transformer lifespans.
- The fourth scenario, with control logic, restored healthy conduction faster.

Thank you!

Ready for questions.

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