Design and Implementation of an Arc Suppression Device for Single Line to Ground Faults in Power Systems

Ahmed M. Elkholy[1,2] Dmitry I. Panfilov[2] Mikhail G. Astashev[2]

[1]Faculty of engineering, Tanta university, Tanta, Egypt
[2]Industrial electronics department, Moscow Power Engineering Institute, Moscow, Russia

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Introduction

- Single line to ground (SLG) faults are the most common type of faults in power distribution systems, accounting for approximately 70% of all faults.
- To mitigate the risks associated with SLG faults, an Arc Suppression Device (ASD) is used.
- The ASD is typically installed in the neutral point of the distribution system transformers to reduce the fault current.
- There are two types of ASD: passive and active.
  - Passive ASD: uses the passive elements to be installed on the neutral point of the distribution system transformers to suppress the fault current.
  - Active ASD: Also installed in the neutral of the distribution system transformers, it actively suppresses the fault current using voltag injection.

Main Contributions

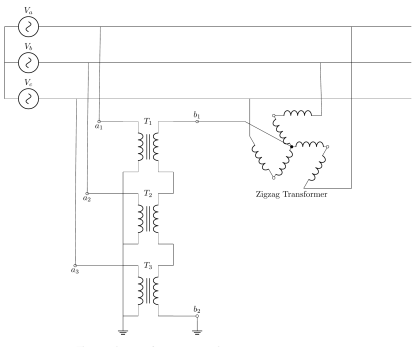
- Proposes an innovative arc suppression device that utilizes the zero sequence component for the suppression of arc faults.
- The device combines features of both active and passive arc suppression techniques.
- The device consists of two parts: a zigzag transformer and a three-phase transformer.
- The three-phase transformer has a configuration that allows it to extract the zero voltage component, enhancing fault detection and diagnosis.
- The zigzag transformer is used to create a neutral point for the system, ensuring proper grounding.

Agenda

3. Arc Suppression Device
4. Case Study
5. Result
6. Discussion of the Results
7. Conclusions

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:

$$v_{n\ \text{zigzag}} \begin{cases} 0 & \text{Case 1} \\ v_{\text{open}\Delta} & \text{Case 2} \end{cases} \tag{3}$$

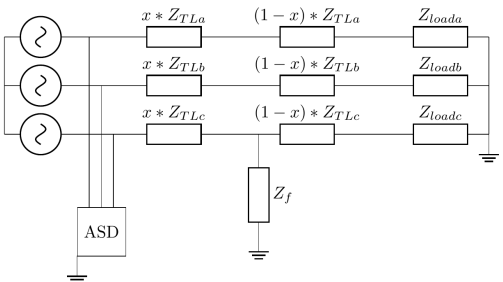
The two cases are: if the system's neutral point is connected to the ground (Case 1) or if the neutral point is connected to the open delta (Case 2).

Case Study I

- The case study involves two buses: the grid bus, which operates at 11 kV, and the load bus, which provides three-phase active power of 1.44 MW and reactive power of 0.57 MVAR.
- These buses are linked by a 606 Configuration type transmission line (TL). The TL spans a length of 0.3048 km.
- System base power: 100 MVA.
- Base voltage (line-to-line): 11 kV.
- Corresponding base current: 5.732 kA.

Case Study II

- A fault, symbolized as x, may occur at any position along the TL, specifically in the middle.
- This fault is designed to transpire between 0.04 and 0.1 seconds, spanning three cycles, in line with common faults encountered in distribution systems.
- The fault itself possesses a resistance of 0.001 Ω, while the ground resistance measures 0.01 Ω.



TL Parameters (606 Configuration)

Table: R (Ω/mile)

	Phase A	Phase B	Phase C
Phase A	0.7982	0.3192	0.2849
Phase B	0.3192	0.7891	0.3192
Phase C	0.2849	0.3192	0.7982

Table: X (Ω/mile)

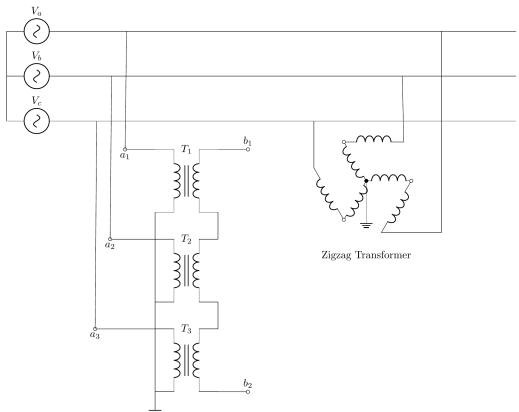
	Phase A	Phase B	Phase C
Phase A	0.4463	0.0328	0.0143
Phase B	0.0328	0.4041	0.0328
Phase C	0.0143	0.0328	0.4463

Table: B (μS/mile)

	Phase A	Phase B	Phase C
Phase A	96.8897	-1e-6	-1e-6
Phase B	-1e-6	96.8897	-1e-6
Phase C	-1e-6	-1e-6	96.8897

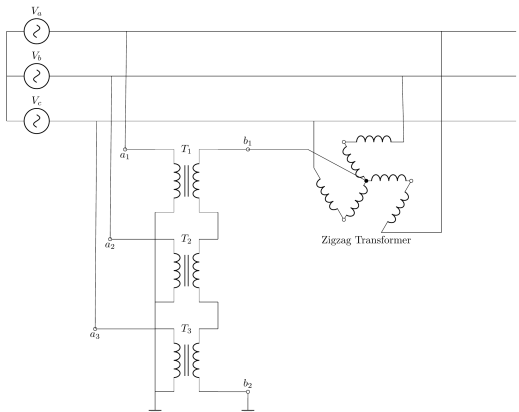
ASD Device - Case 1

The first case involves grounding the system at the neutral point of the zigzag transformer.



ASD Device - Case 2

The second case involves connecting the neutral point of the zigzag transformer to the open delta.



Fault Current

- The fault current is reduced to less than 2000 amperes with the addition of the ASD, compared to 10000 amperes without it.
- The fault current includes all fault components, while the device current only represents the ground current.

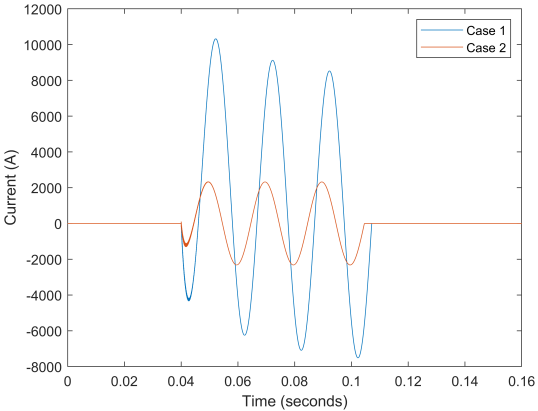


Figure: Fault Current

Impact of Injecting $3V_o$

As seen in the figure, the open delta voltage is reduced by 30%, indicating a significant reduction in the zero sequence component, which is the main component in the SLG fault.

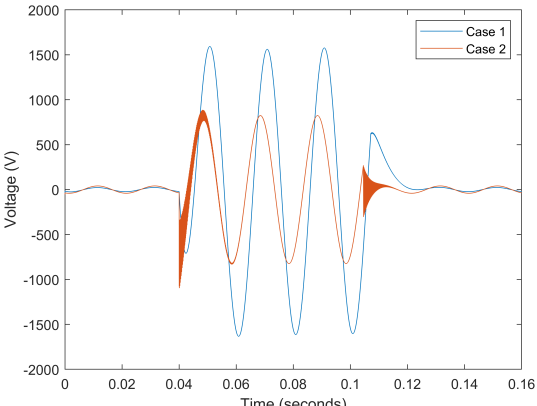


Figure: Open Delta Voltage between Terminal b1 and b2

Voltage at the Load Bus

- The presence of the ASD device does not impact the voltage at the load terminal compared to the base case.
- However, it enhances fault transition by eliminating the open delta voltage from the fault path.

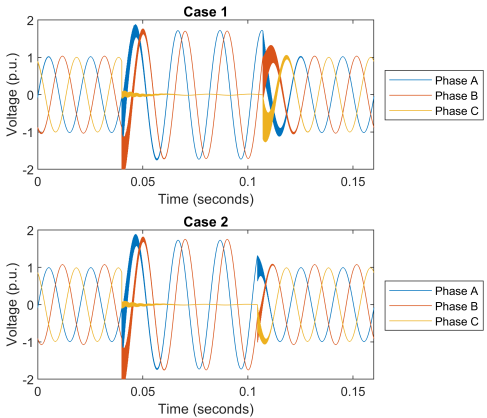


Figure: Voltage at the Load Bus

Three-Phase Sending End Current

- In the first case, the current in the faulty phase reaches six times the normal current, while the current in the other phases reaches five times the normal current.
- The second case shows the currents when an ASD device is added to the system, significantly limiting the fault current in the faulty phase.

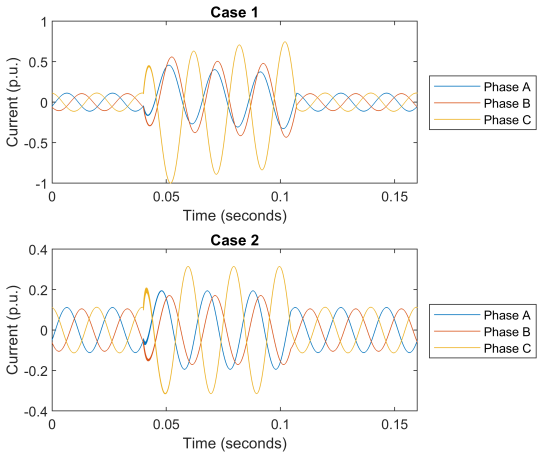


Figure: Three-Phase Sending End Current.

the zigzag transformer neutral point current

- Figure illustrates the current passing through the ASD, representing only the ground or third component current.
- As shown in the figure, the addition of the ASD significantly reduces the ground current in the faulty phase to near zero, which is similar to an isolated system.

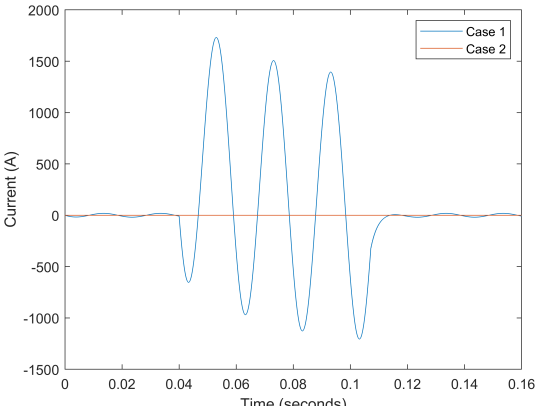


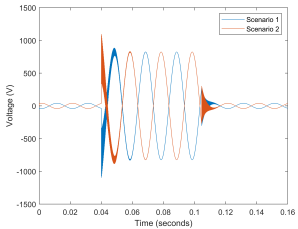
Figure: The Device Current or the Current Passing Through the Zigzag Neutral Point.

the Polarity of the Open Delta

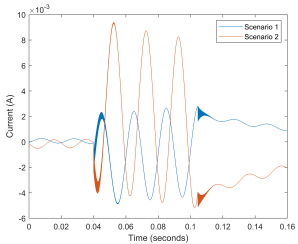
- Two scenarios were tested by changing the polarity of the open delta.
- The results show that the current flow in the open delta changed, but the device's effect as an ASD remained the same.
- This means that the current flow in the neutral point of the zigzag transformer is not affected by the polarity of the open delta.

(a) Open Delta Voltage between Terminal b1 and b2

(b) Device Current when Changing the Polarity



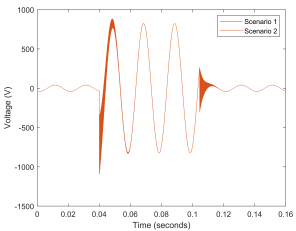
(a)



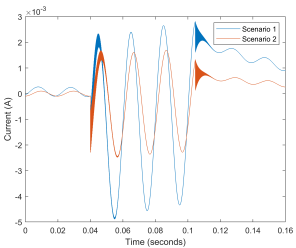
(b)

Changing the Transformer Ratio

- Two scenarios were created to test the impact of changing the transformer ratio.
- No significant changes were observed in the system when increasing the ratio beyond 2.
- The open delta voltage between terminal b1 and b2 remained the same.
- However, there was a small change in milliamperes in the current flow to the neutral point.



(a)



(b)

(a) Open Delta Voltage between Terminal b1 and b2 when Changing Transformer Ratio

(b) Device Current when Changing Transformer Ratio

Discussion of the Results I

- The study demonstrates the impact of injecting a zero-sequence voltage component at the neutral point of a zigzag transformer.
- The addition of a device that injects $3V_o$ significantly limits the fault current in the faulty phase, reduces the ground current in the faulty phase to near zero, and reduces the fault current to a small value.
- The voltage at the load terminal is not affected by the addition of the device.
- The device is a low-cost and advantageous alternative to active arc suppression devices.
- It combines the benefits of passive devices, such as complex control, with the advantages of active devices, such as near complete compensation of active and reactive power during a fault.

Discussion of the Results II

- The device avoids the negative effects of passive devices that isolate the neutral point even when no fault is present and sidesteps the intricate control systems needed for active devices.
- Changing the open delta polarity or transformer ratio does not affect the fault current but does affect the device current to adapt to these changes.
- In the first scenario, where the polarity of the open delta was changed, it was found that while the device current changed, its effect as an ASD remained unchanged.
- In the second scenario, where the transformer ratio was changed, it was found that despite increasing it beyond 2, no significant changes occurred in the system compared to the base case scenario.

Conclusions I

- The study demonstrates the effectiveness of a device that injects a zero-sequence voltage component at the neutral point of a zigzag transformer.
- The device limits the fault current and reduces the ground current in the faulty phase.
- The device is a low-cost and advantageous alternative to active arc suppression devices, combining the benefits of passive and active devices while avoiding their negative effects.
- The results show that the fault current is decreased by 80% and the neutral voltage is decreased by 40%.
- Changing the open delta polarity or transformer ratio does not affect the fault current but does affect the device current to adapt to these changes.

Conclusions II

- Future work could include taking into account the location of the fault with changes in the unbalancing ratio, the effect of fault resistance, and the effect of the fault inception angle.

Thank you!

Ready for questions.

ahmed_elkholy@f-eng.tanta.edu.eg