# Understanding Generator Stator Ground Faults and Their Protection Schemes


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# Overview

- Stator winding deterioration
- Fundamental neutral overvoltage
- Third-harmonic schemes
- Subharmonic injection

# Thermal Deterioration

Weakening of insulation when heated beyond its design temperature

| Location | Cause |
|---|---|
| Overall | Overloading |
| | Cooling system failure |
| Local | High-resistance electrical connections |

# Electrical Deterioration

Decomposition of insulation due to arcing

| Location | Cause |
|---|---|
| Voids in the insulation | Partial discharge |
| Between groundwall and core | Slot discharge |
| End winding | Surface tracking |

# Mechanical Deterioration

Insulation wear or cracking due to excessive movement or vibration

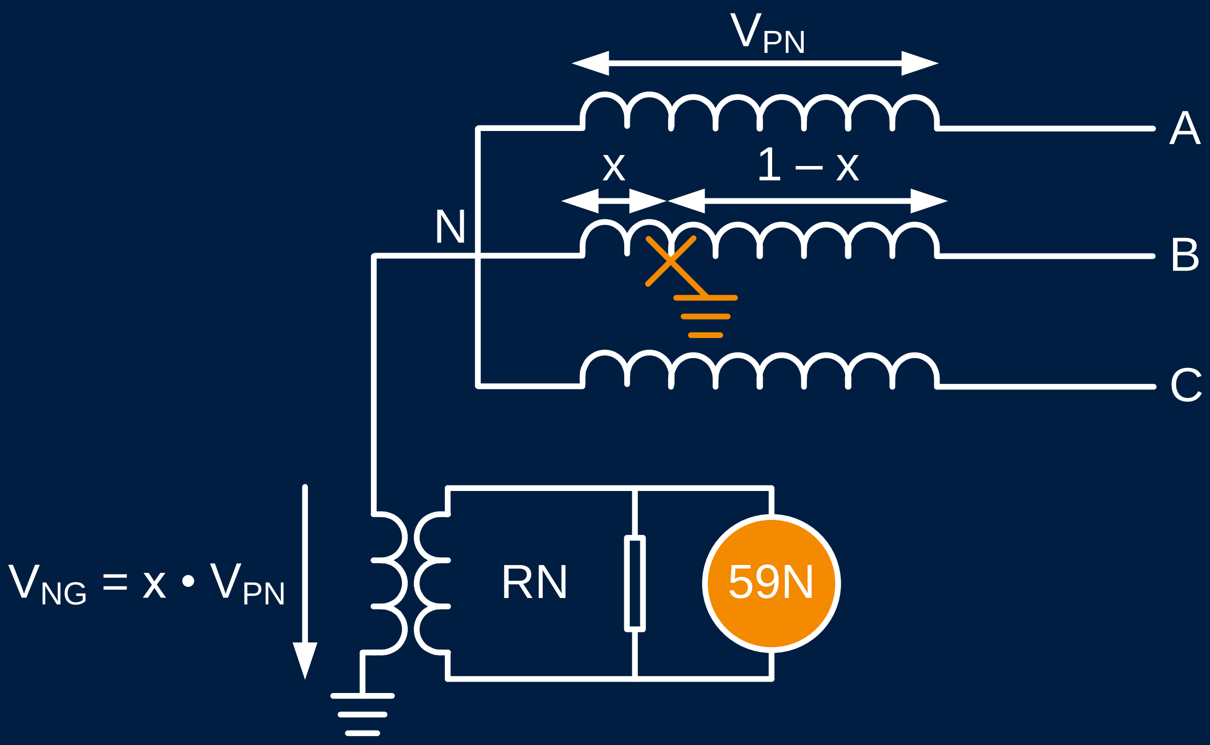
| Location | Cause |
| --- | --- |
| Slot | Insulation shrinkage |
| | Poor construction |
| | Thermal cycling |
| End winding | Inadequate bracing |
| | Transient torque event |

# Environmental Deterioration

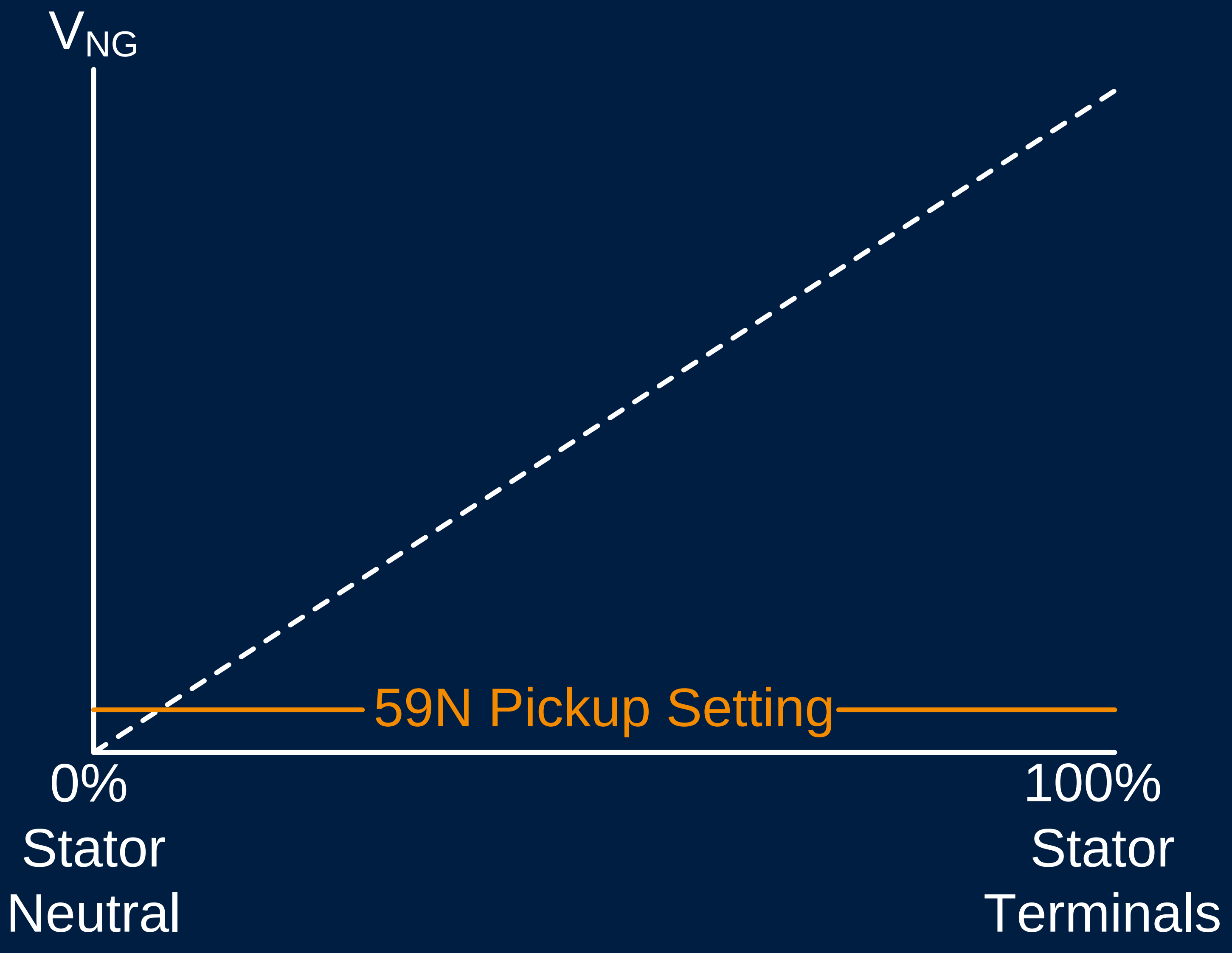
Reduces electrical or mechanical insulation strength, provides medium for surface tracking

| Location | Cause |
| --- | --- |
| End Winding | Water |
| | Oil |
| | Dust |

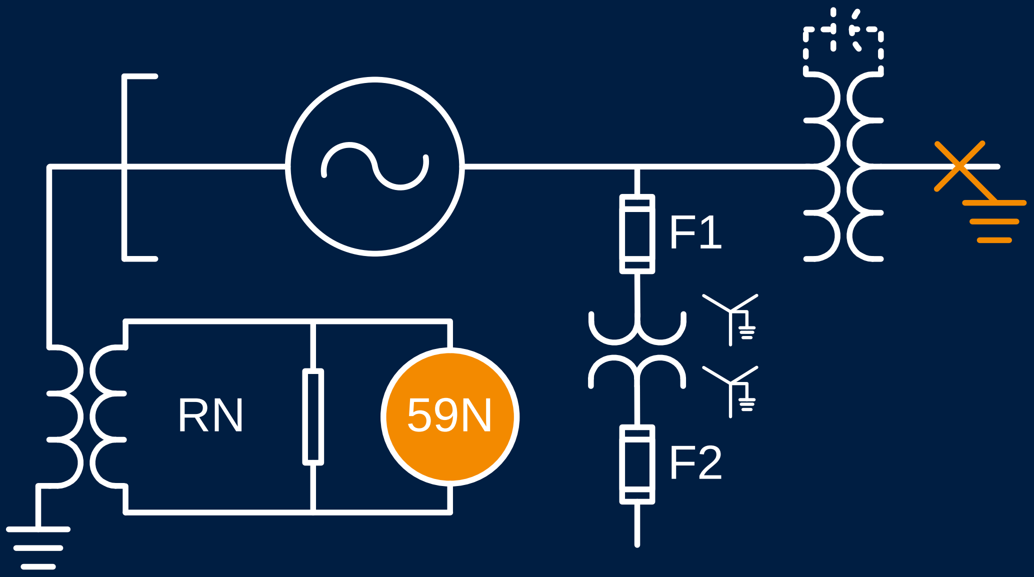
# Fundamental Neutral Overvoltage



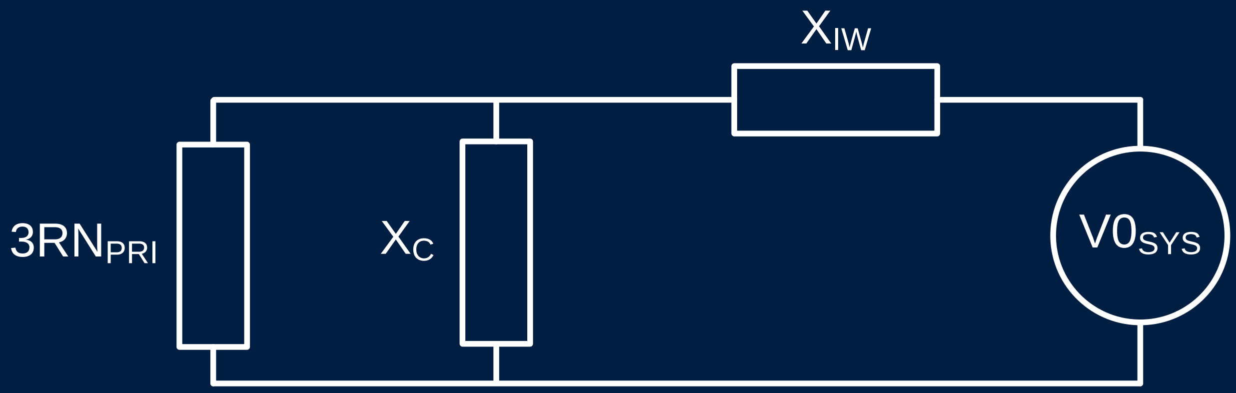
# Coverage Is Proportional to Location



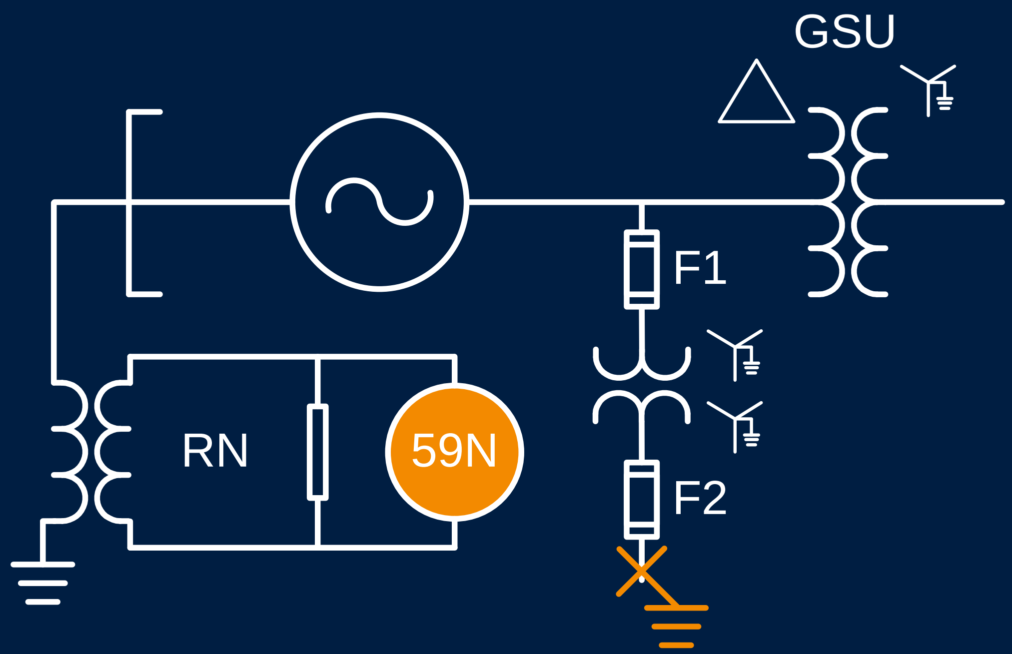
# Response to GSU High-Voltage Ground Fault



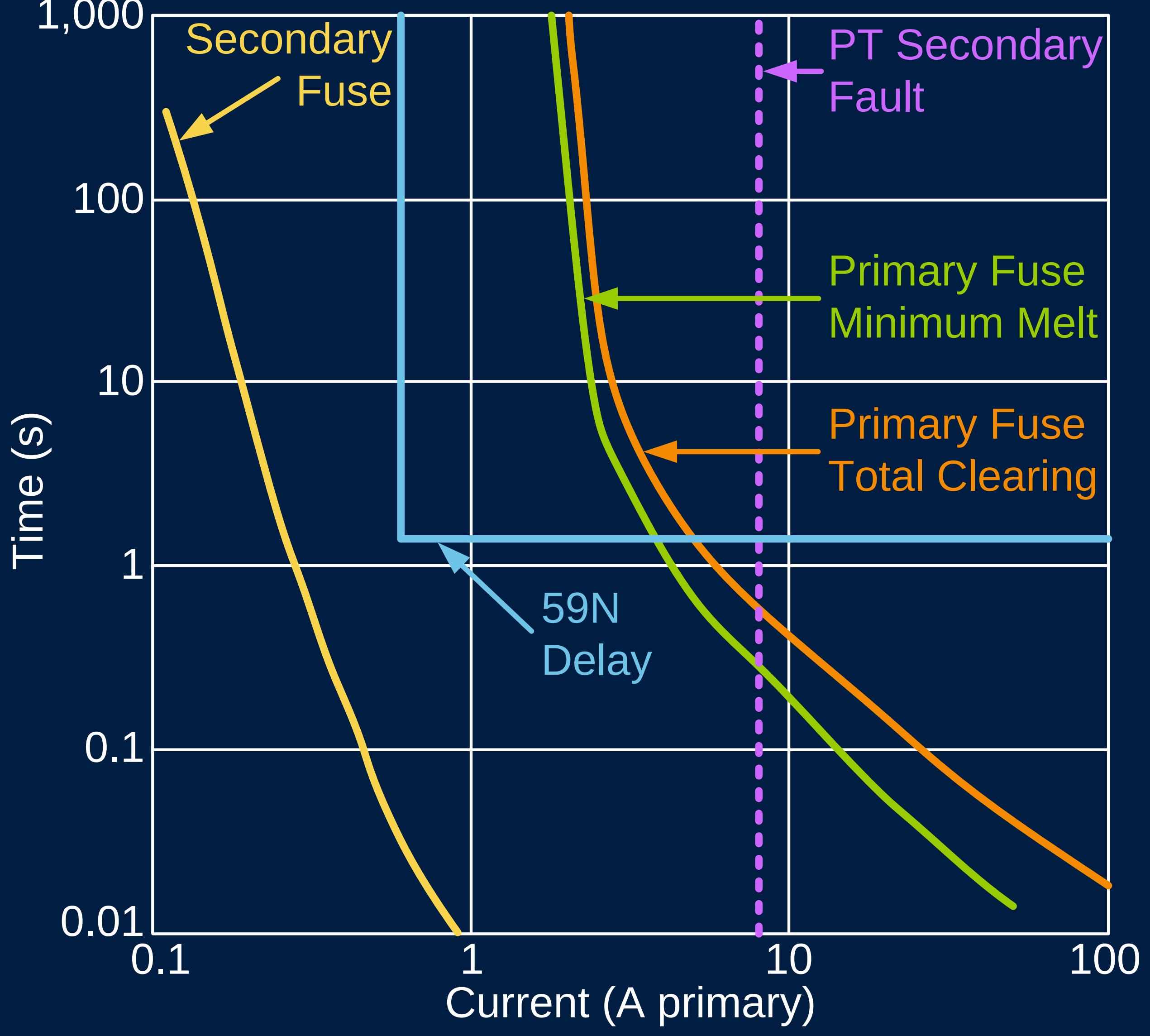
# GSU High-Voltage Ground Equivalent Circuit



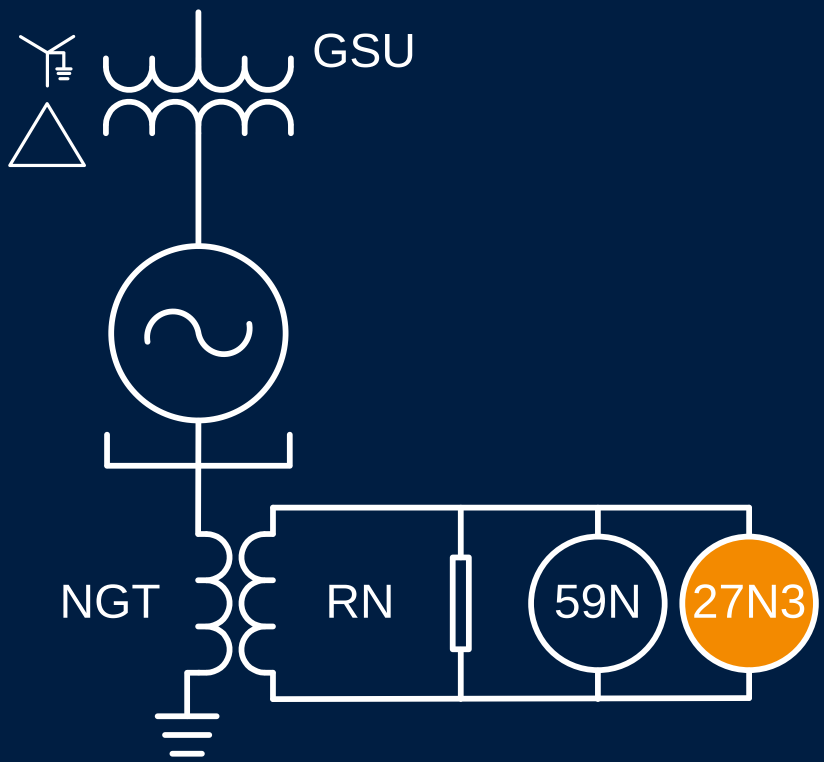
# PT Secondary Fault



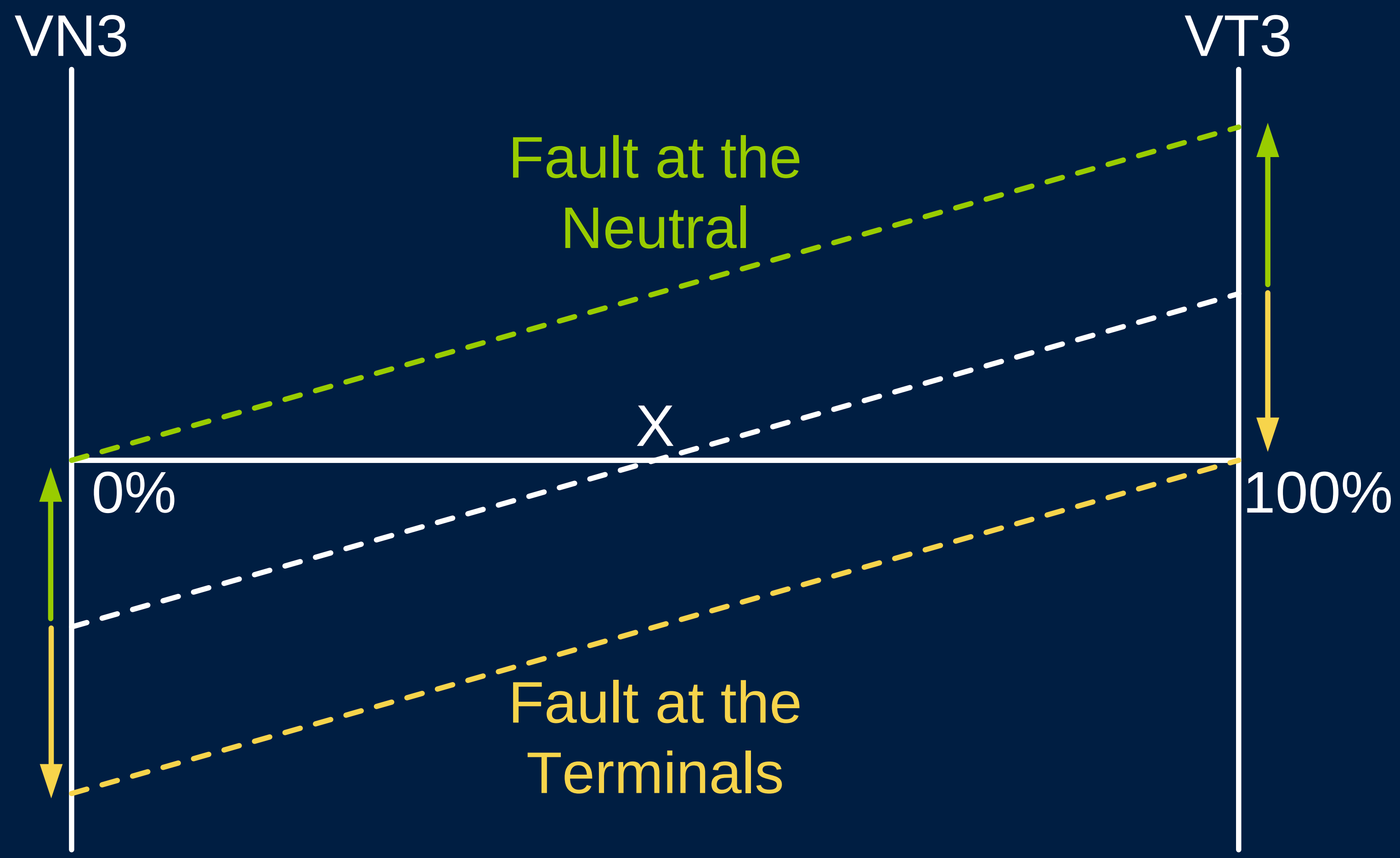
# Coordination of 59N With PT Fuses



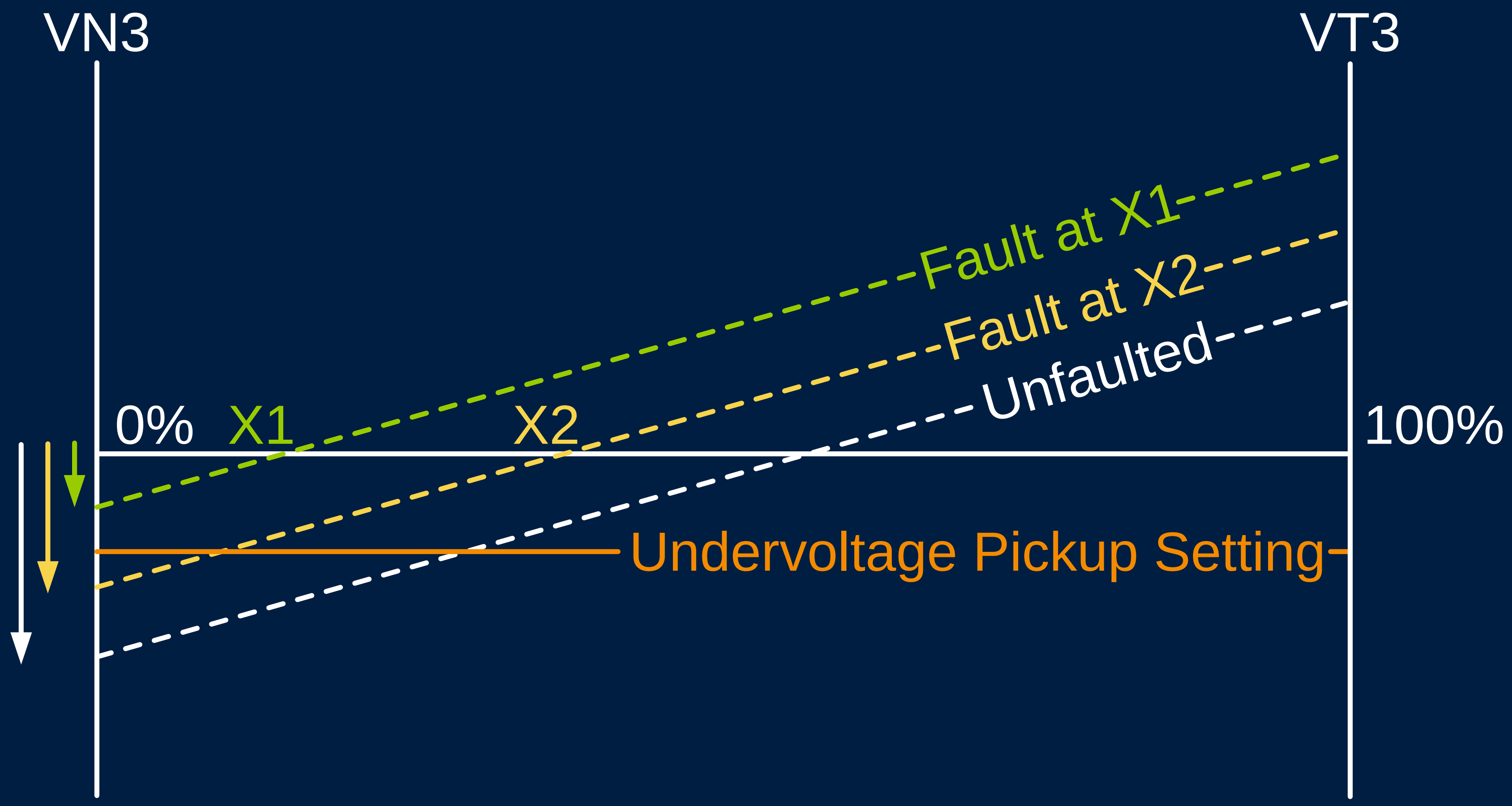
# Third-Harmonic Neutral Undervoltage



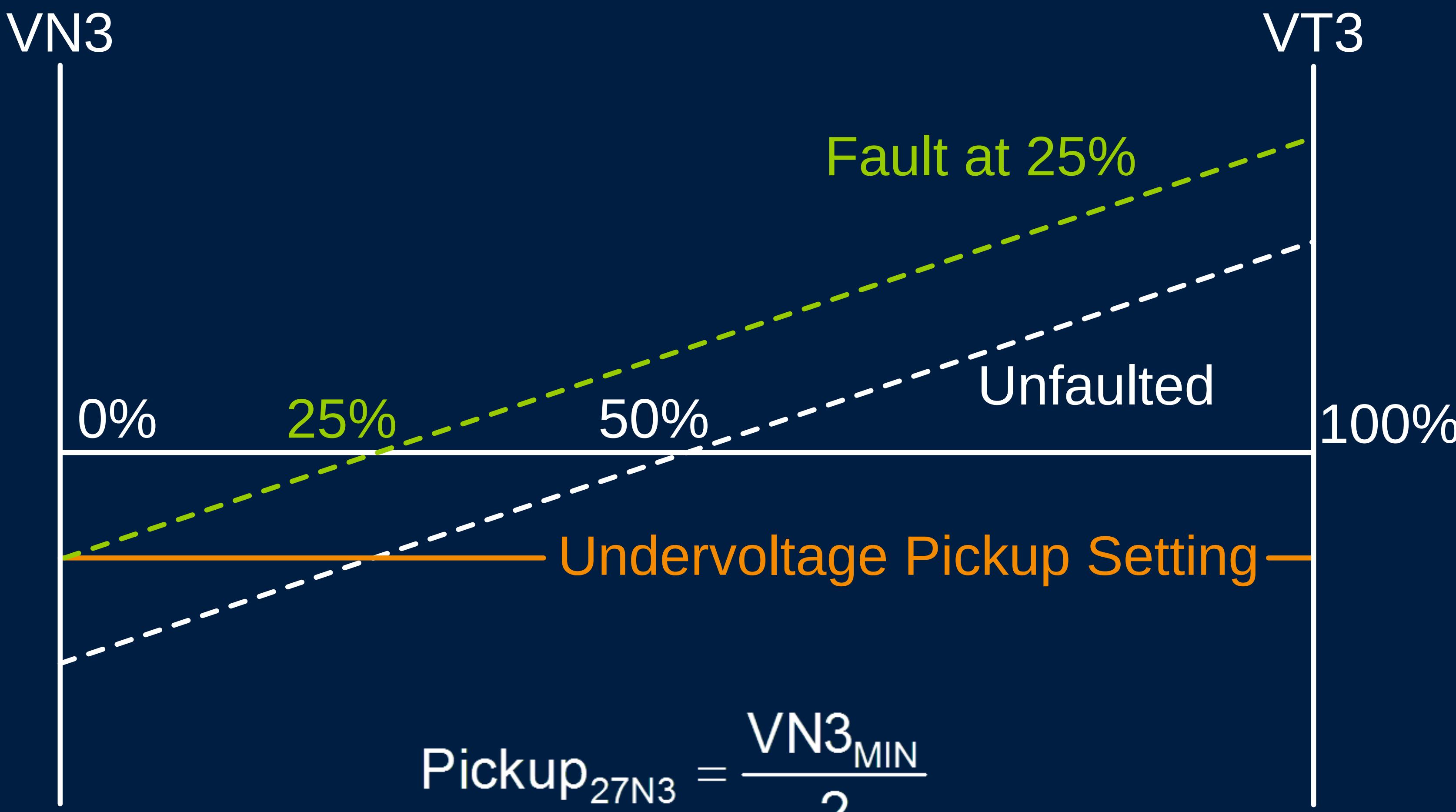
# Distribution of Third Harmonic



# VN3 for Faults at X1 and X2

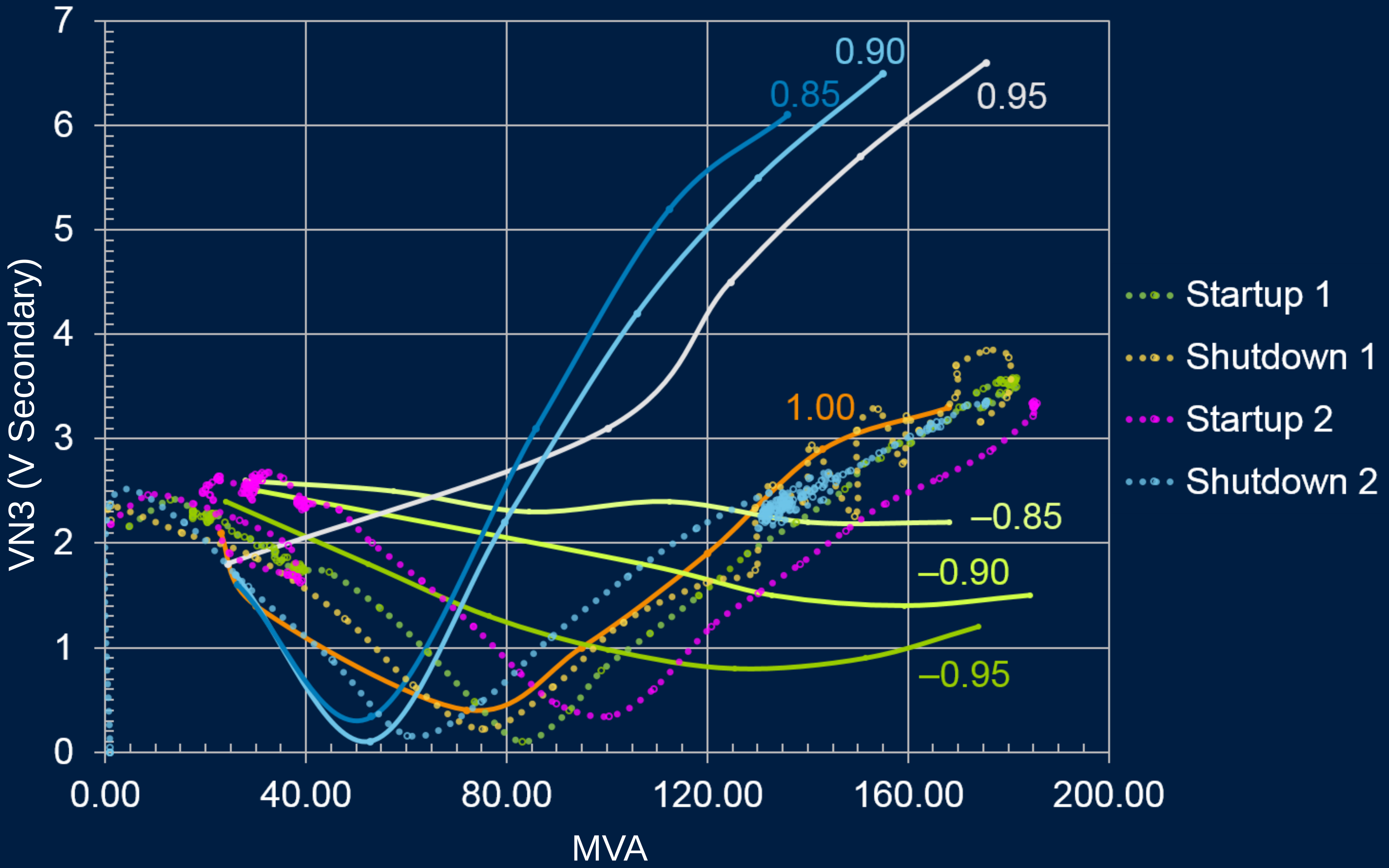


# Setting the 27N3 Pickup

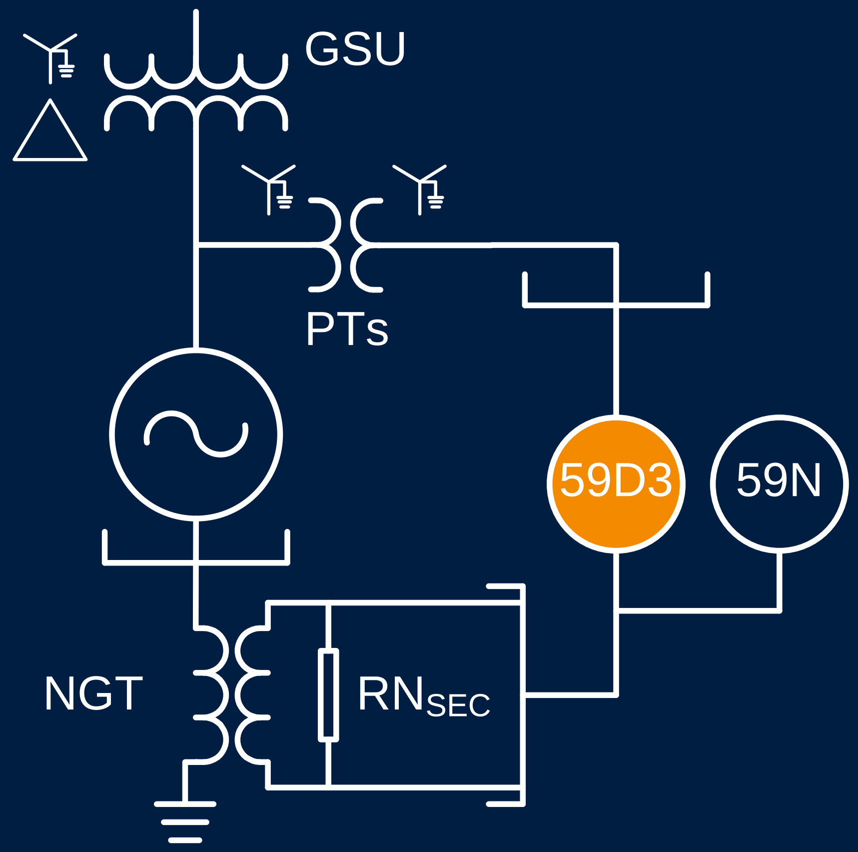



$$\text{Pickup}_{27N3} = \frac{\text{VN3}_{\text{MIN}}}{2}$$

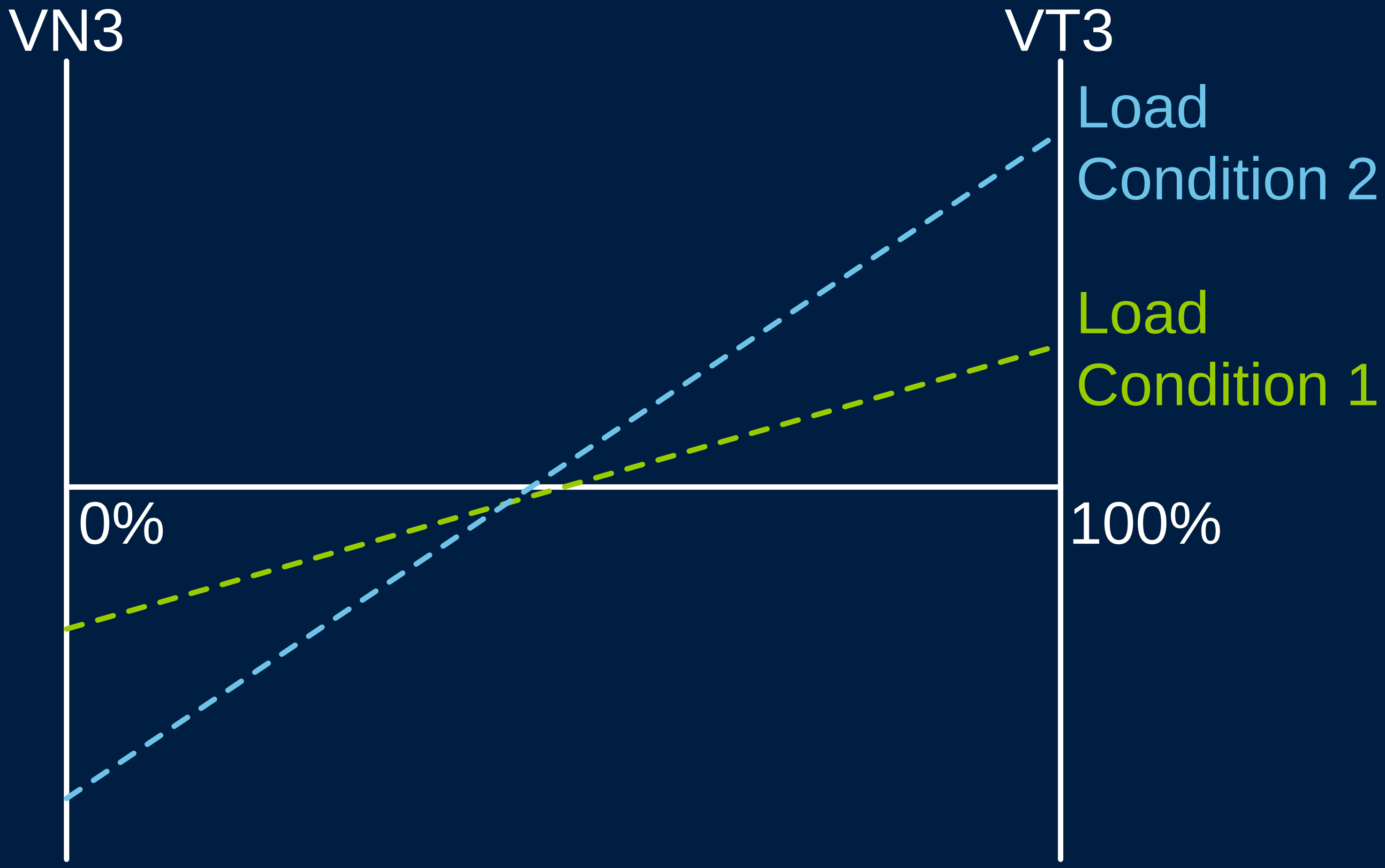
# Third-Harmonic Survey



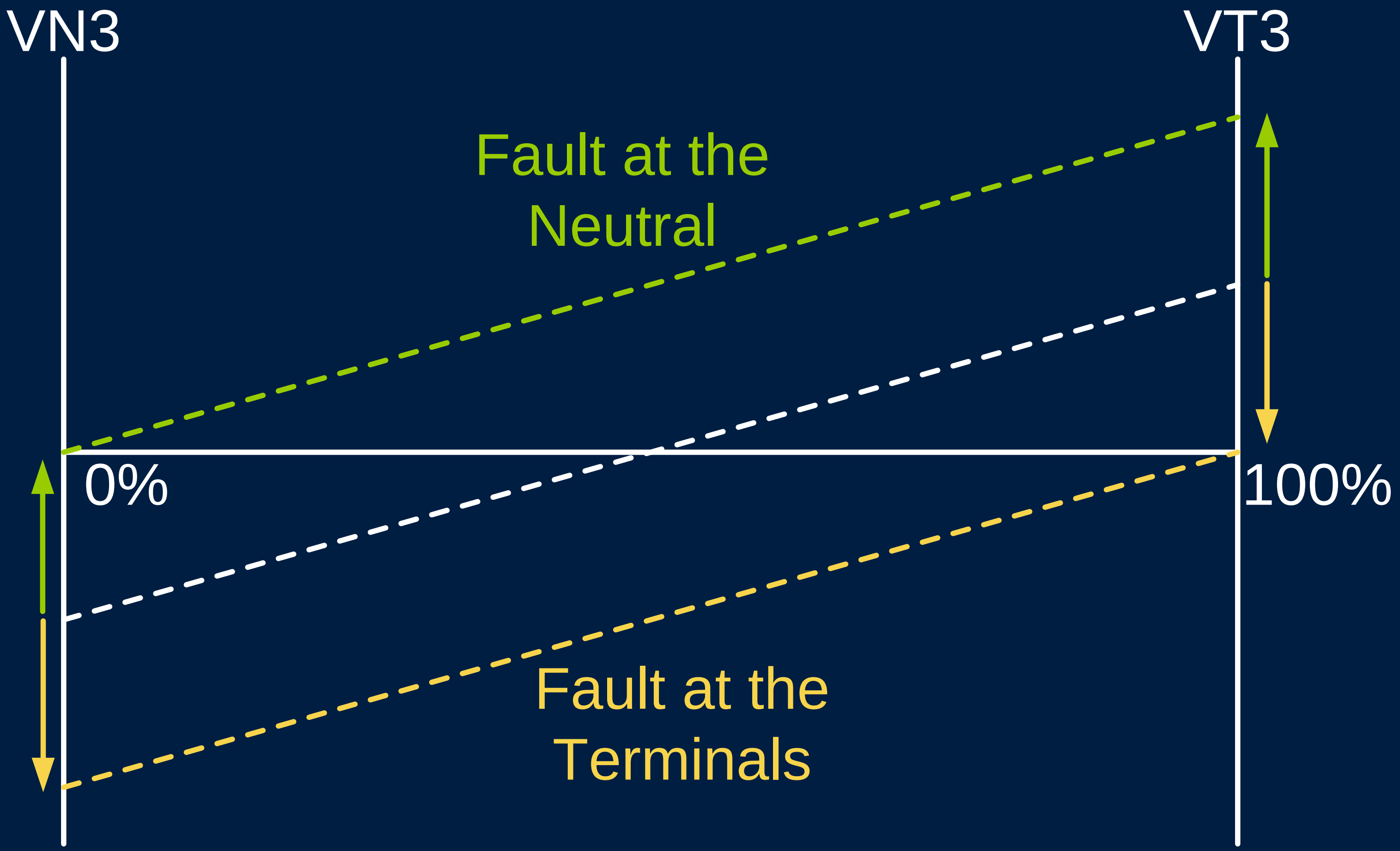
# Third-Harmonic Differential



# Third-Harmonic Ratio Is Not Sensitive to Load Changes



# Distribution Shift Due to Fault



# Setting the 59D3

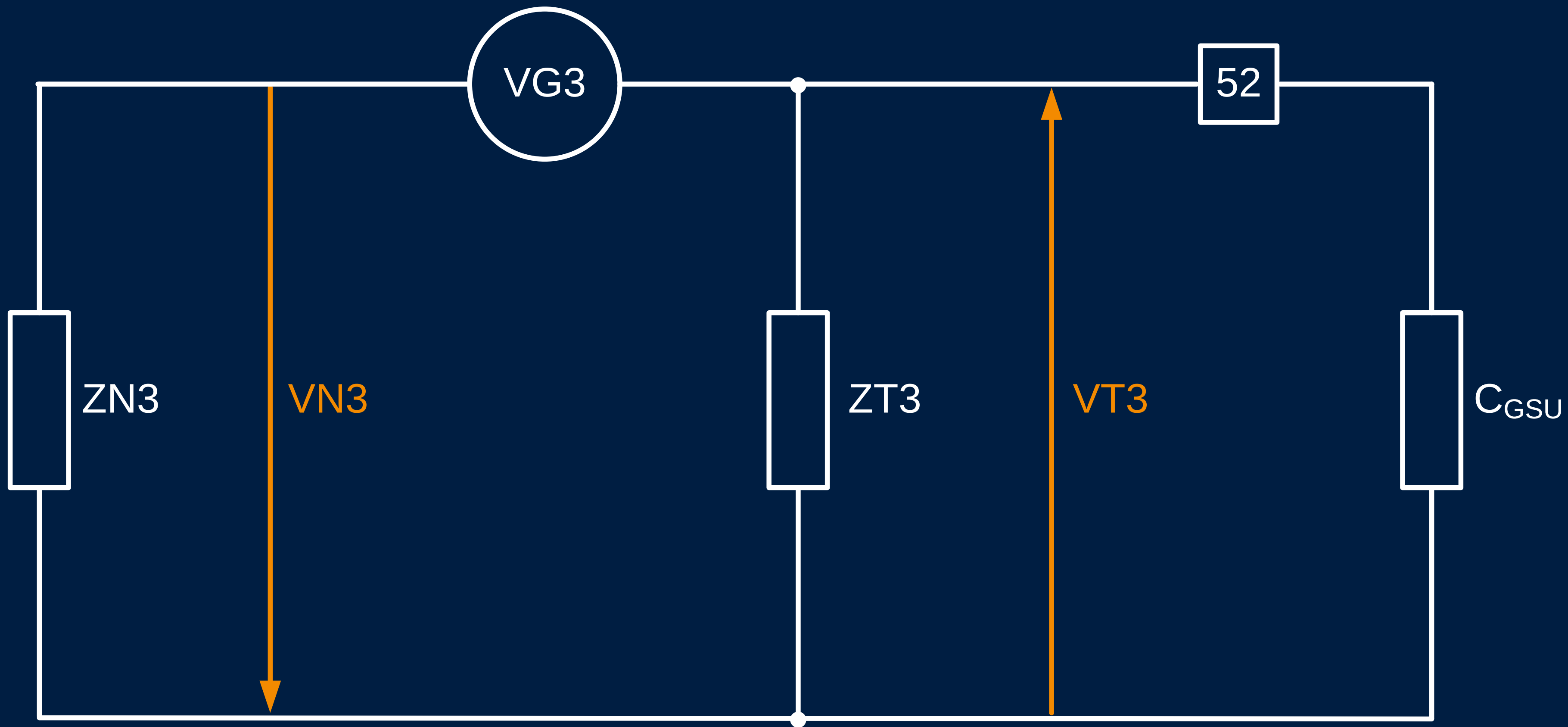
$$OP = \left\| VN3\_SEC \right| - RAT \left| VT3\_SEC \right\| > PKP$$

$$RAT = \frac{\sum_{n=1}^{N} VN3\_SEC_n}{\sum_{n=1}^{N} VT3\_SEC_n}$$

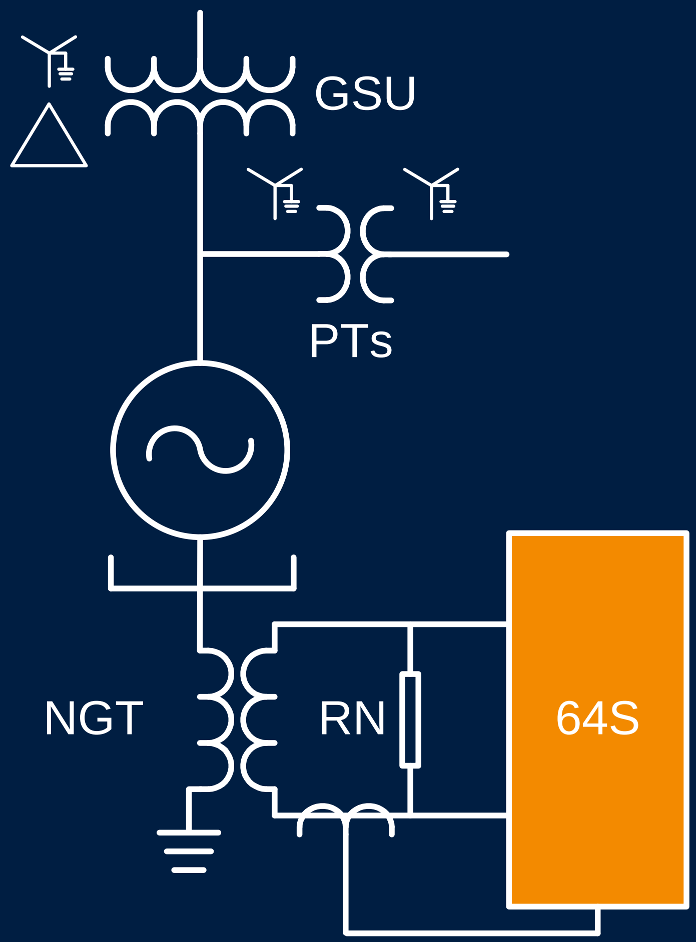
$$Pickup_{59D3} = 1.1\left(0.1 + MAX_n \left\{ \left\| VN3\_SEC_n \right| - RAT \left| VT3\_SEC_n \right\| \right\}\right)$$

where N is the number of measurements

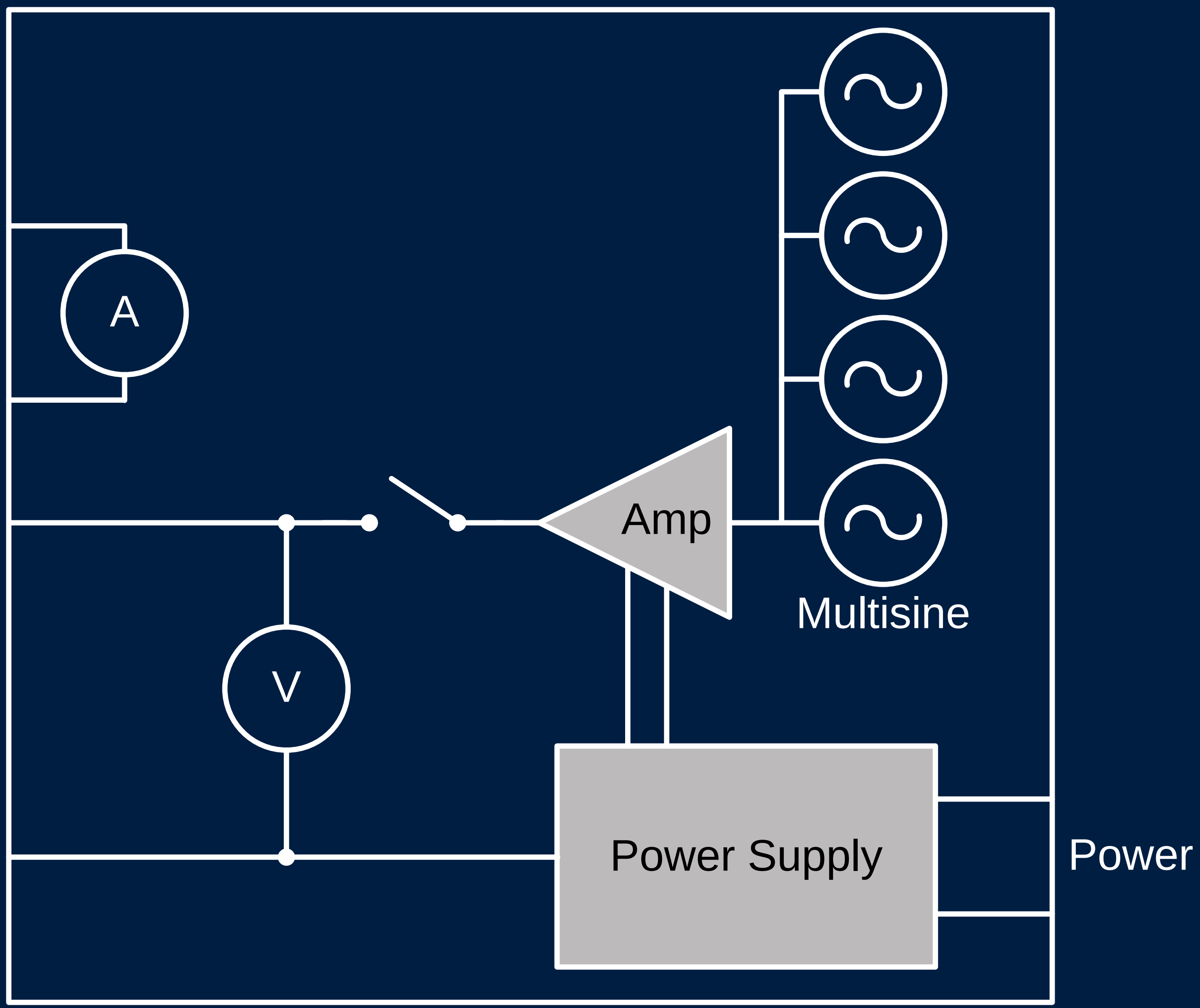
# Influence of Low-Side Breaker



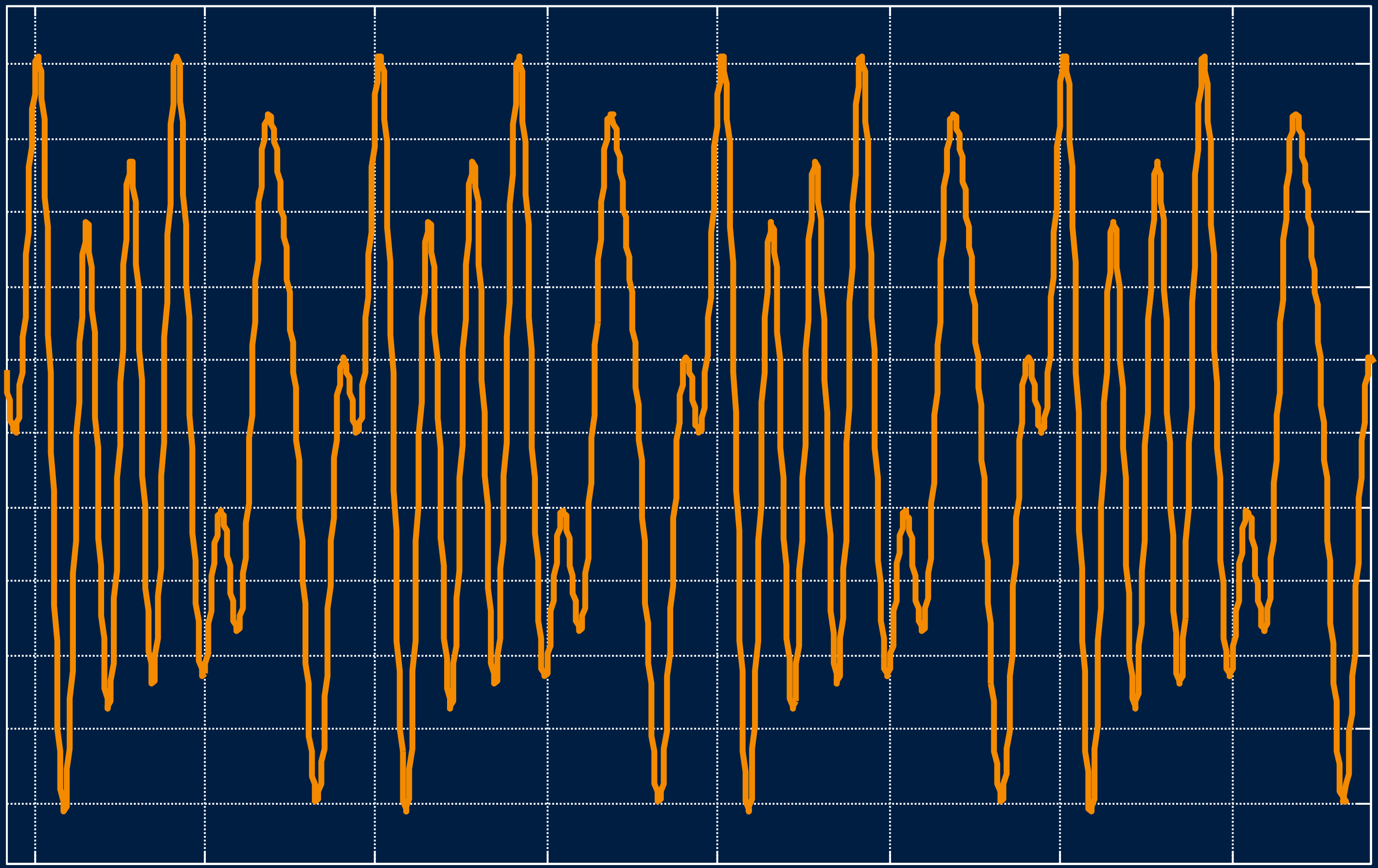
# Subharmonic Injection



# Injection Source

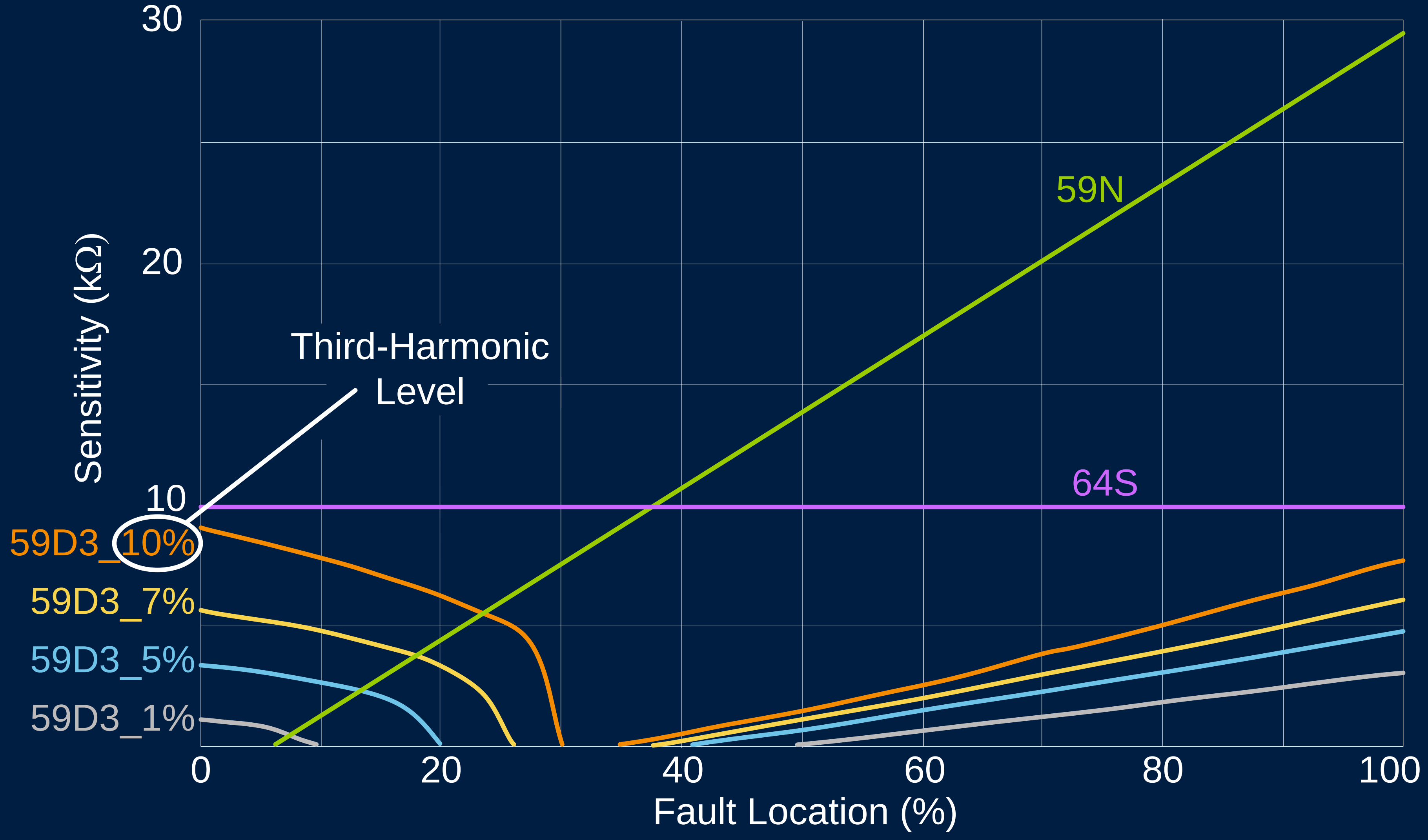


# Multisine

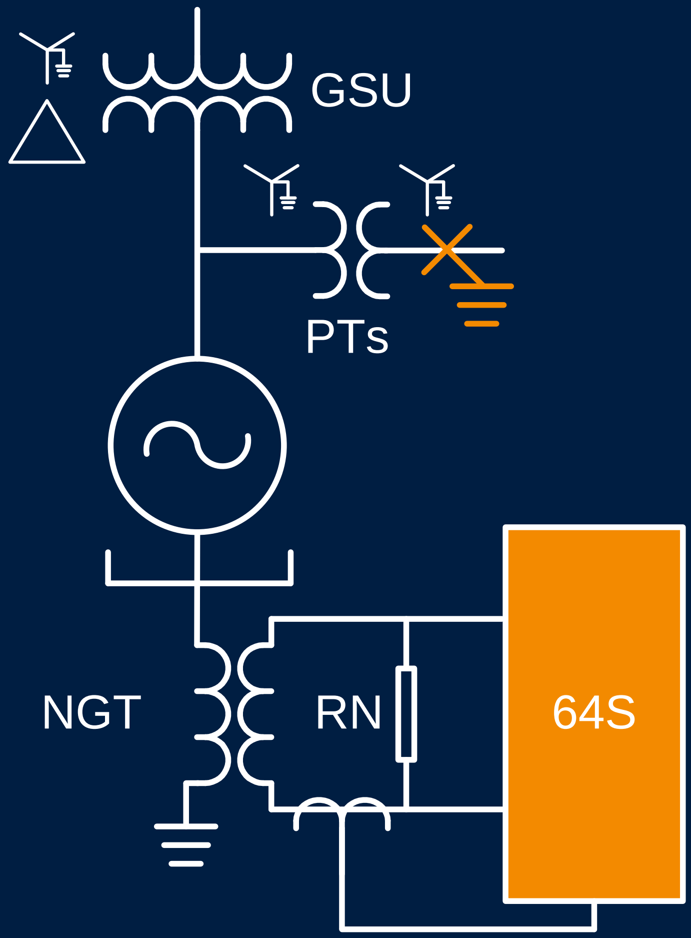


Injection of multiple sources allows application of redundant 64S units

# 64S Coverage Does Not Depend on Location



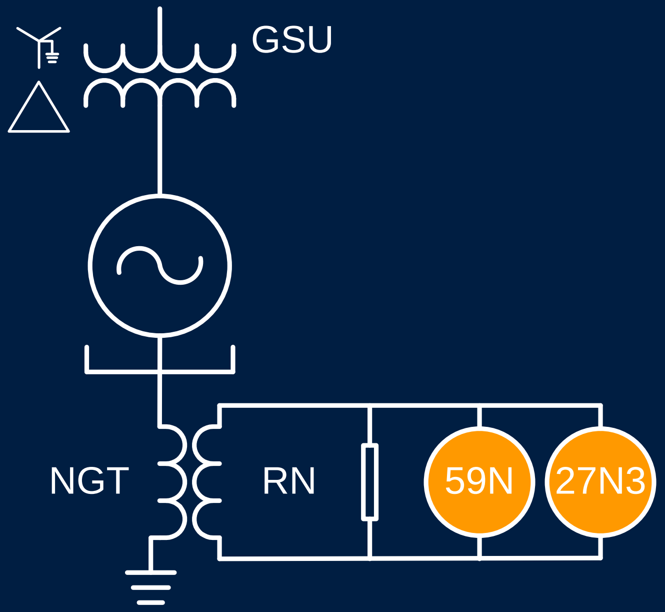
# PT Secondary Ground




| Test | Insulation (kΩ) |
|---|---|
| Unit offline | 59.2 |
| PT ground, X phase | 8.57 |
| PT ground, Y phase | 8.11 |
| PT ground, Z phase | 8.05 |

# Conclusions

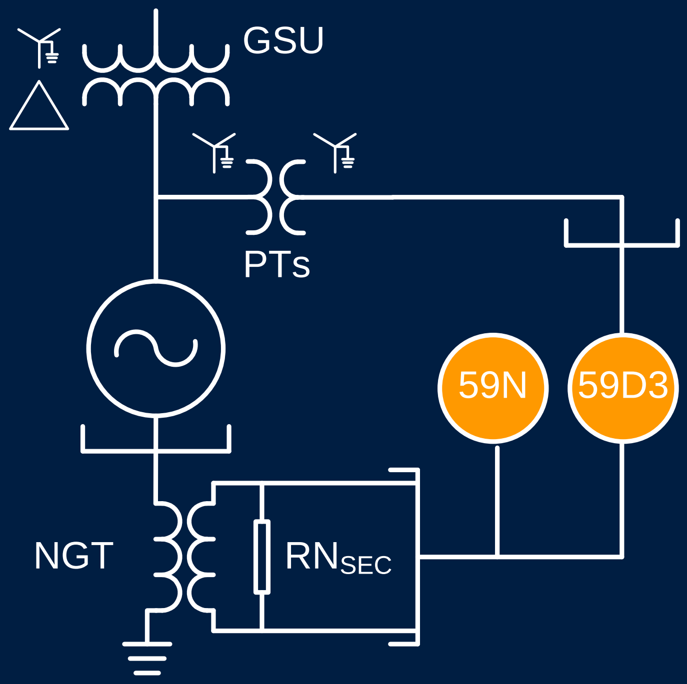
- 59N protects ~95% of winding (need to consider system and PT faults)
- 27N3 can protect remaining 5% (can be challenging to set)



# Conclusions

## 59N3 Can Protect Remaining 5%

- Requires grounded-wye PT
- Is easier to set



# Conclusions

## 64S Can Protect Entire Winding

- Requires extra hardware
- Is straightforward to set
- Works at standstill and starting
- Is applicable to parallel generators

# Questions?