Texas A&M Relay Conference

Slingshot Disconnection!

Understanding the effect of disconnecting an un-stabilized ungrounded source

The Authors

Sebastien Billaut PE [1]

James Steele EIT [1]

Koustubh Banerjee, PE [3]

Joseph Johnson PE [1]

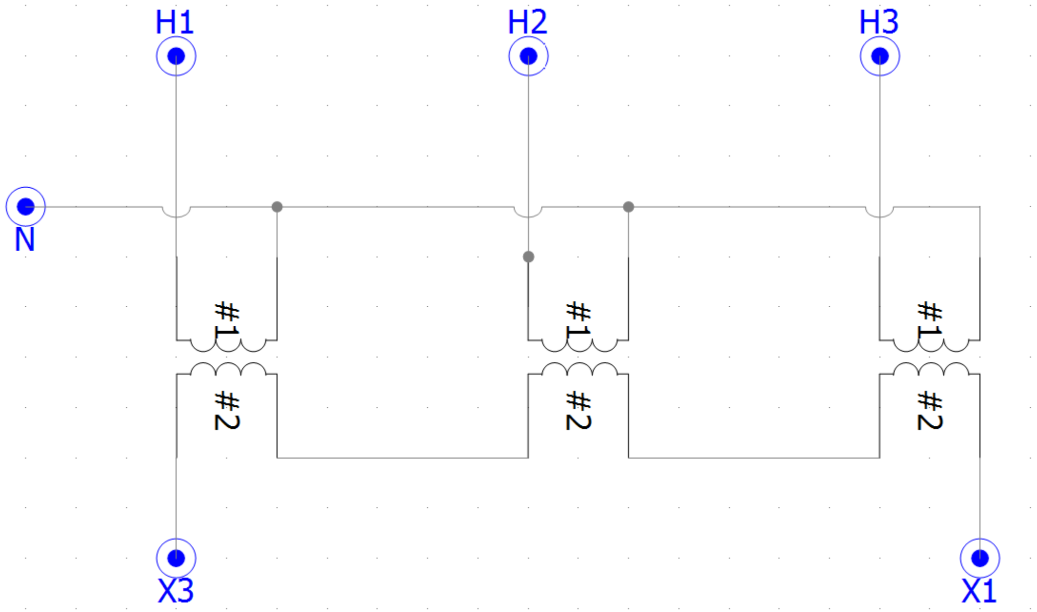
Stephen Miller, PE [2]

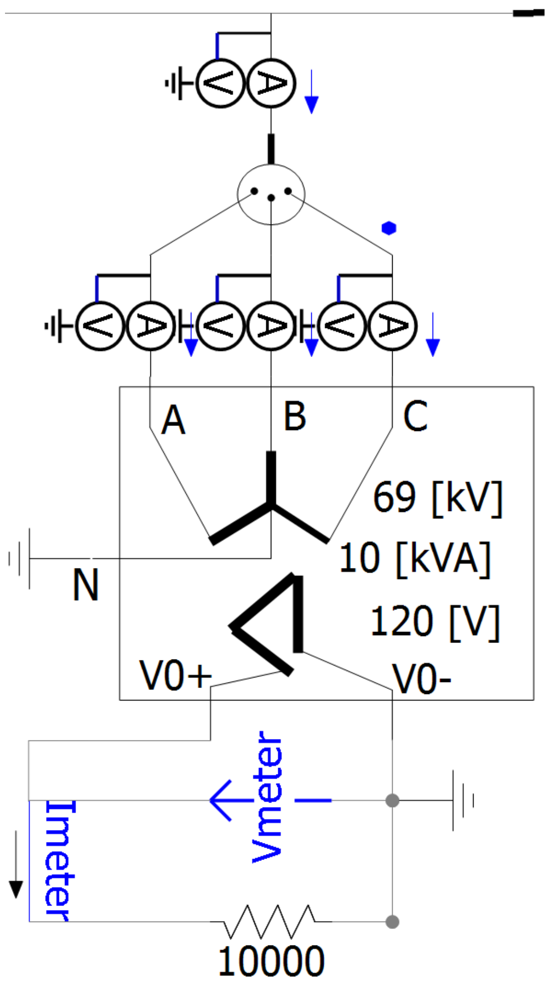
1. Commonwealth Associates, Inc
2. Energy Emissions Intelligence
3. Eversource Energy, Inc

Introduction - Background

Y-Grounded primary – Broken delta secondary

- Ungrounded system applications
- Allows first ground detection
- Detects faults when there is no fault current



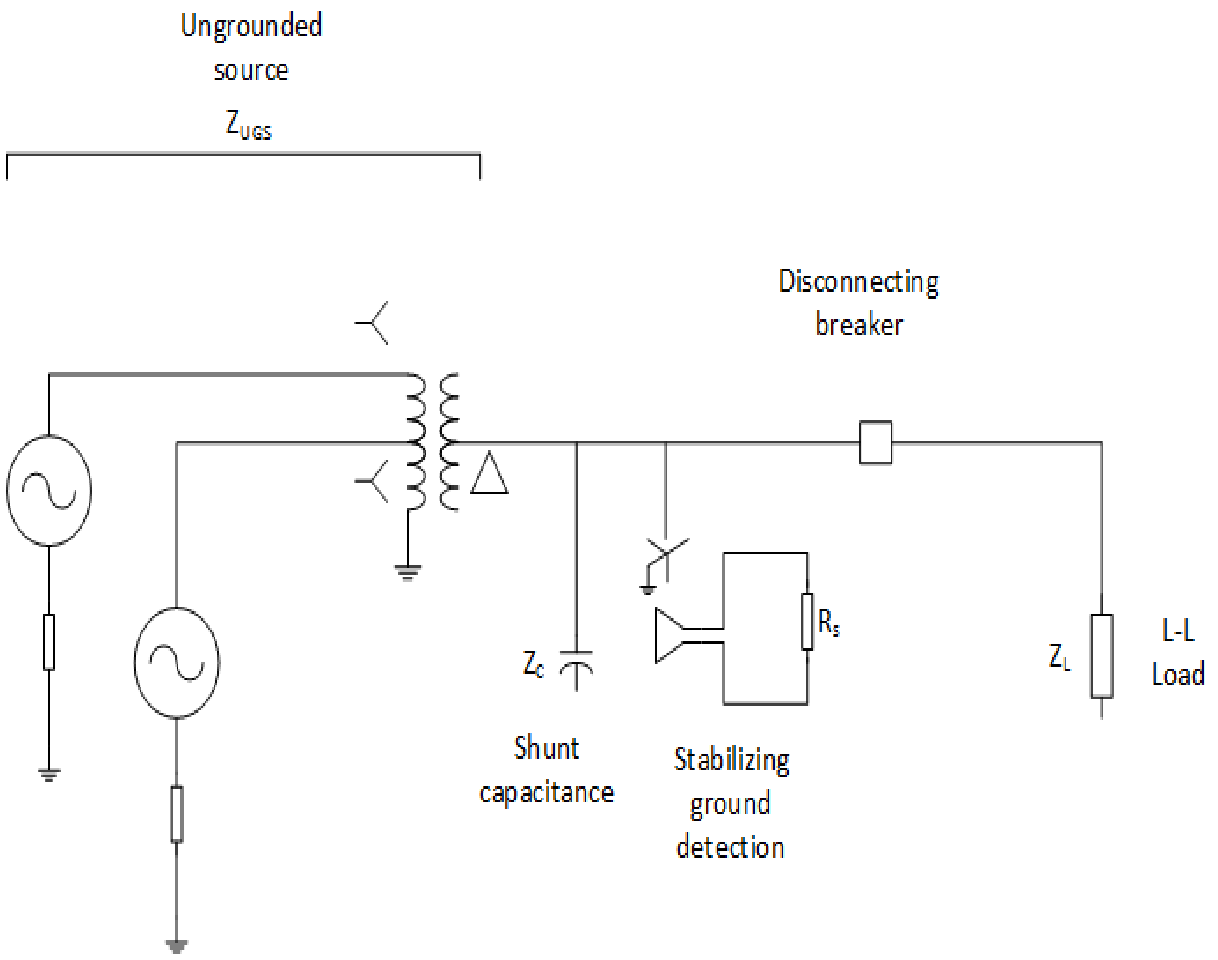


Why ungrounded?

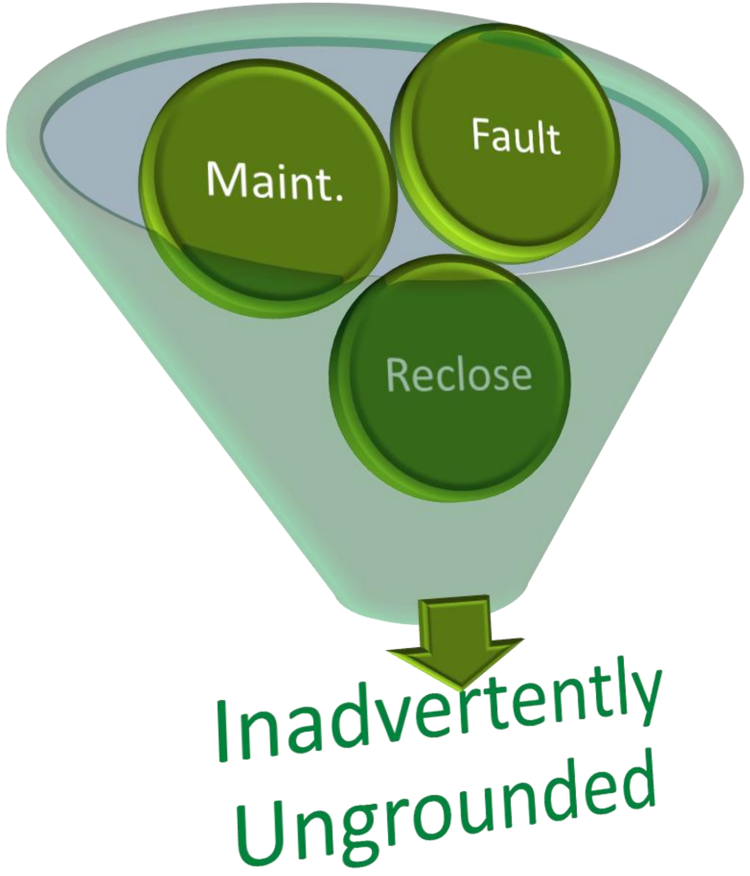
Reactor, Capacitor, STATCOM

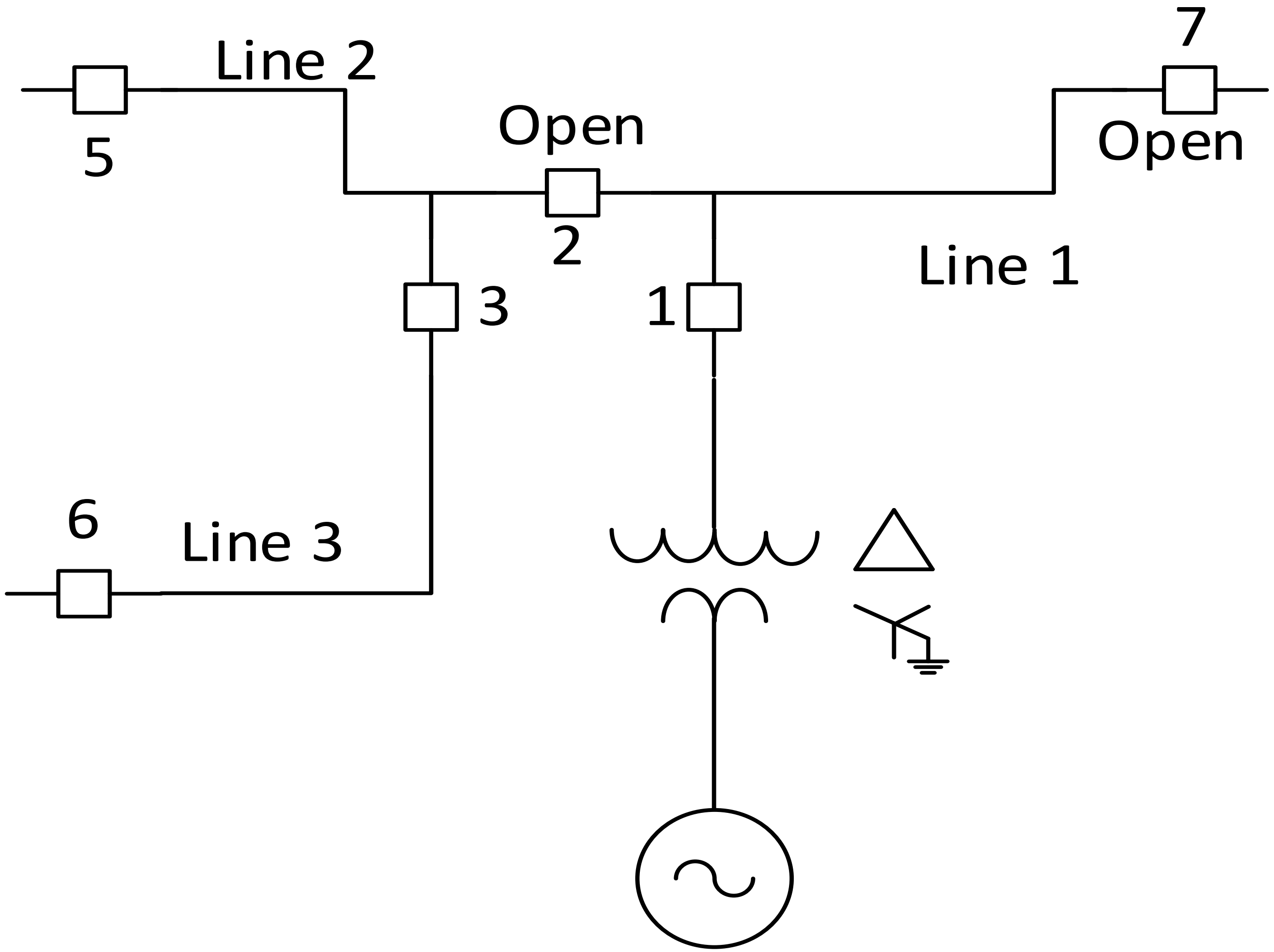
Intentionally Ungrounded

Higher Reliability



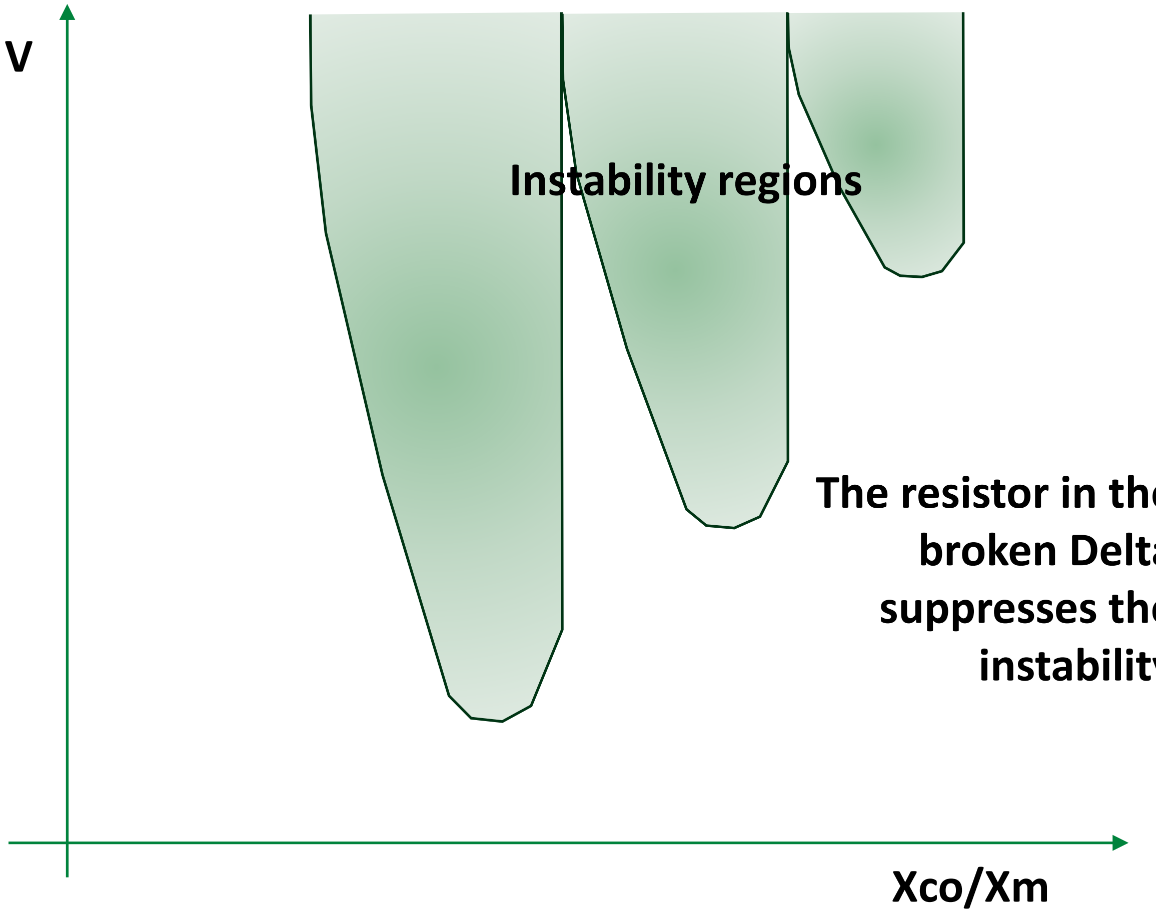
Inadvertently Ungrounded



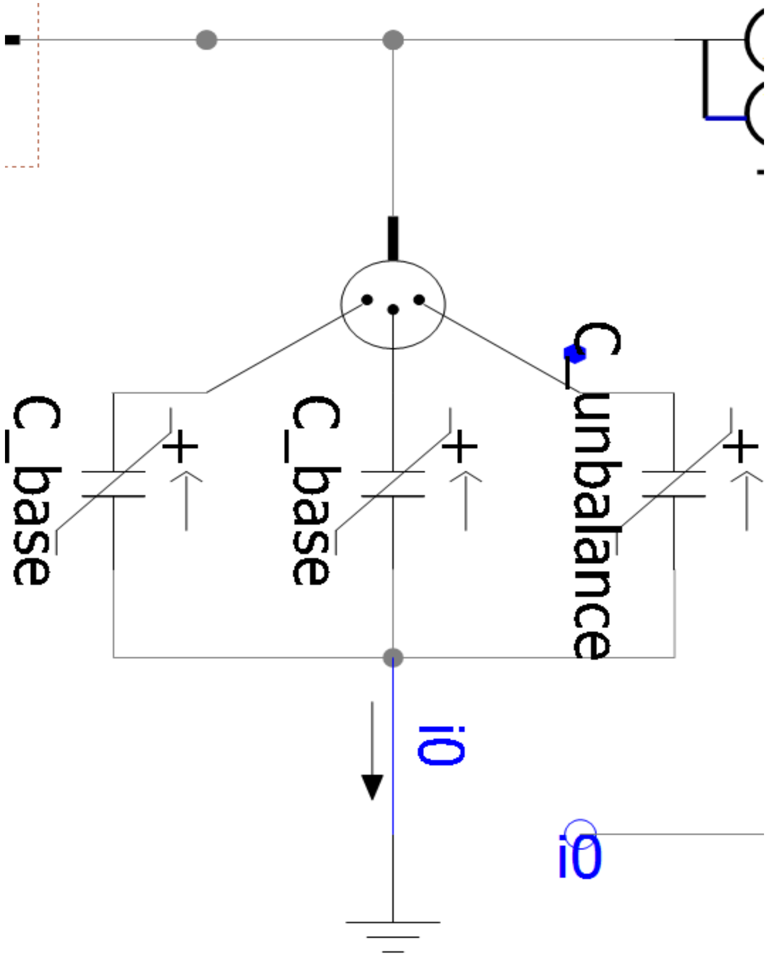


Historical Knowledge

1920-1940 Study of Y-grounded – Broken Delta Instabilities



The resistor in the broken Delta suppresses the instability



EMT Model Studied in 1st Study

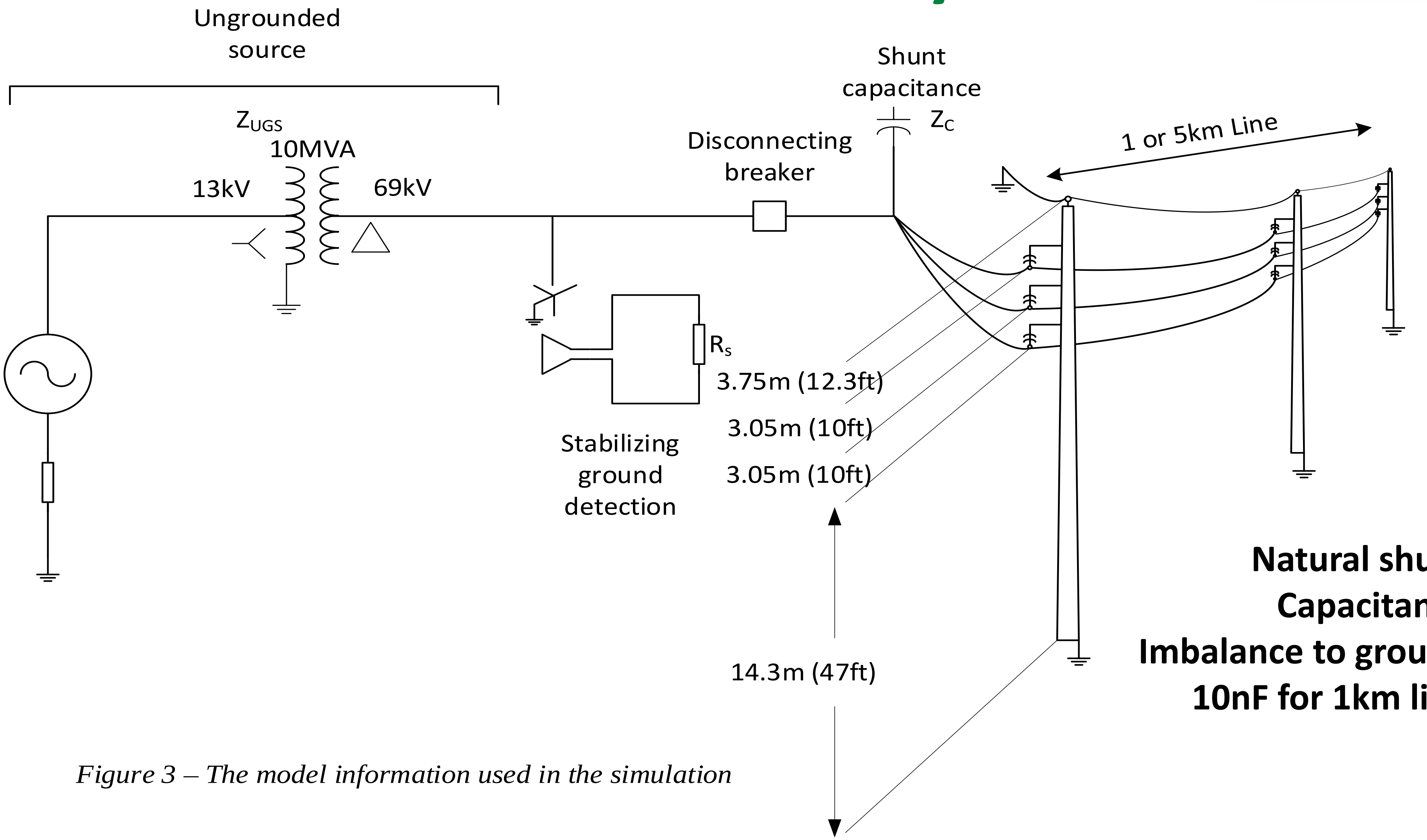


Figure 3 – The model information used in the simulation

Natural shunt Capacitance Imbalance to ground 10nF for 1km line

Impact of Imbalance

Shunt capacitance imbalance creates a constant phase voltage imbalance

1km vs 5km $3V_0$

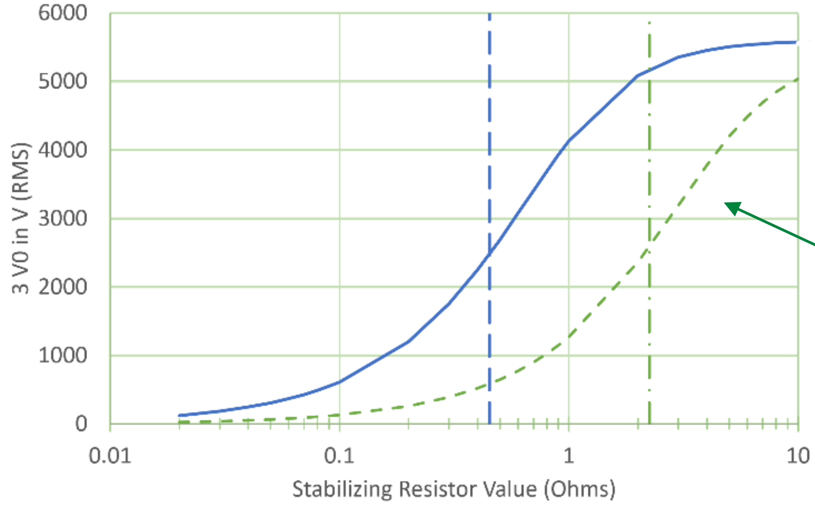


Figure 5 - 1km line and 5 km line vs R

The resistor can lower the phase voltage imbalance

The average capacitance shift horizontally

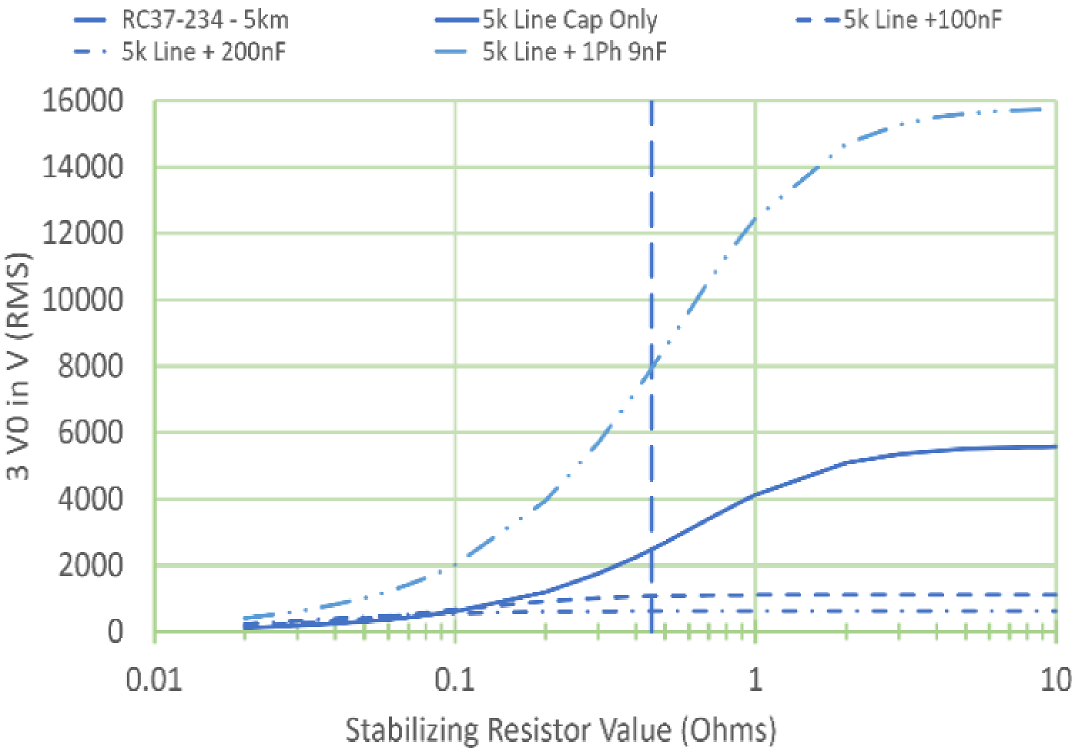
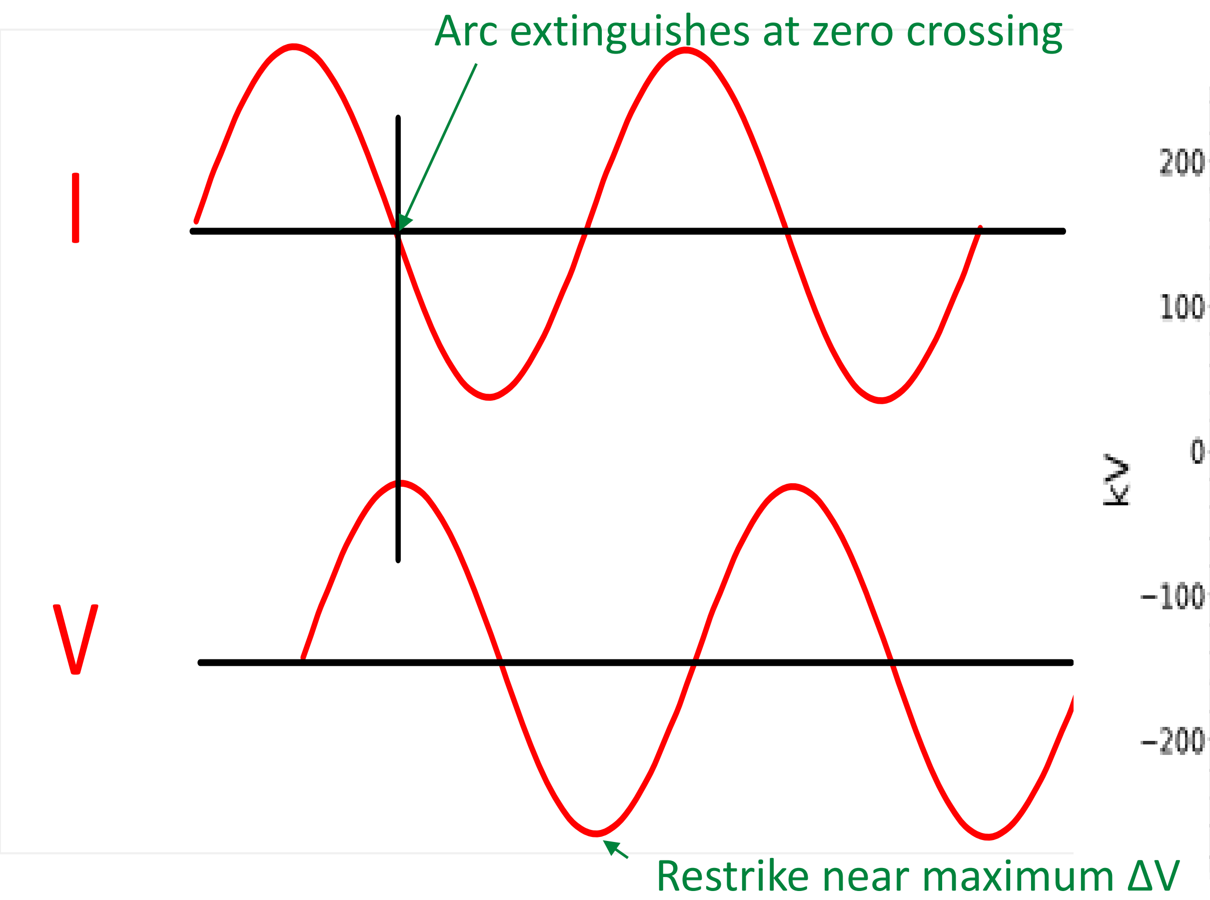
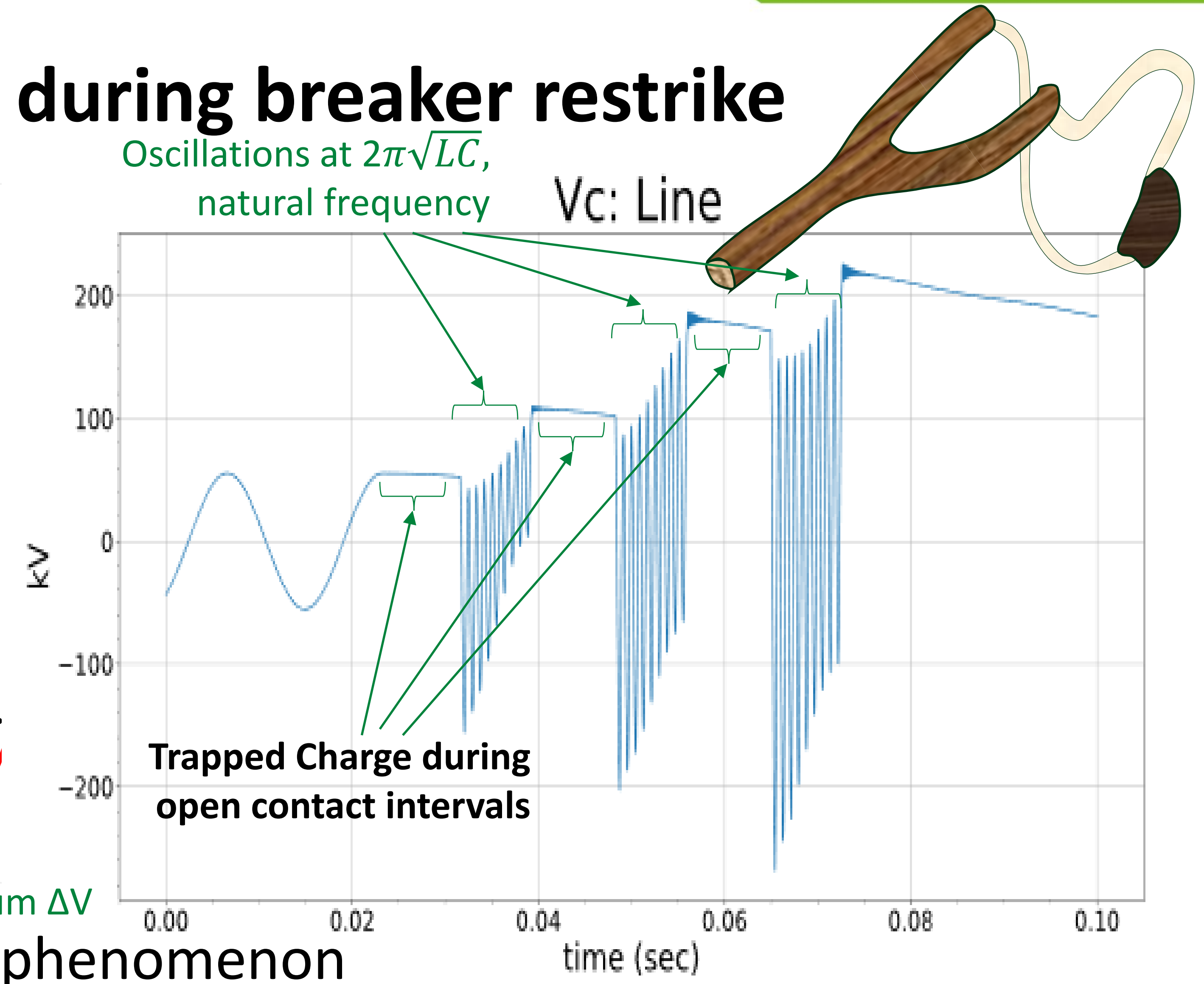


Figure 4 - Variation of the resistor impedance for the Stabilization of a 5km line imbalance capacitance

The Slingshot Effect is Real

During a fast reclose or during breaker restrike

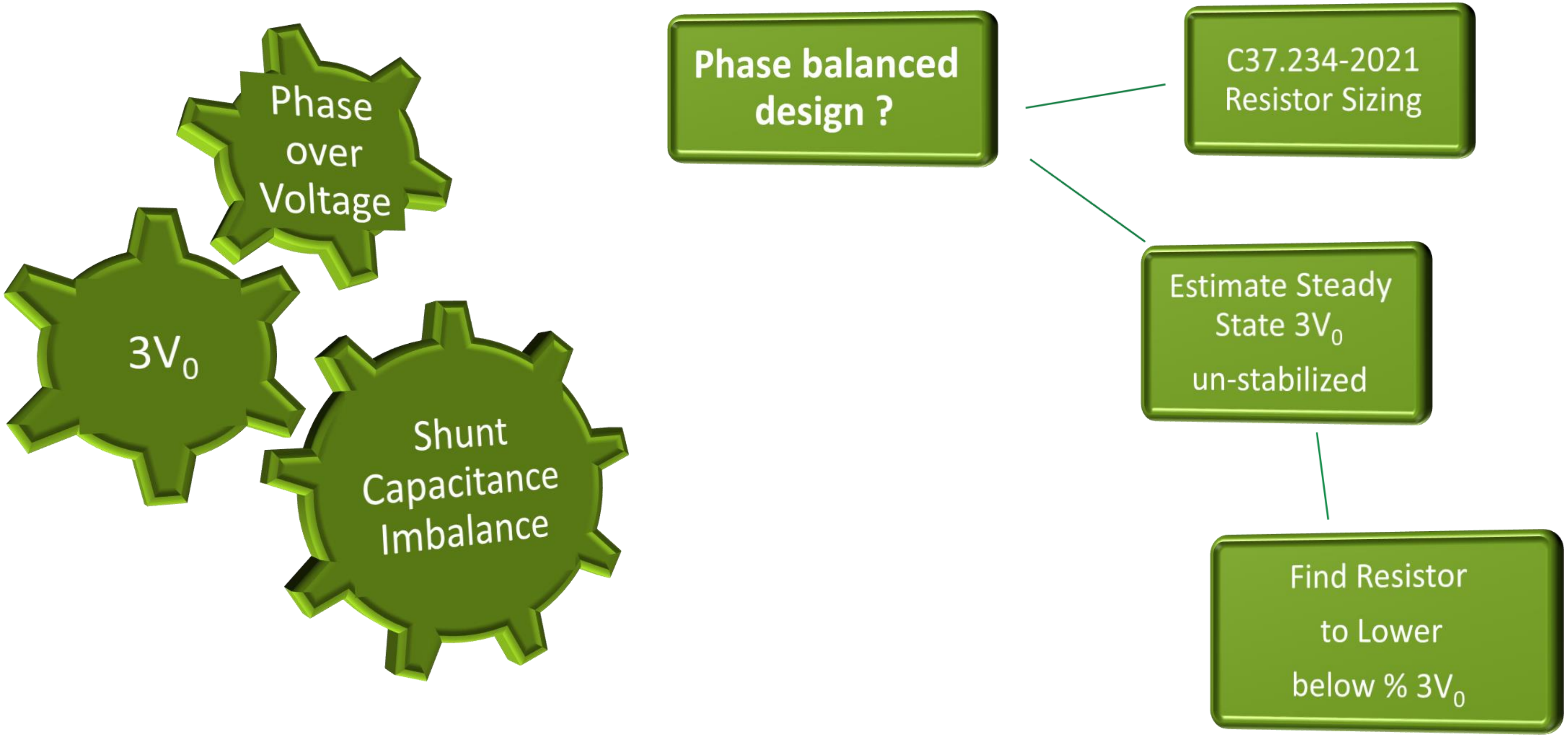




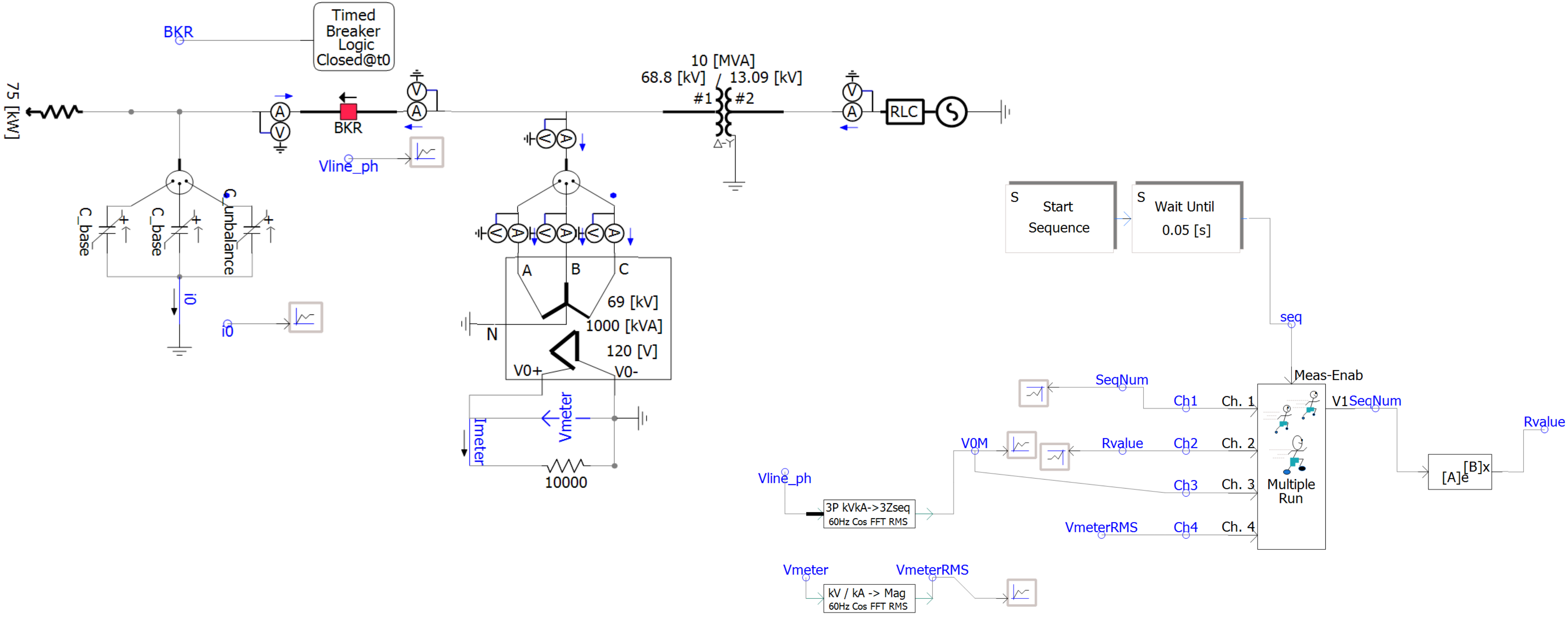
The resistor has no effect on this phenomenon

Conclusion from First Version

Need to quantify how to size based on unbalance



EMT model used



Find estimation Function

2 parts in the estimations

$$3V0 = f_1(C_u) \cdot f_2(C_a)$$

Function of
capacitance imbalance
-
Capacitance sweep

Function of
average capacitance
-
Resistor sweep

To find estimation function

Get 100 points of data

→ Pick a type a function that has the appropriate shape

→ Process the coefficient to find the least square differences

Scipy.optimize

Need to Sweep Shunt Capacitance

Varied shunt capacitance Imbalance

$$V_{3V0pu} = a \cdot \ln(b \cdot C_u + c) + d$$

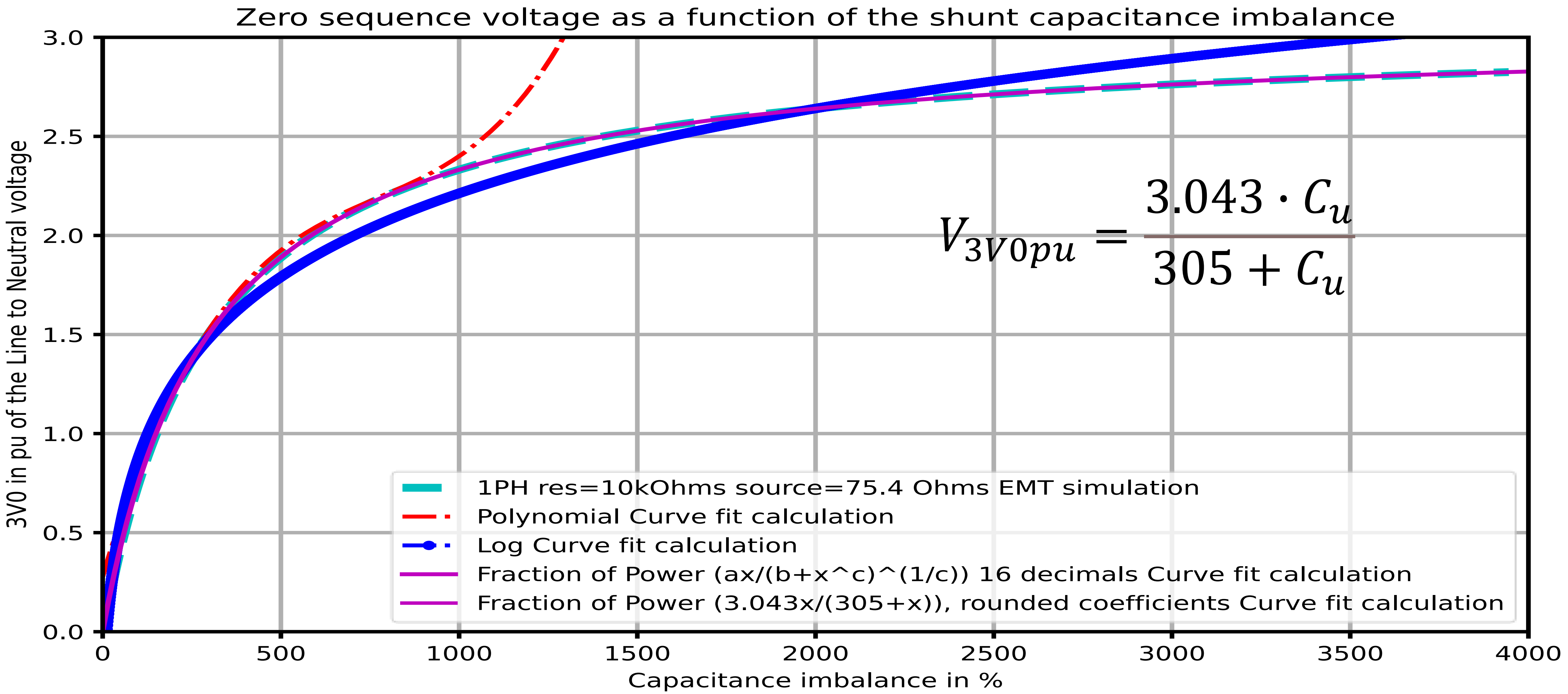
$$V_{3V0pu} = \frac{a \cdot C_u}{(b + C_u{}^{c})^{\frac{1}{c}}} + d$$

$$V_{3V0pu} = a \cdot C_u{}^{3} + a \cdot C_u{}^{2} + a \cdot C_u + d$$

t	a	b	c	d	Maximum error from all samples
Logarithmic	0.626073	0.244194	4.722191	-1.241454	23.58%
Fraction of the power	3.042784	304.87199	1.00000015	$-3.3605 \cdot 10^{-9}$	$2.68 \cdot 10^{-9}$%
Polynomial	$2.712278 \cdot 10^{-1}$	$5.893840 \cdot 10^{-3}$	$-6.663924 \cdot 10^{-3}$	$2.870167 \cdot 10^{-9}$	3.1%*

* Samples between 100 to 1000% capacitance unbalance.

Need to Sweep Shunt Capacitance



$$V_{3V0pu} = \frac{3.043 \cdot C_u}{305 + C_u}$$

F2 - Resistor values sweeps

While average capacitance is constant

Average Shunt Capacitance	Phase A and B	Phase C
1 nF	0.222 nF	2.56 nF
2 nF	0.222 nF	5.11 nF
4 nF	0.888 nF	10.22 nF
8 nF	1.777 nF	20.444 nF
16 nF	3.55 nF	40.88 nF

Average Shunt Capacitance	a	b	c	Maximum Error
1 nF	-0.00618	23.218	1.8299	1.41%
2 nF	-0.0084	11.526	1.834	1.38%
4 nF	-0.0101	5.7233	1.847	1.33%
8 nF	-0.0104	2.8558	1.8741	1.14%
16 nF	-0.00994	1.4230	1.9021	0.92%

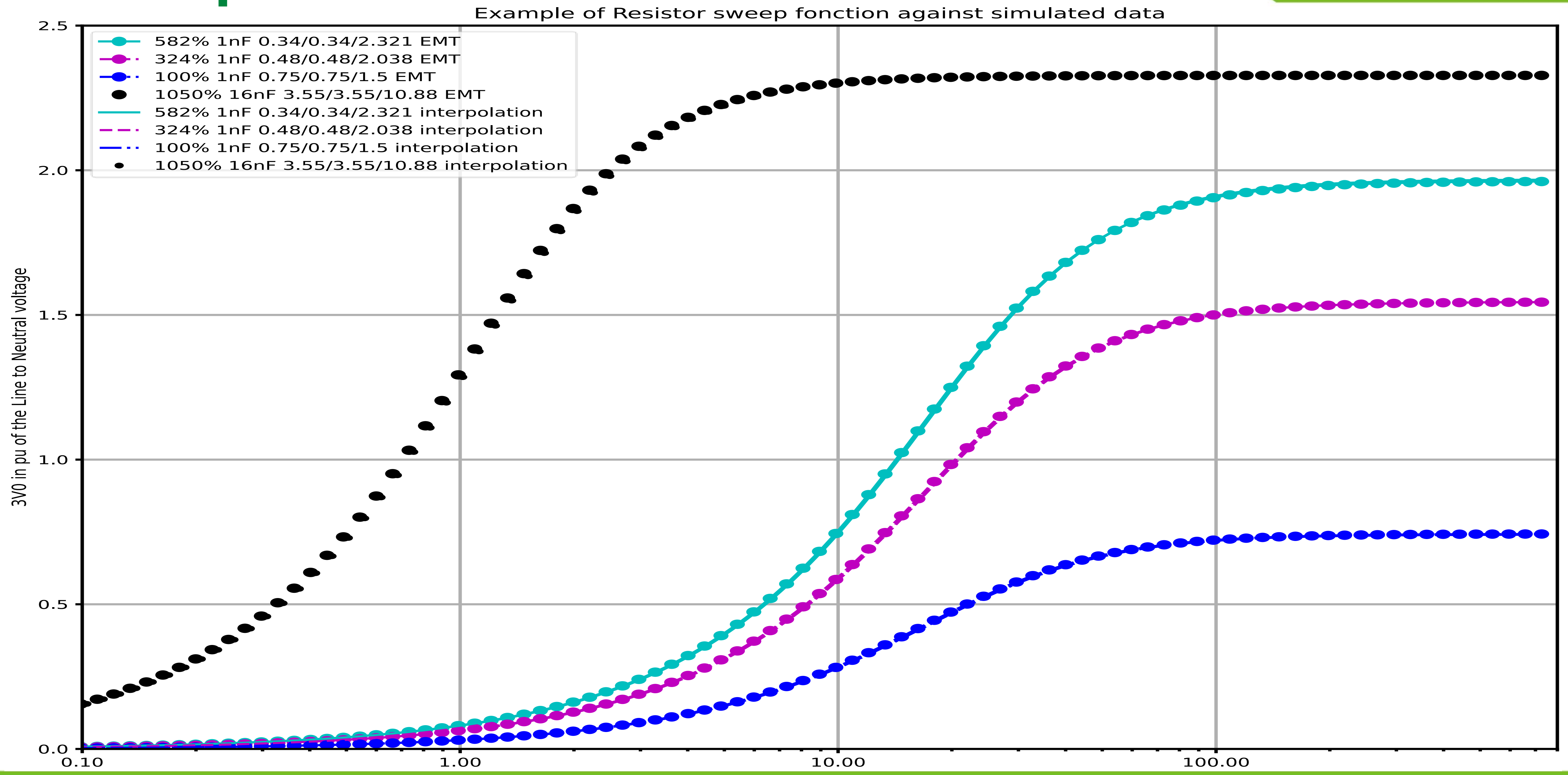
$$V_{3V0norm} = a + \frac{r}{(b^c + r^c)^{\frac{1}{c}}}$$

F2 – Simplify some parameters

Average Shunt Capacitance	a	b	c	Maximum Error
1 nF	0	24.968	2	1.93%
2 nF	0	12.4937	2	1.94%
4 nF	0	6.2229	2	1.86%
8 nF	0	3.0832	2	1.59%
16 nF	0	1.5197	2	1.29%

$$V_{3V0norm} = \frac{r}{\sqrt{\frac{600}{{C_a}^2} + r^2}}$$

The performance



Estimate the resistor Size

$$r = \frac{\sqrt{600 \cdot V_{3V0m}}}{C_a \cdot \sqrt{1 - V_{3V0m}{}^2}}$$

$$\text{where } V_{3V0m} = \frac{V_{3V0pu} \cdot (305 + C_u)}{3 \cdot C_u}$$

V_{3V0pu} is the desired content of $3V_O$ per unit of the line-to-line voltage.

Conclusion

When Shunt capacitance imbalance is large

The resistor sizing is **not only** about **stabilization**

We need to **reduce the voltage imbalance** to **differentiate** faulted and non-faulted conditions.

We have created **mathematical estimations** that allow us to size the resistor accordingly.