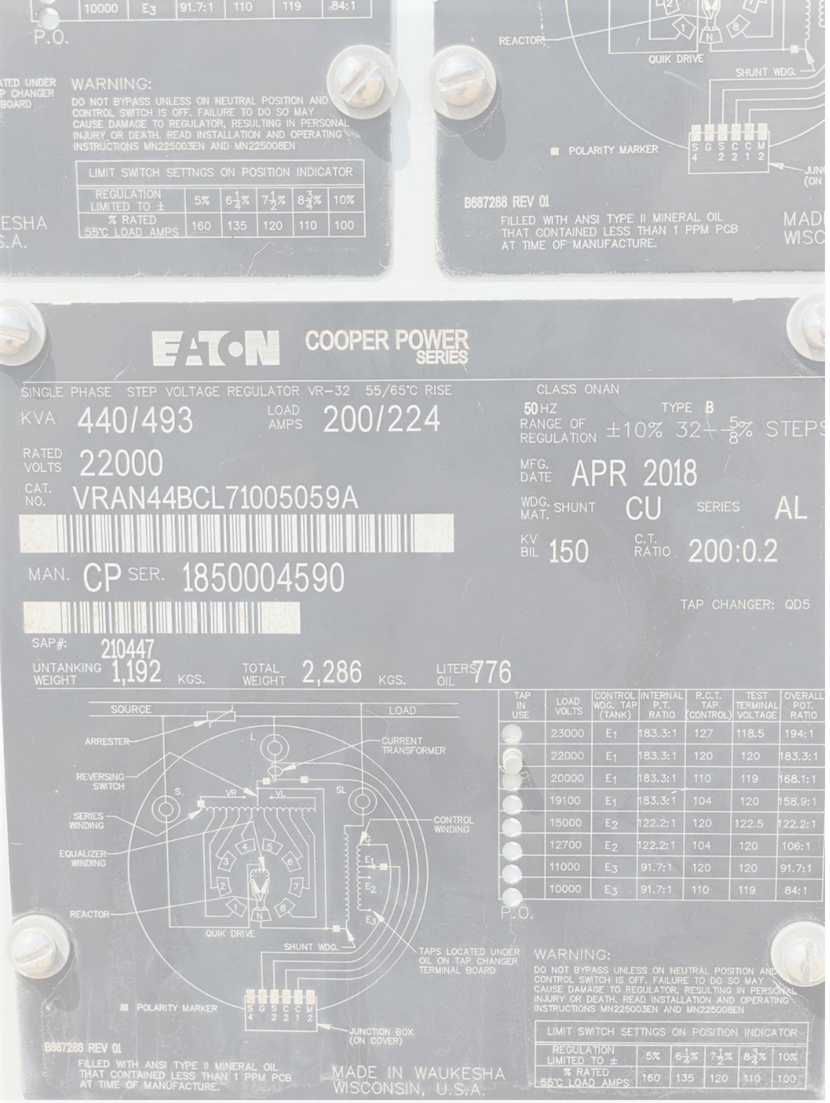

Network operations: Back to the future

"A journey where field data, a good understanding and innovative solutions become enablers of the future" – Anonymous, ErongoRED

AEDU, 2024
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Introduction

- Namibian electricity distribution – digital era present interesting opportunities
- A highly meshed network with multiple transmission connections and high fault levels, serving customers well – that is a lesser challenge.
- A Namibian distribution network – lower fault levels serving smaller loads, distributed over long distances, and with limited transmission infeeds and limited network contingencies, a challenge worthy of consideration.
- To measure is to know –well-developed solutions and operational (#1)
- A well-developed user-friendly network simulator (#2)
- From fundamental network principles to a digital support tool: the ErongoRED case made simple – The Digital Twin is born (#1 + #2)
- ErongoRED to be ready for possible significant investments (and growth)

What is a Digital Twin?

M ✗ F ✗ Other ✓

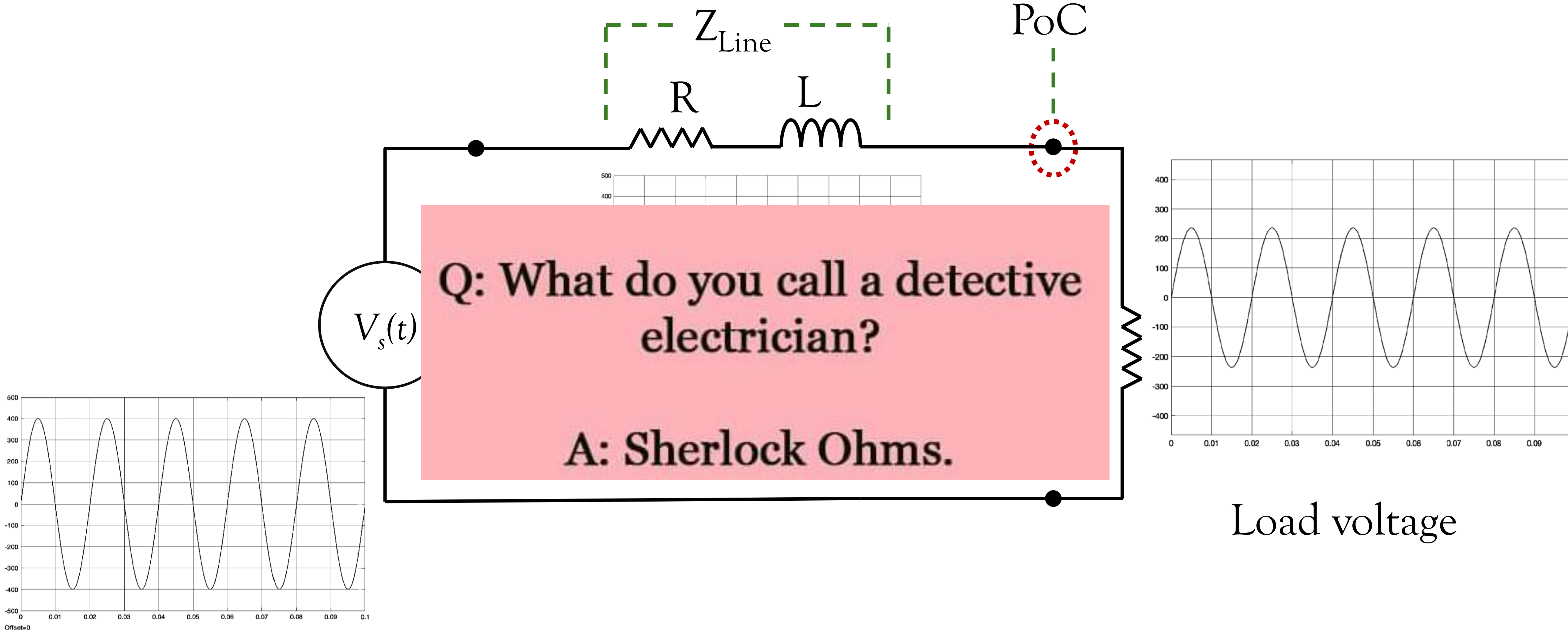
- Virtual replica of an electrical distribution system (i.e.)
- Near real-time simulation, analysis - and control as and when needed.
- To support operational (and energy) efficiency, reliability, serving end-user.
- It is a concept of "thinking": Integrating various sources of information and resources
- ErongoRED: An accurate electrical equivalent circuit – simulated and supported by real-time field data
- Network simulation not only to plan future network operation and investment;
- But - a network computer model that accept measured field data to estimate/predict how a specific network contingency is affecting voltage stability/quality – end-user service levesl
- In near- real-time – simple operating features – accessible to operators/engineers
- Validated (true) network performance support operational decision making

Where is an opportunity for ErongoRED?

- The physical (as-is) specifications of the ErongoRED network exists.
- A network equivalent model using first principles has been (mostly) constructed.
- It includes network contingencies (switching – i.e. maintenance)
- DigSilent as implementation platform
- Comprehensive: modeling, analysis, and simulation – from basic to complex configurations and to include distributed renewable energy sources
- Comprehensive monitoring of load flow and voltage quality in near real-time – it exists.
- If a DigSilent simulation/prediction can be done, using recent ("just now") measurements to reflect the network state, then the assessment of voltage performance when a configuration change is considered, being a reliable prediction, is useful/practical.
- Digital model: predict impact on end-user where no monitoring is done – "state estimation"
- = A Digital Twin is no a longer a new-born

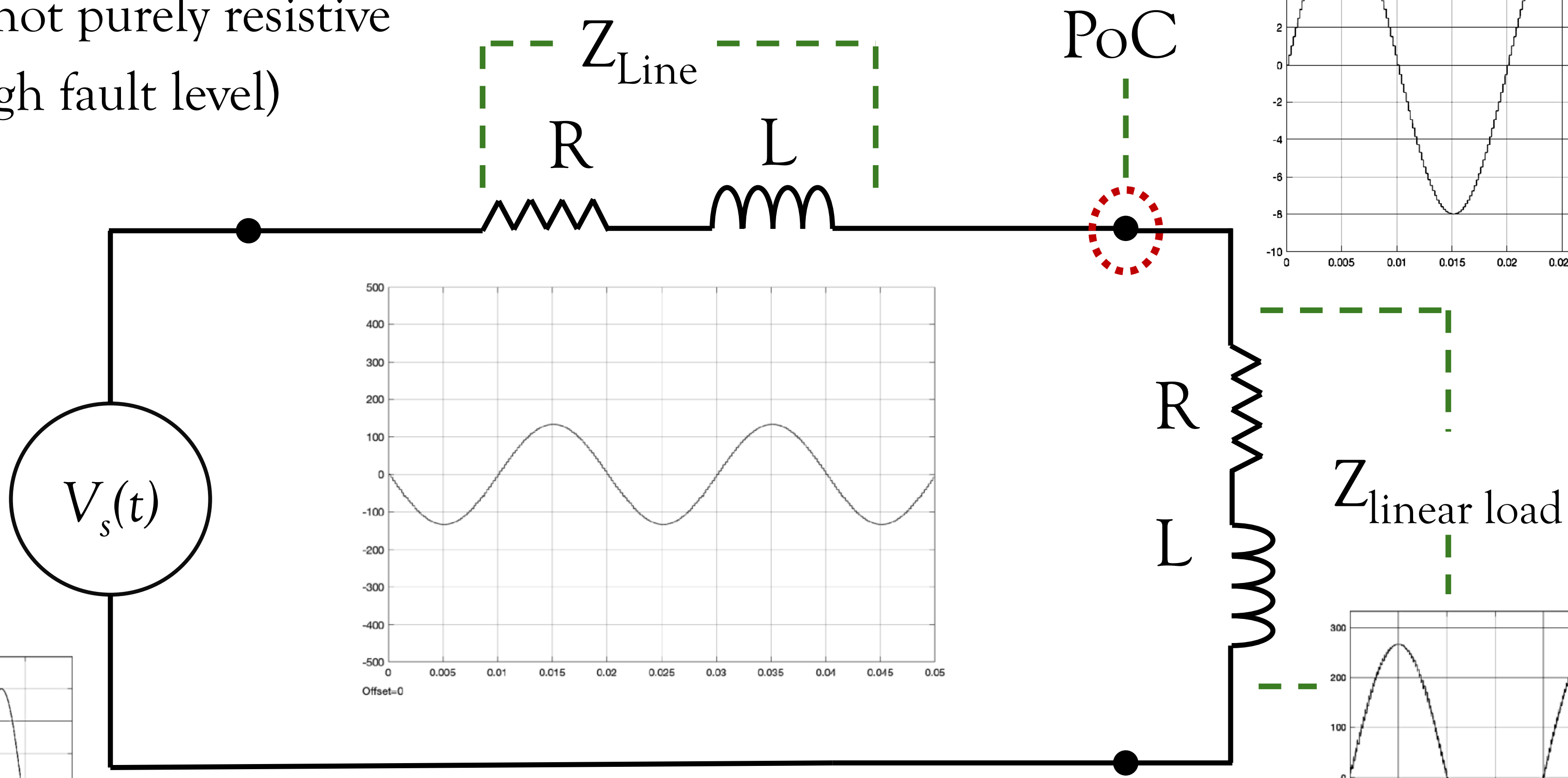
Voltage quality– the perfect world

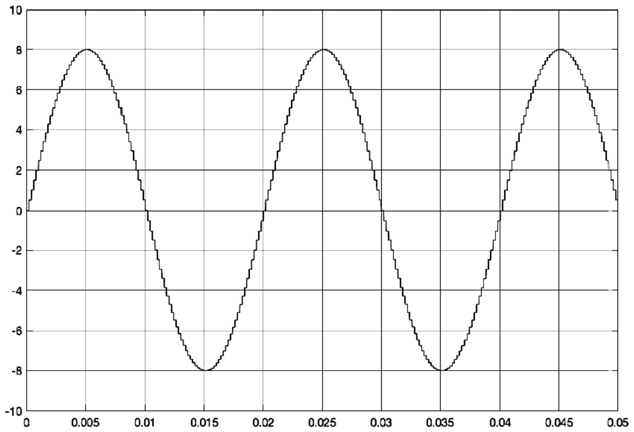
- Linear load – Source impedance set voltage regulation
- The perfect load is linear – voltage "looks" like current
- Such as a perfect resistance

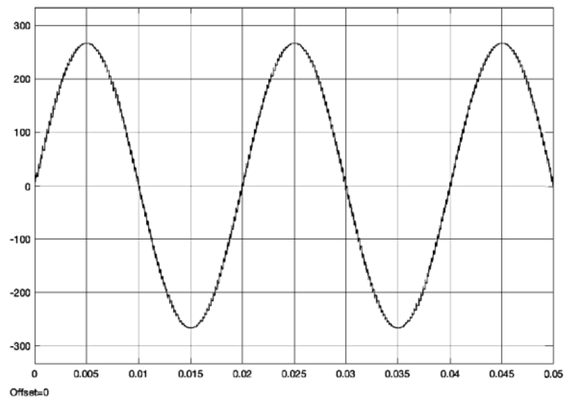


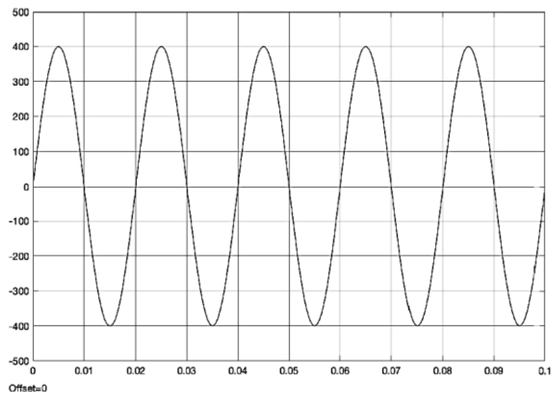
Voltage quality – in the near perfect world

- Linear load – not purely resistive
- “Sufficient (high fault level)





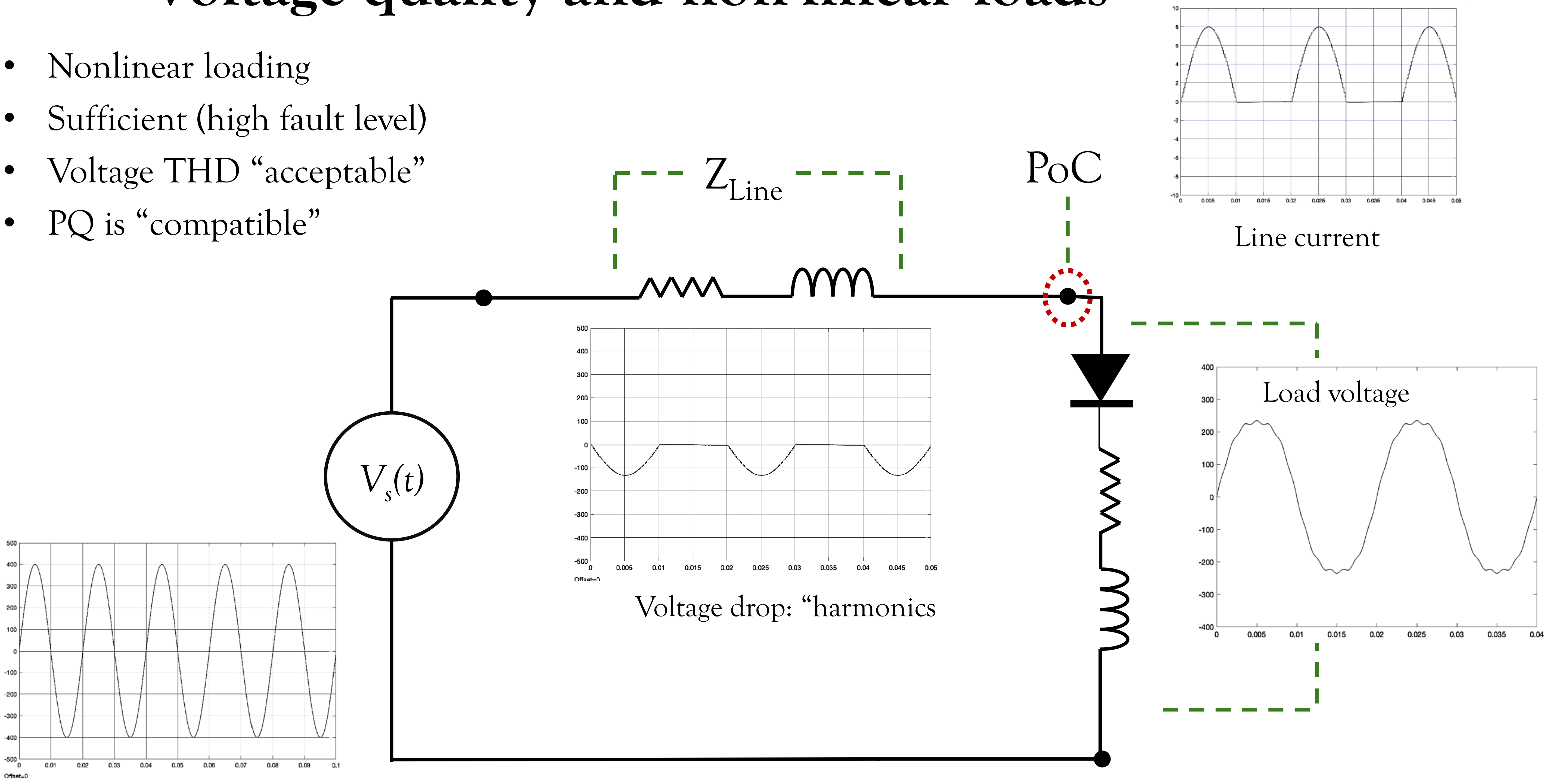




Voltage regulation the only concern

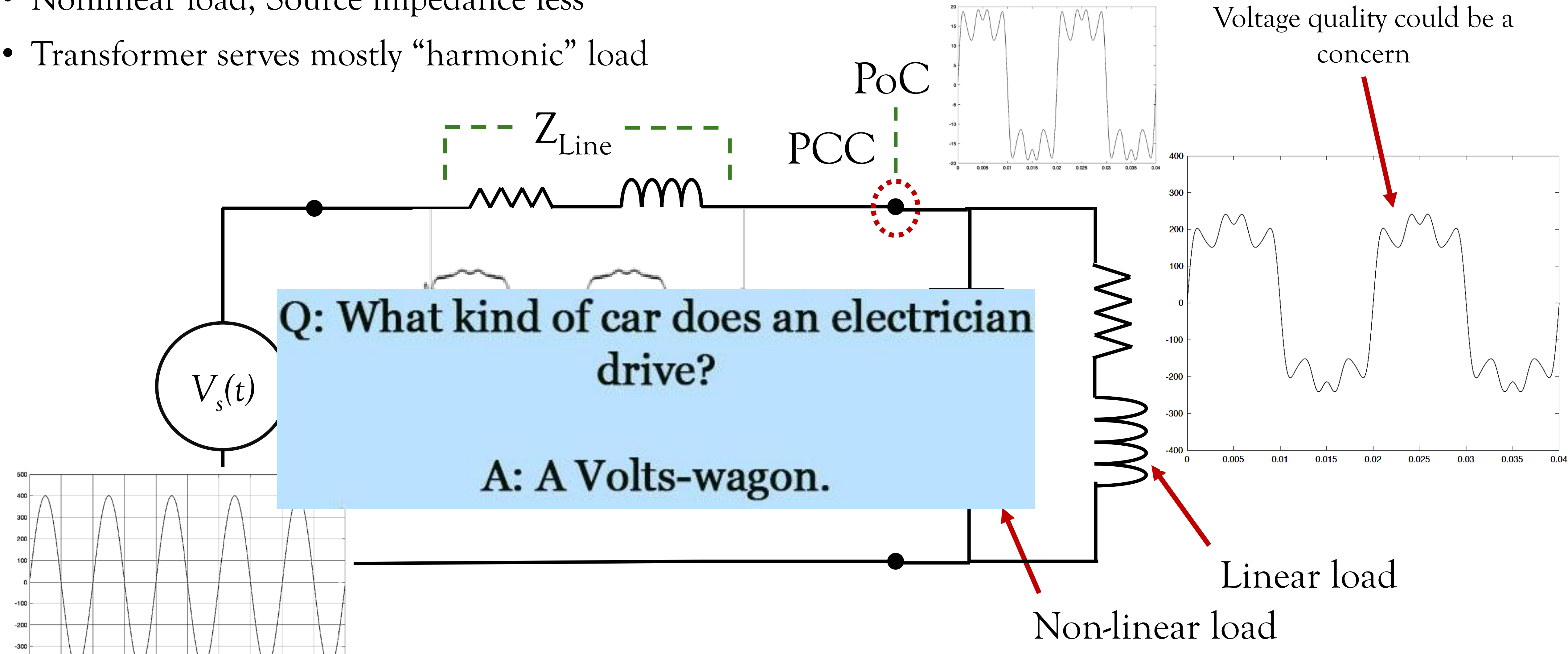
Voltage quality and non-linear loads

- Nonlinear loading
- Sufficient (high fault level)
- Voltage THD "acceptable"
- PQ is "compatible"



Voltage quality in the real world

- Nonlinear load, Source impedance less
- Transformer serves mostly “harmonic” load

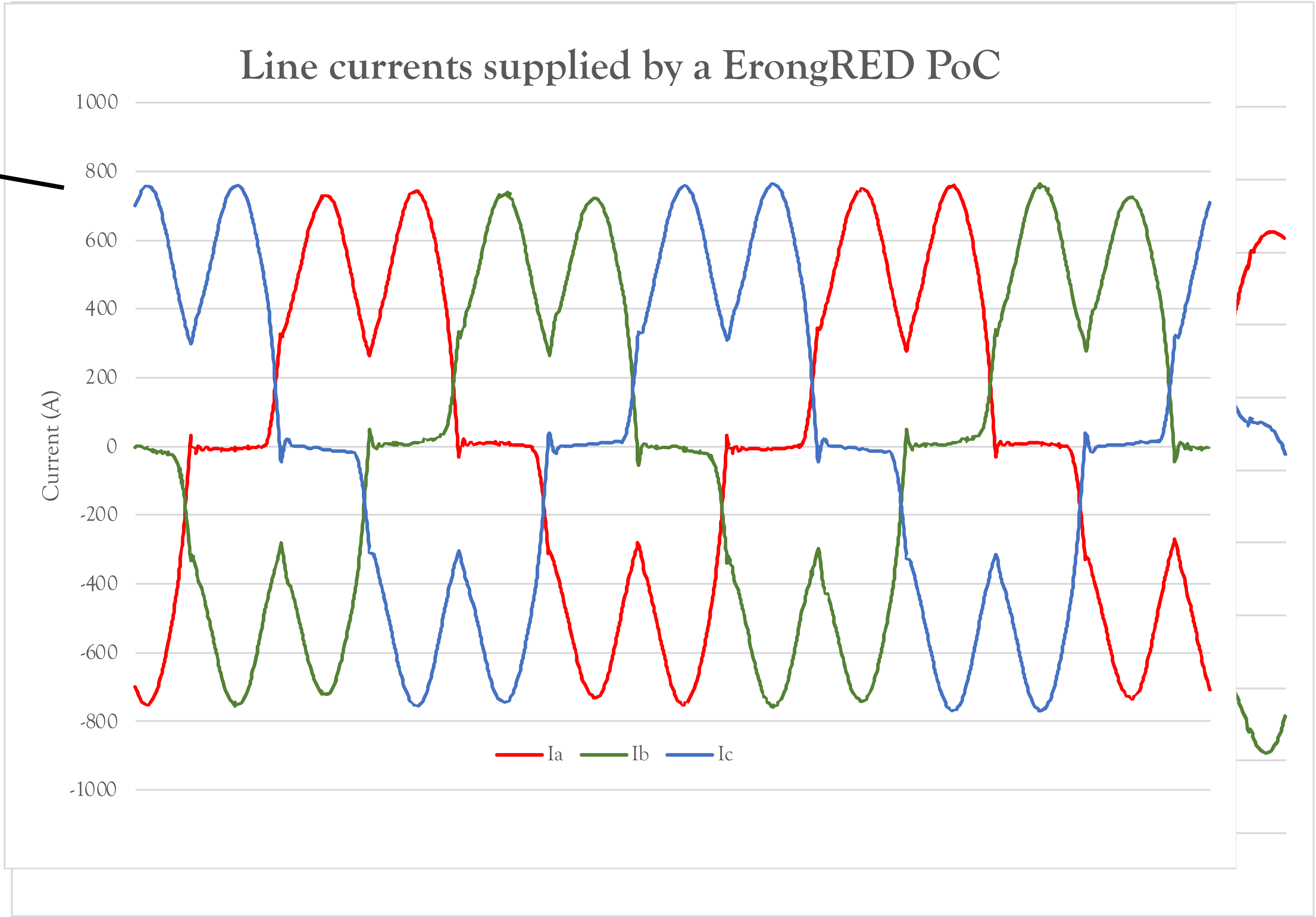


Emission of voltage harmonics, unbalance, flicker

Case study: Mitigation of voltage distortion

- What is the root-case of voltage harmonics?

800 A @ 400 V

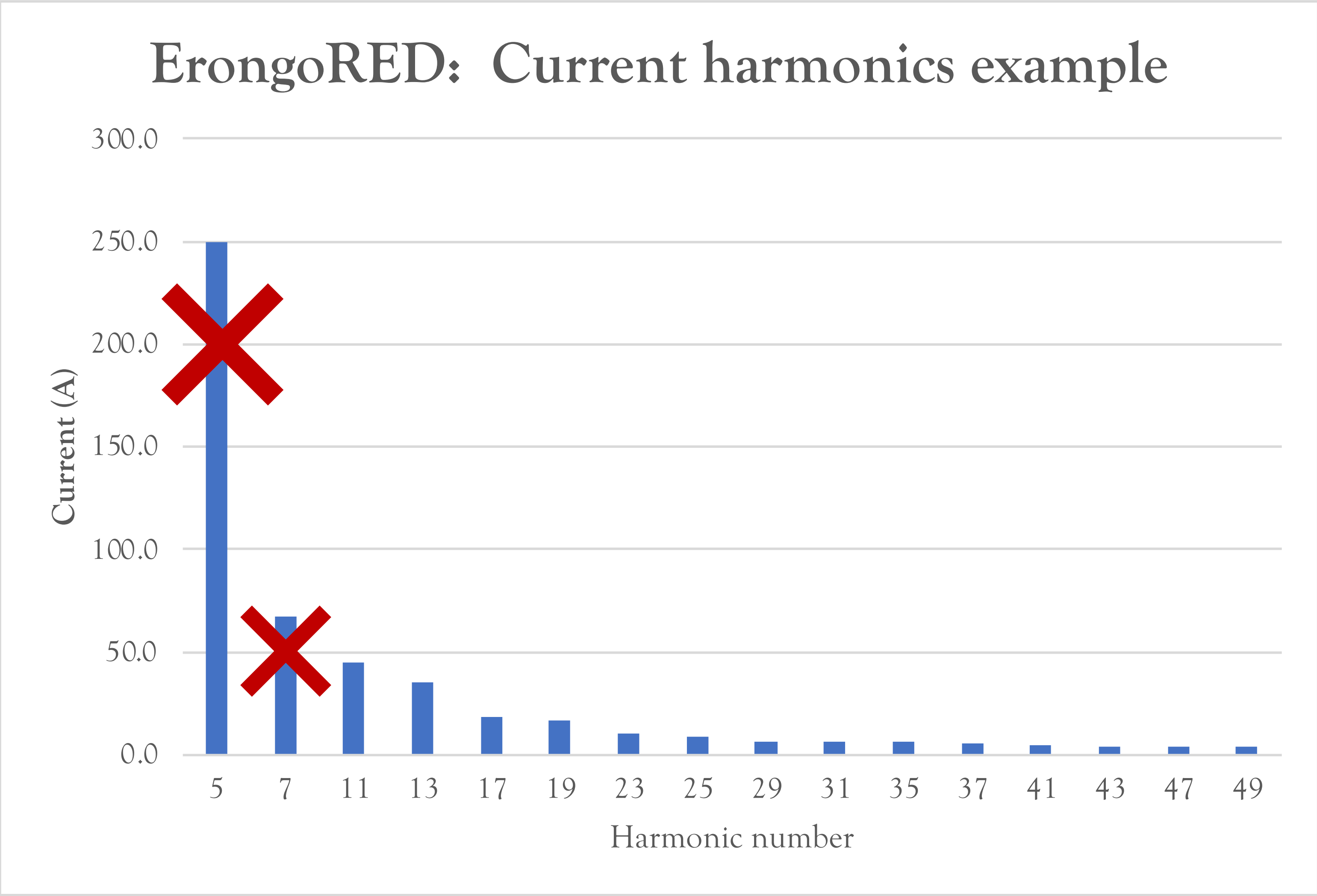


Case study: How to mitigate voltage waveform distortion

- Harmonic current must not flow in supply network (Ohms law!)
- Prevent harmonic voltage drop across supply impedance (Ohms law)

1) Do not withdraw harmonic currents: active ”front-ends” - expensive
2) Active harmonic filter – power electronics, high maintenance and energy losses
3) Passive harmonic filters in different configurations:
   a) Tuned well: customised design to not affect network impedance profile
   b) Designed to be self-tuning – hybrid passive filters
   c) Energy-efficient, robust, low maintenance
   d) But: need careful design and network analysis – and verification by modelling (the one Digital Twin – DigSilent i.e.)

Choose the harmonics



Briefly: What voltage emission is about

V_h: Harmonic voltage phasor, PoC.

I_h: Harmonic current phasor injected into supply network.

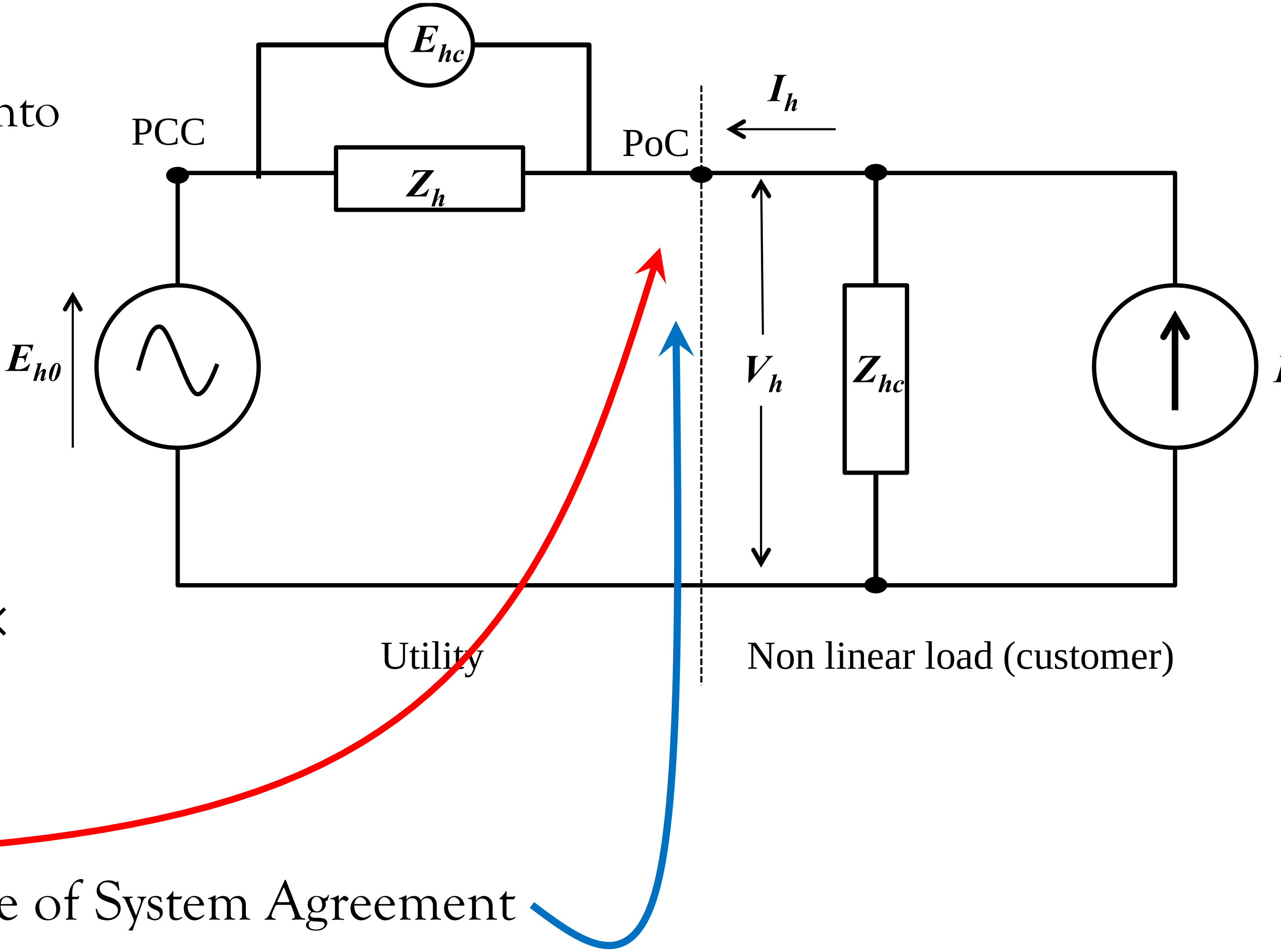
E_{h0}: Network harmonic voltage phasor, PCC

Z_h: Grid (supply) impedance.

Z_{hc}: Load impedance.

I_{hc}: Harmonic current source

E_{hc}: Voltage harmonic emission: $\boldsymbol{E}_{hc} = \boldsymbol{I}_h \times \boldsymbol{Z}_h$



Options for mitigation:

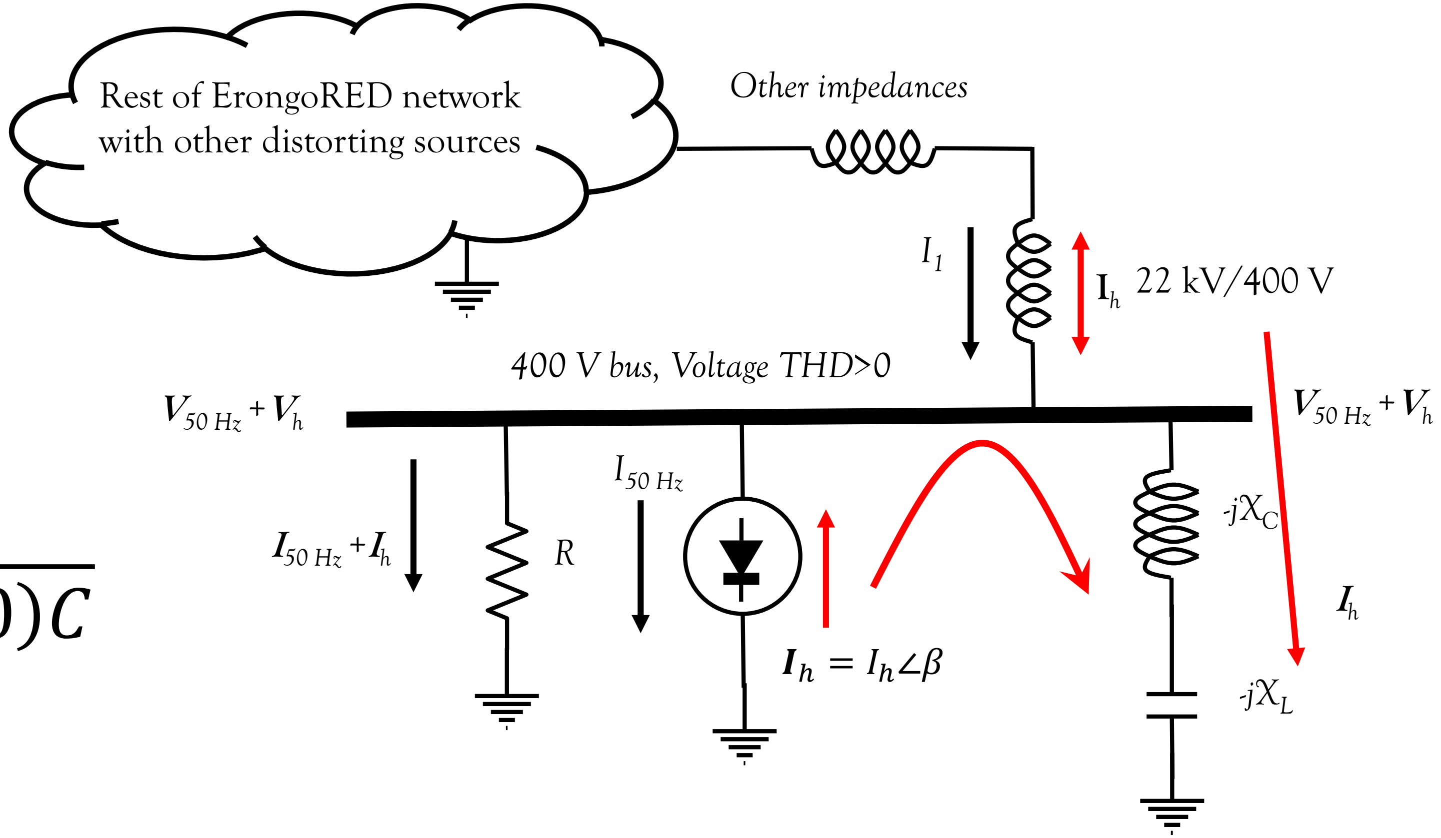
1. Filter
2. DCUOSA: Distribution Customer Use of System Agreement

Passive harmonic filter: trap harmonic current

$$Voltage\ THD = \frac{\sqrt{\sum_{h>2}^{N} V_h^2}}{V_1}$$

Filter the 5th current harmonic:

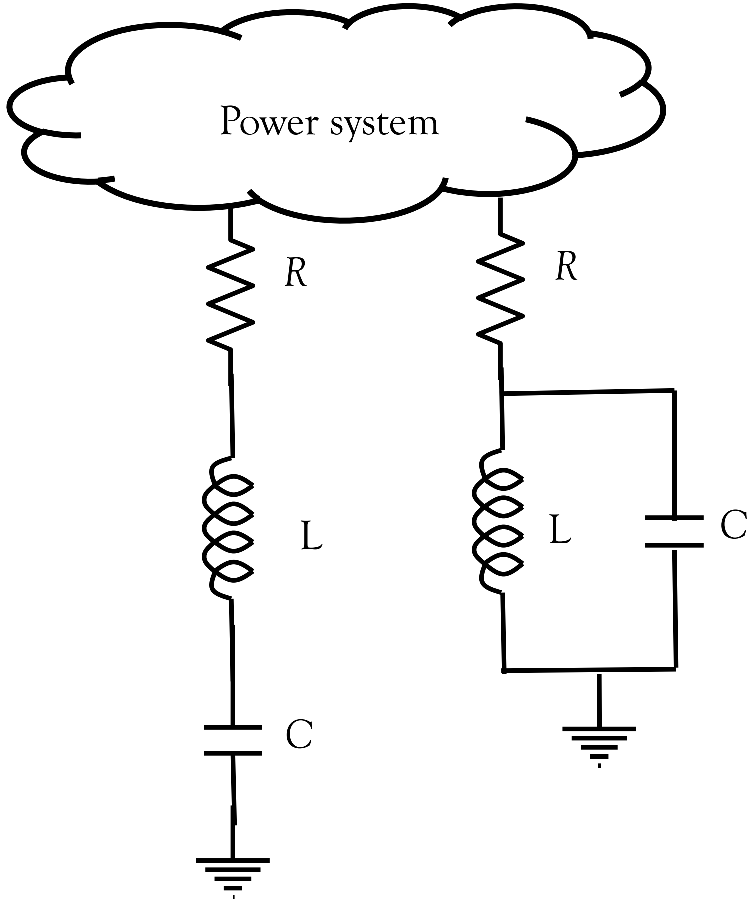
$$Z_{Filter} = j(2\pi 250)L - j\frac{1}{(2\pi 250)C}$$



Harmonic amplification – by resonance

Impedance can be very low, or very high, at specific frequencies - resonance

Series and parallel resonant paths will exist, always, in any power system

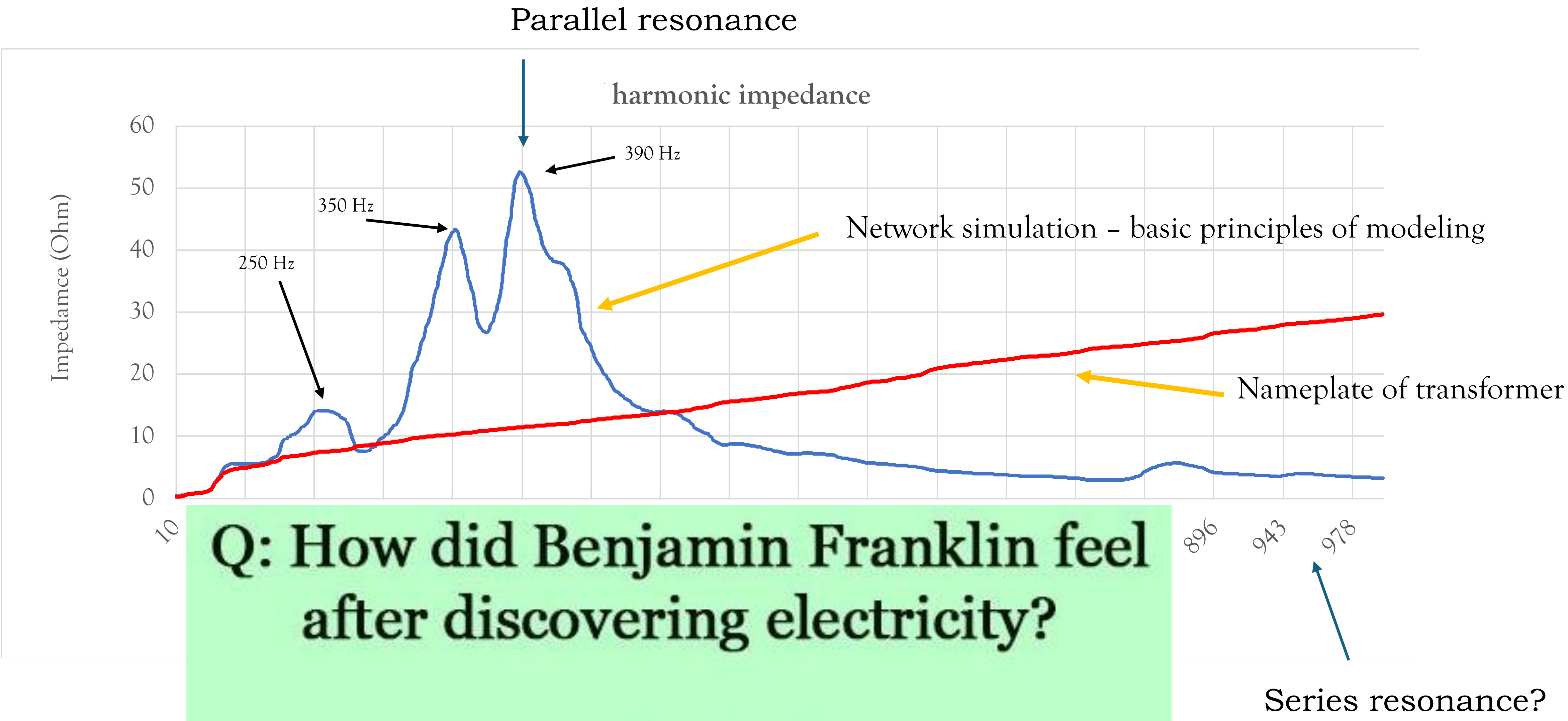


$$\boldsymbol{Z}(f)_{Series} = R + j2\pi fL + {}^{1}/_{j2\pi fC} = R + jX_L - jX_C$$

If harmonics do not align with resonant frequency, not a concern – need to know where resonant points are = DigSilent

$$\boldsymbol{Z}(f)_{Parallel} = R + \frac{(j2\pi fL) \times \left({}^{1}/_{j2\pi fC}\right)}{(j2\pi fL) - \left({}^{j}/_{2\pi fC}\right)}$$

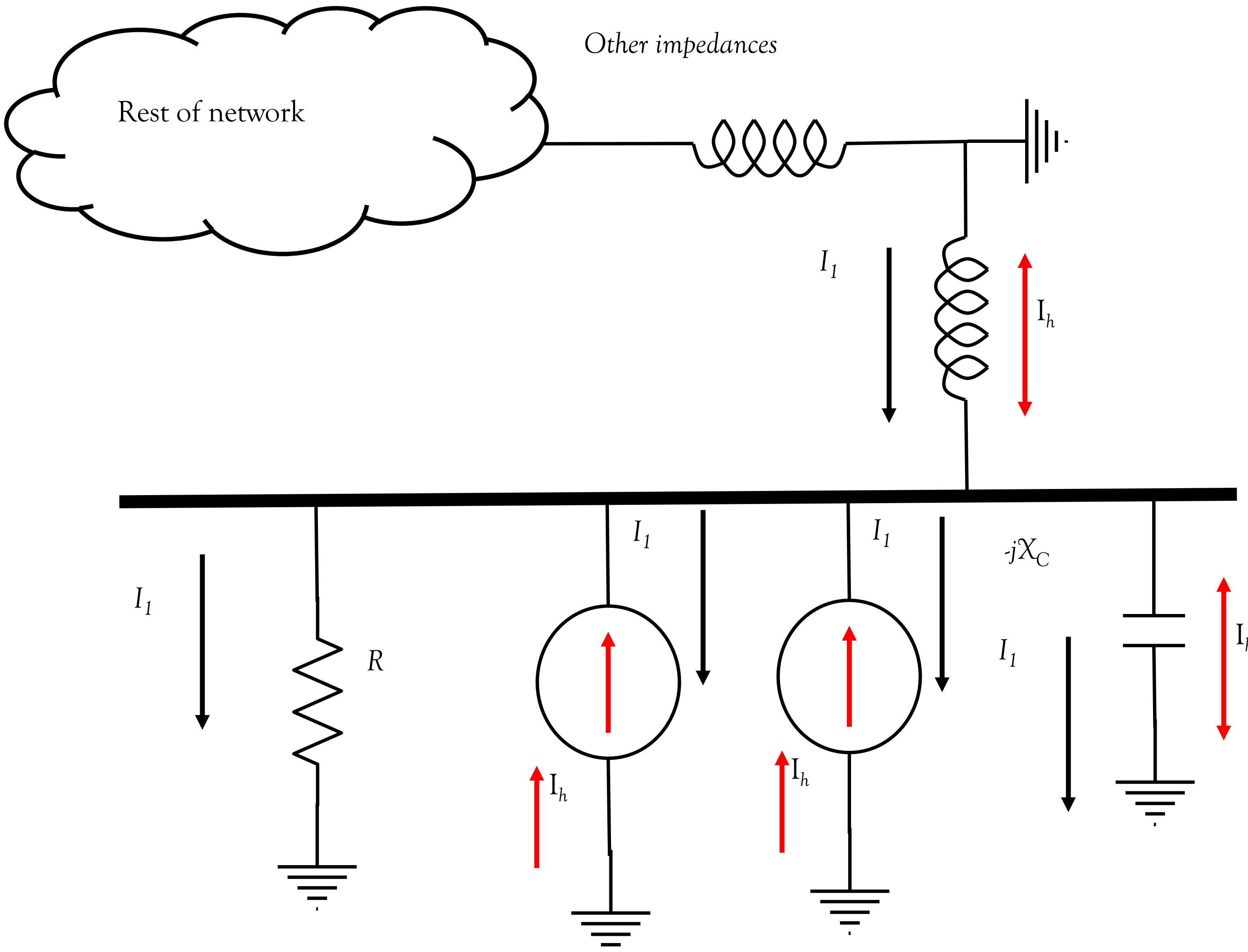
Example of harmonic resonant amplification



Q: How did Benjamin Franklin feel after discovering electricity?

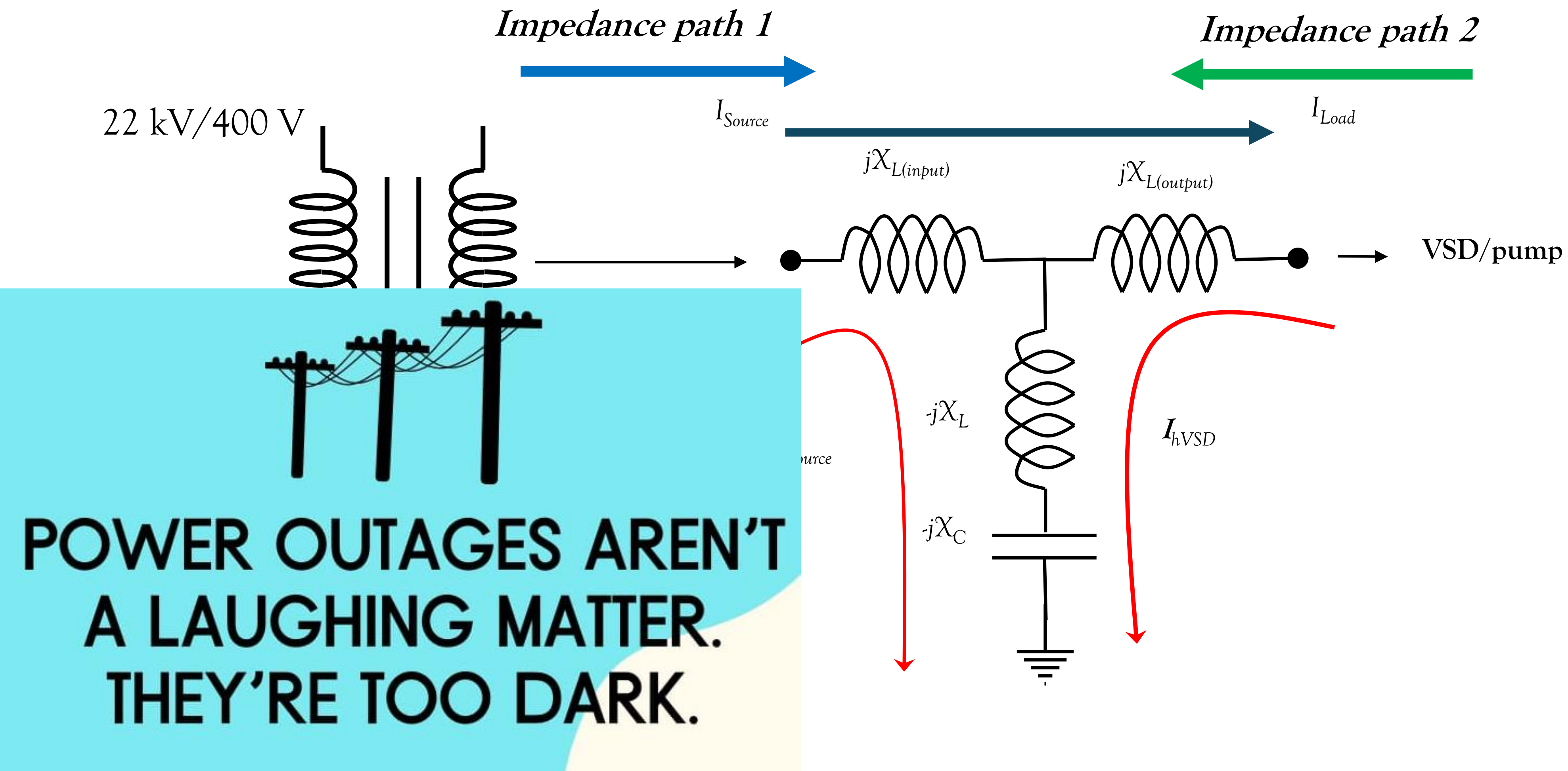
A: Shocked.

The harmonic resonant path(s)

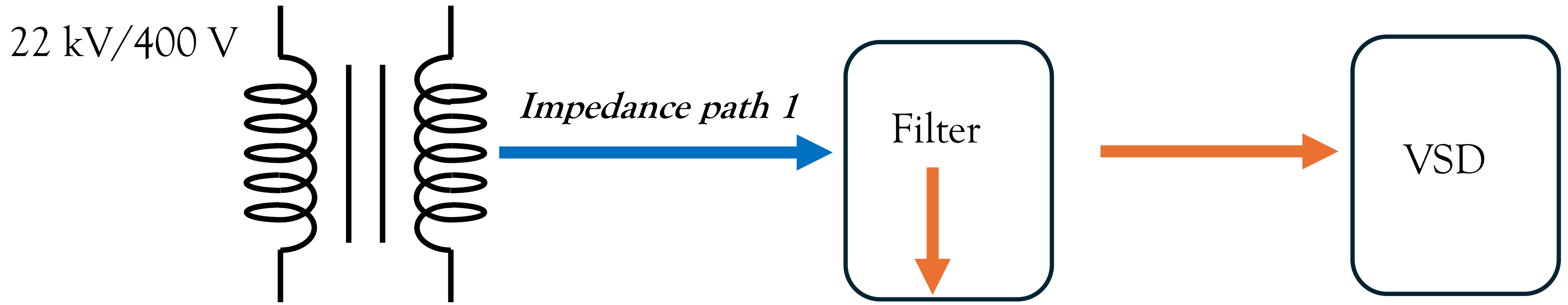


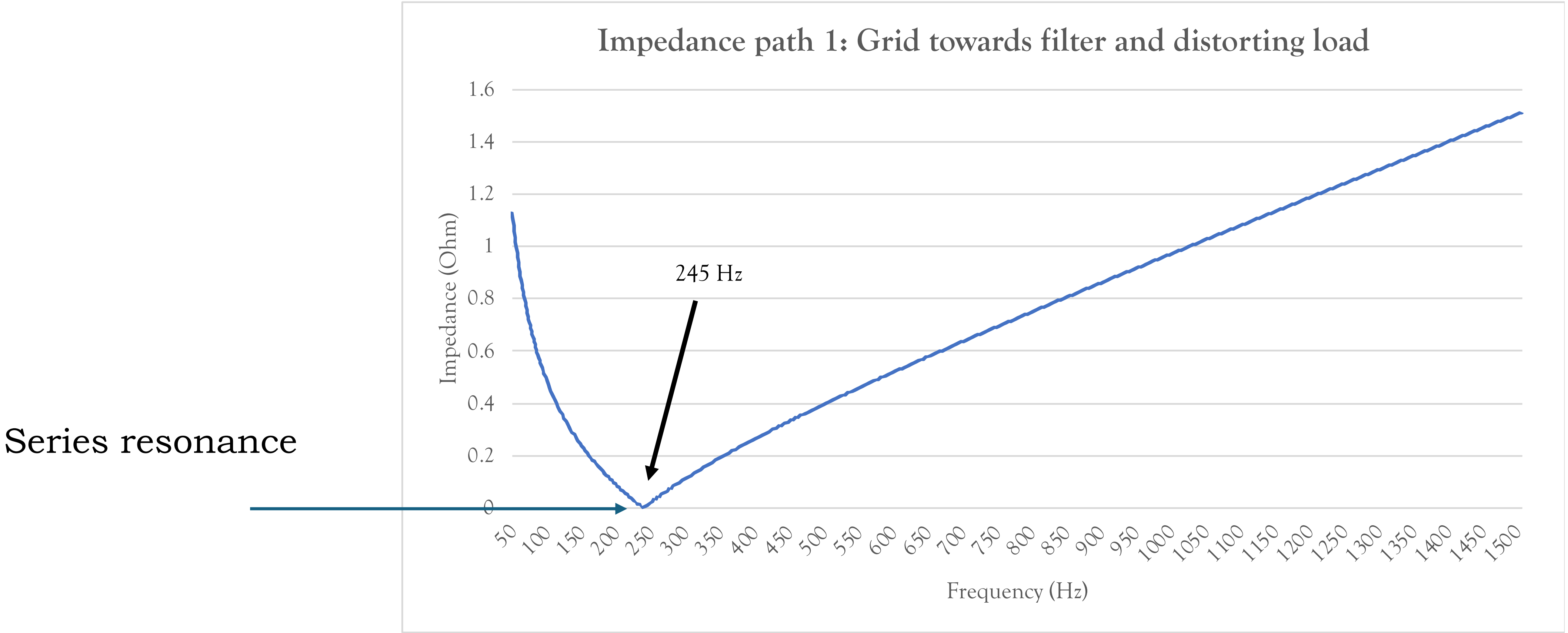
Filter design demonstration

Harmonic filter should trap harmonic currents from distorting load, and not be overloaded by harmonic currents from grid

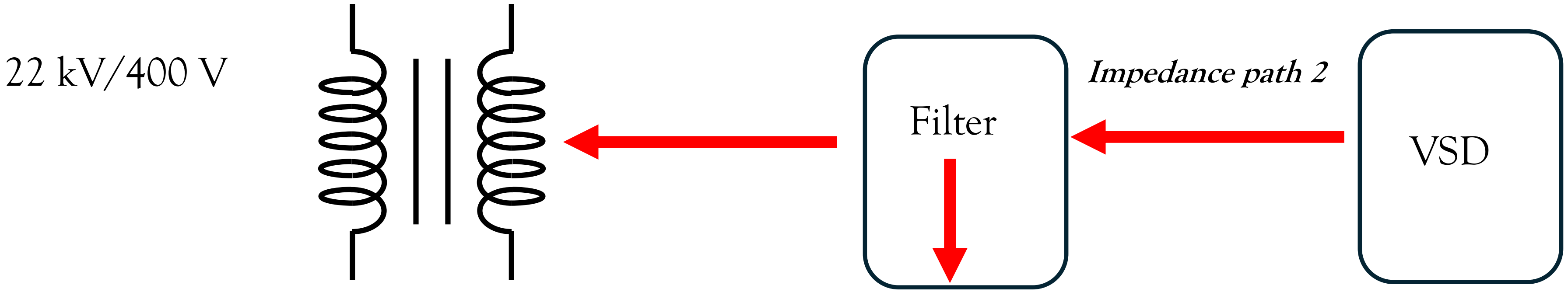


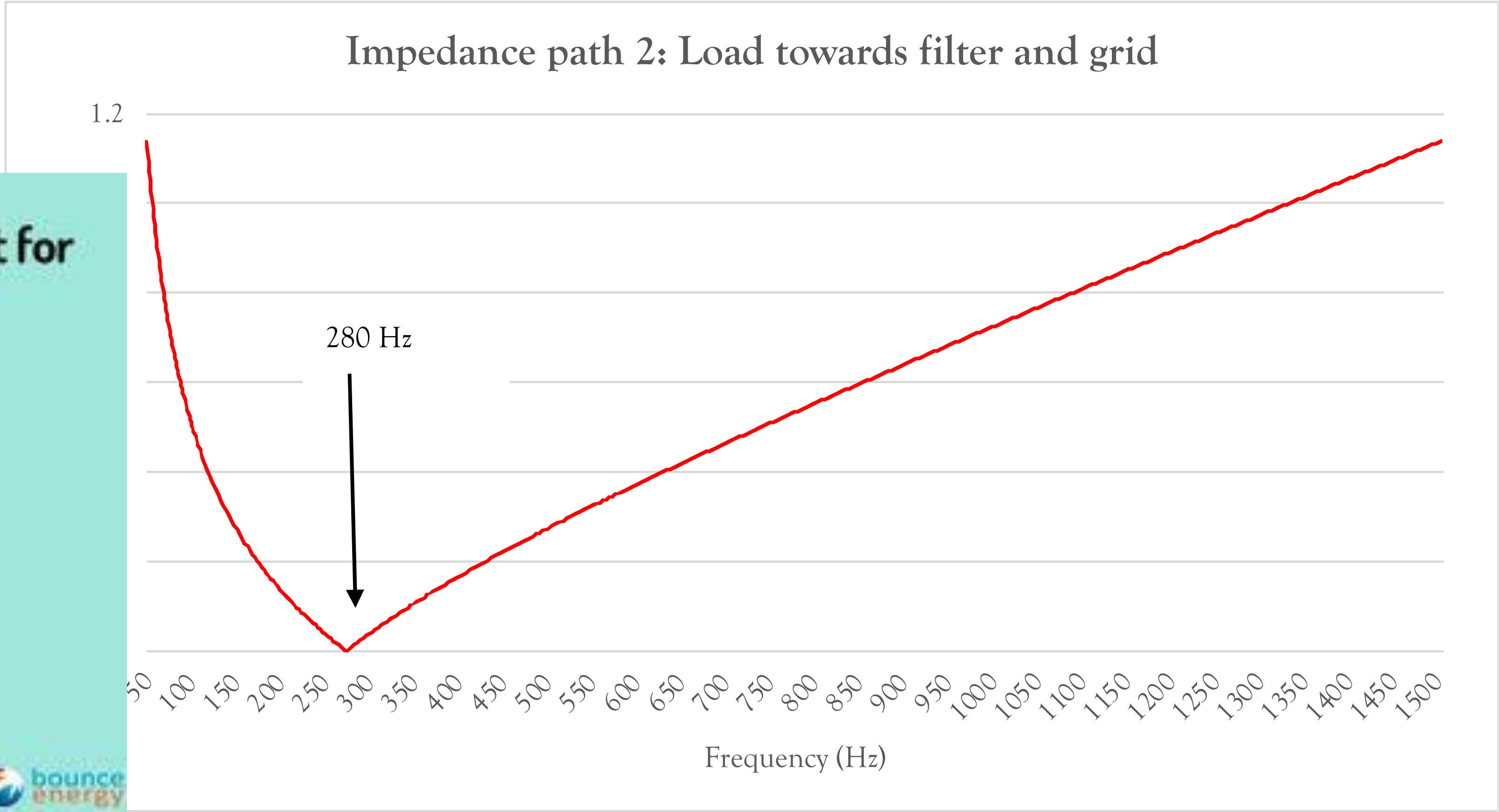
Harmonic filter: Theoretical performance (1)



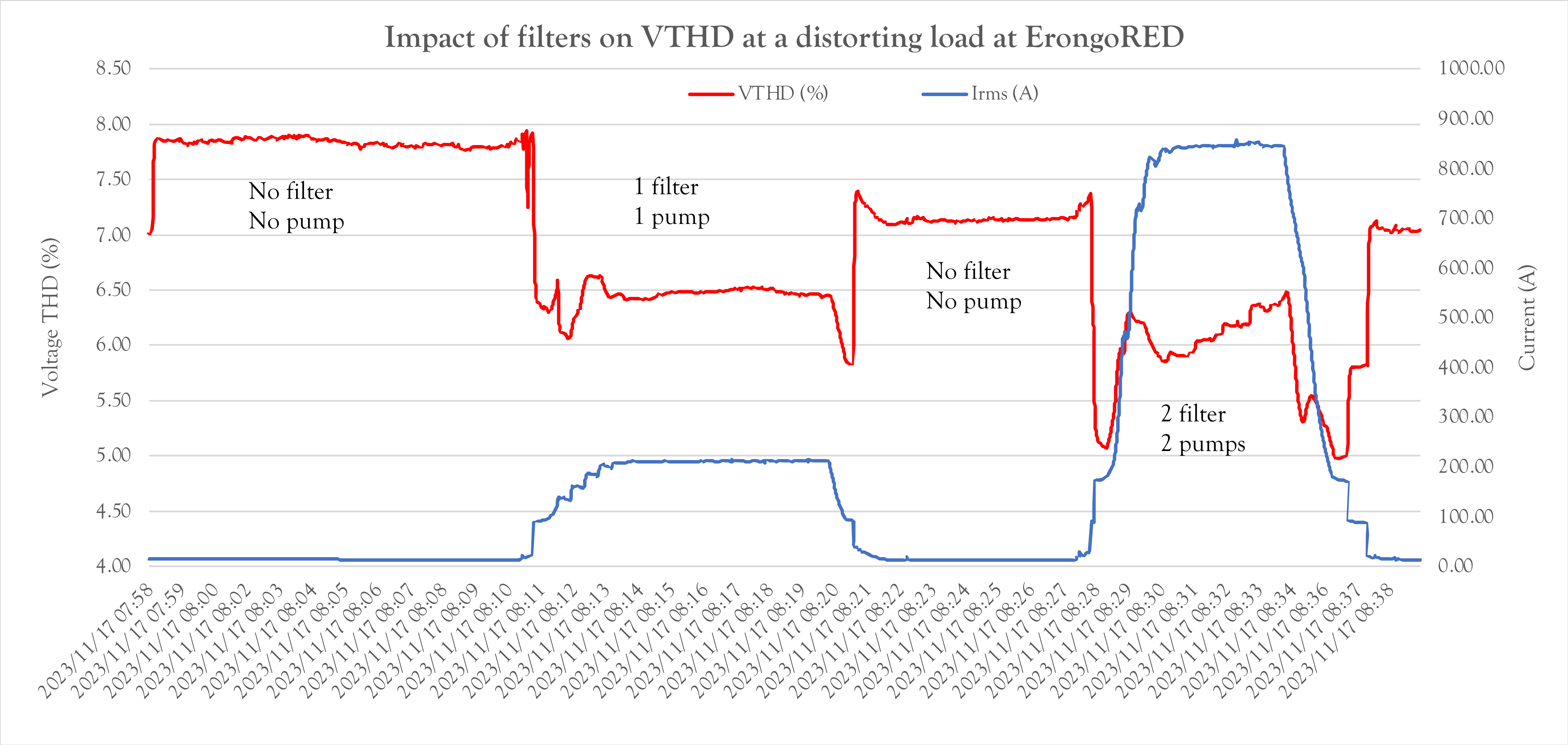


Harmonic filter: Theoretical performance (2)

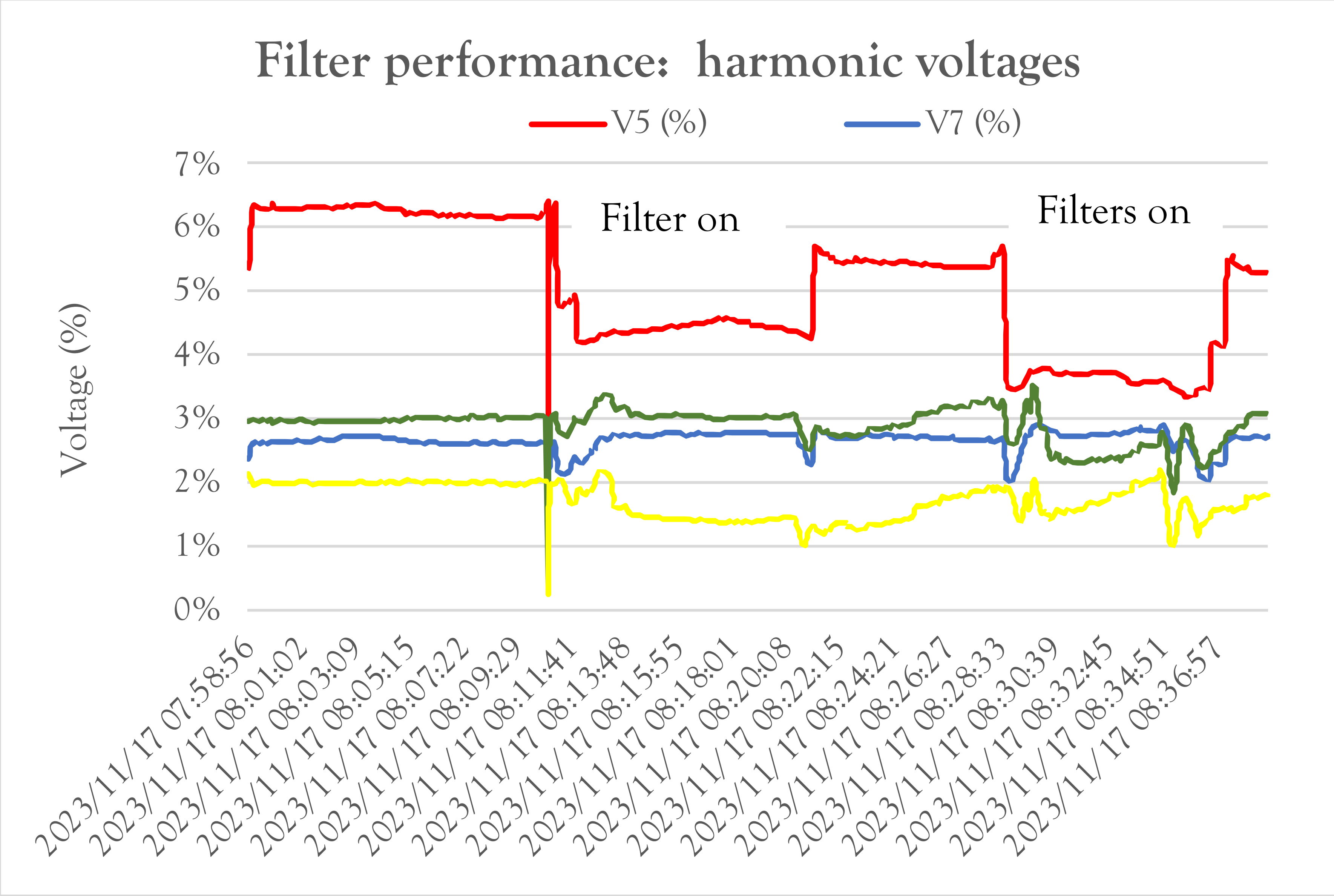




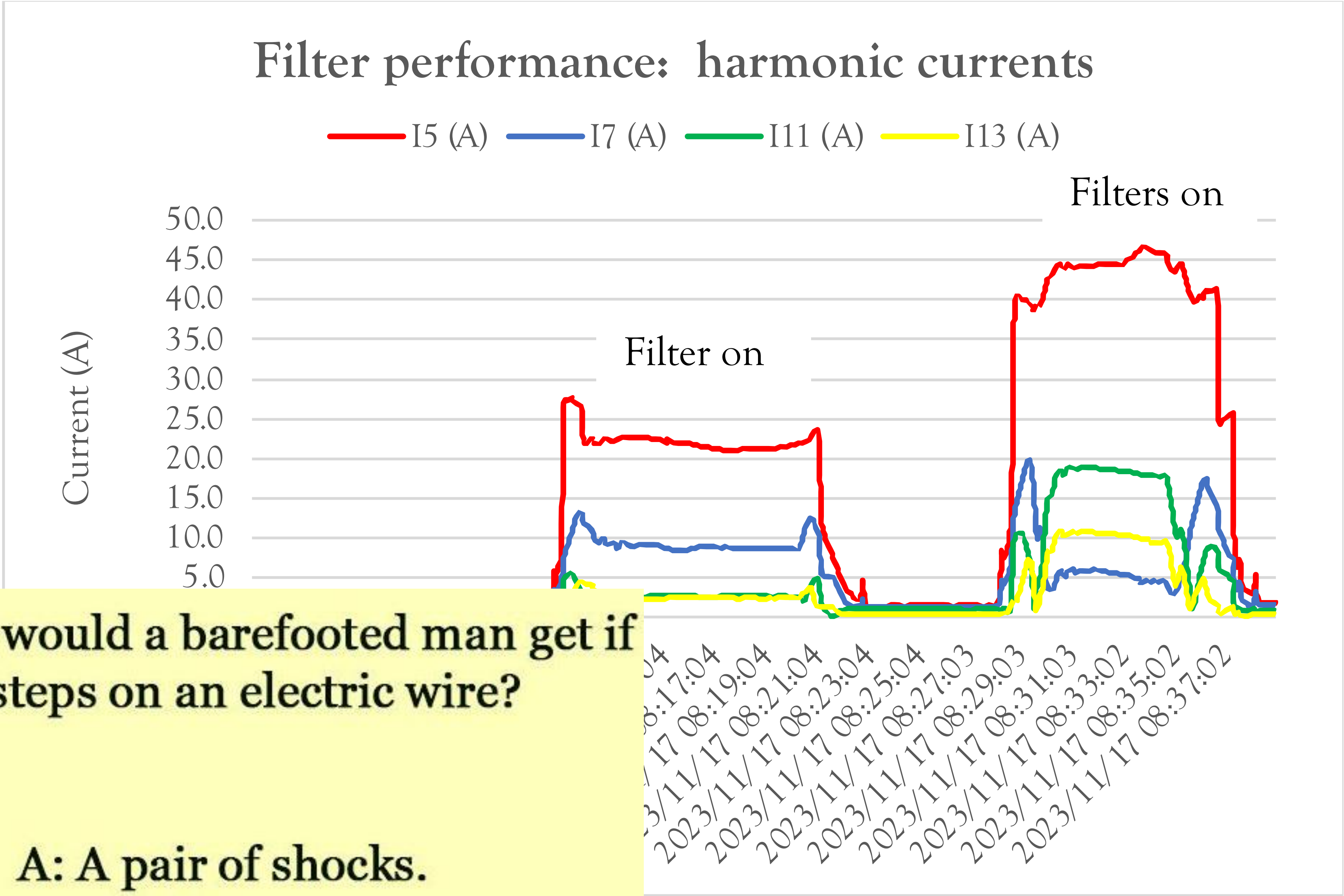
Field measurements: Voltage THD



Field measurements: harmonic voltages



Field measurements: harmonic currents



Q: What would a barefooted man get if he steps on an electric wire?

A: A pair of shocks.

Conclusion

- Feel free to invest in ErongoRED: The commitment to serve customers well, is real.
- Operational risk to end-users are being monitored, managed well.
  - System technical performance: Daily and historical data is available.
  - SCADA to track load flow, configurations, network operations
  - Capable field teams to do field work
  - Containing financial risk: Embedded generation for self-consumption, less consumers, same operational costs vs lower income
- Network planning is done and supported by a verification tool: DigSilent
- Innovation to remain financially viable within a dynamic business model
- Realising the vision of ErongoRED:

Enabling growth through innovative electricity distribution and supply to our communities.