TSDOS TRANSMISSION & SUBSTATION DESIGN & OPERATION SYMPOSIUM

THE UNIVERSITY OF TEXAS AT ARLINGTON

WideBand Voltage Sensors for the Modern Substation

Presented By: Theo Laughner, PE

Acknowledgements: Erik Sperling, Bob Elliott

Overview

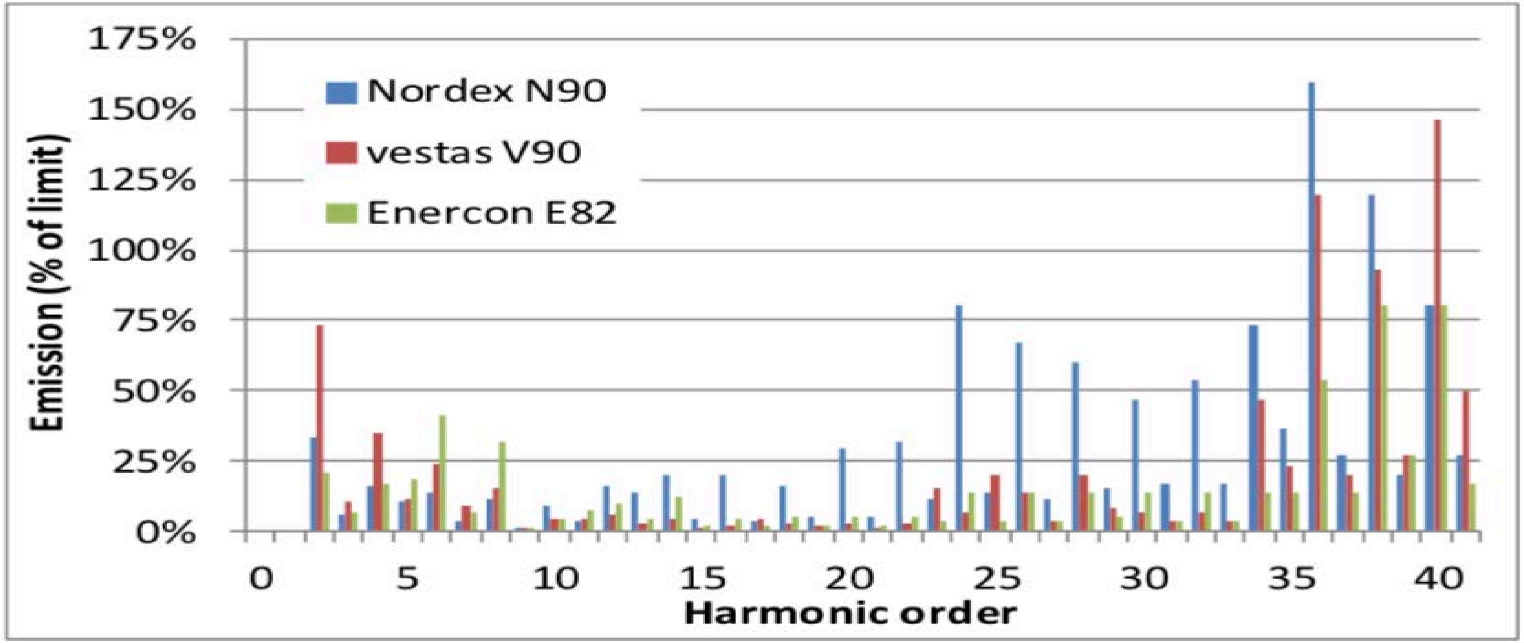
- Introduction
- Impacts To The High Voltage Equipment In A Network
- Types Of Instrument Transformers For Voltage Measurement
- Theoretical Aspects of RC-Dividers
- Frequency Response Behavior Of RC-Dividers
- Conclusions

Introduction

Generation

Consumer / Industrial

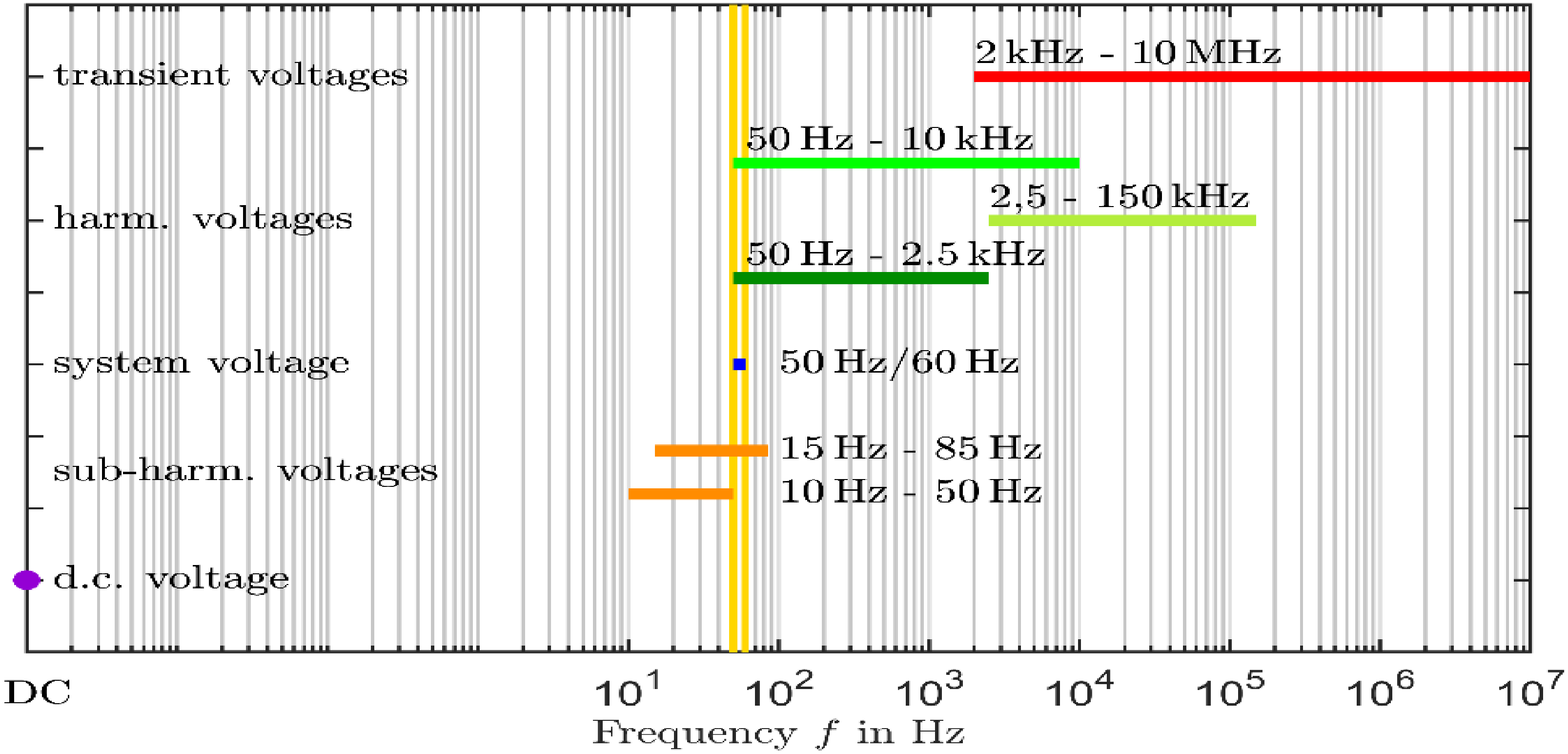
Harmonic Emissions – Per IEEE 519 Limits



Other Emission Sources

Equipment	Voltage dips	Voltage swells	Harmonics	Interharmonics	Subharmonics	Supraharmonics	Slow voltage variations	Fast voltage variations	Transients	Voltage unbalance	Frequency variation	DC components
PV inverters	X											
Production units	X											
Active converters	X	X	X	X	X	X	X	X	X	X	X	X
LED lamps				X				X				
PLC						X			X			
Transformers						X			X			
Rotating machines						X			X			
Cable insulation						X						
Instrument transformers						X						
Three-phase converters										X		
Circuit breaker								X	X			

Frequency Content



Impacts To The High Voltage Equipment In A Network

- Increasing of power losses within the network
- Increasing electric stresses within the HV insulation system (permanently as well as transient)
- Thermal stresses within the connected equipment due to harmonic currents
- Increasing sound noise emission (transformers, coils, capacitors, etc.)
- Saturation effects (measuring and power transformers)
- Incorrect control of equipment
- Faulty activation of protection equipment (old protection system)
- Forced aging of high voltage equipment

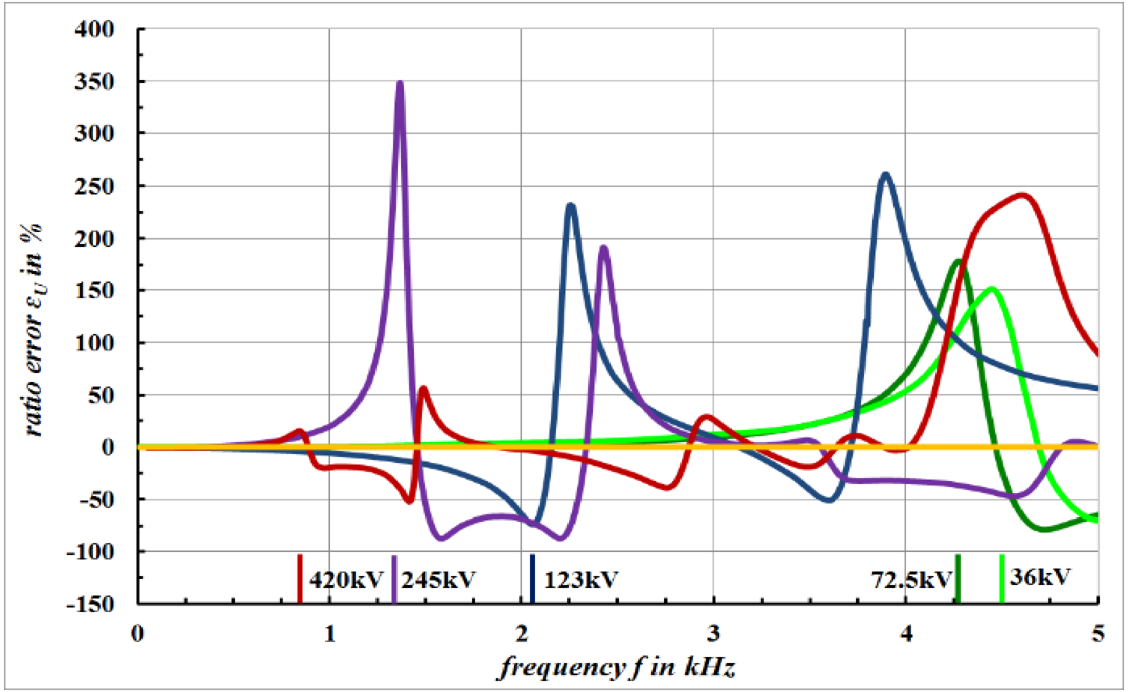
Types Of Instrument Transformers For Voltage Measurement

- Potential Transformer (PT)
  - Magnetically Coupled
  - Most Frequently Used

- Capacitive Coupled Voltage Transformer (CCVT)
  - As the name suggests capacitive coupling
  - Mature technology, but less frequently used

- Optically Coupled Voltage Transformer
  - Uses Faraday effect.
  - In Development.

Frequency Response – Magnitude Accuracy



Legend

36kV-VT(light green)

72.5kV-VT(dark green)

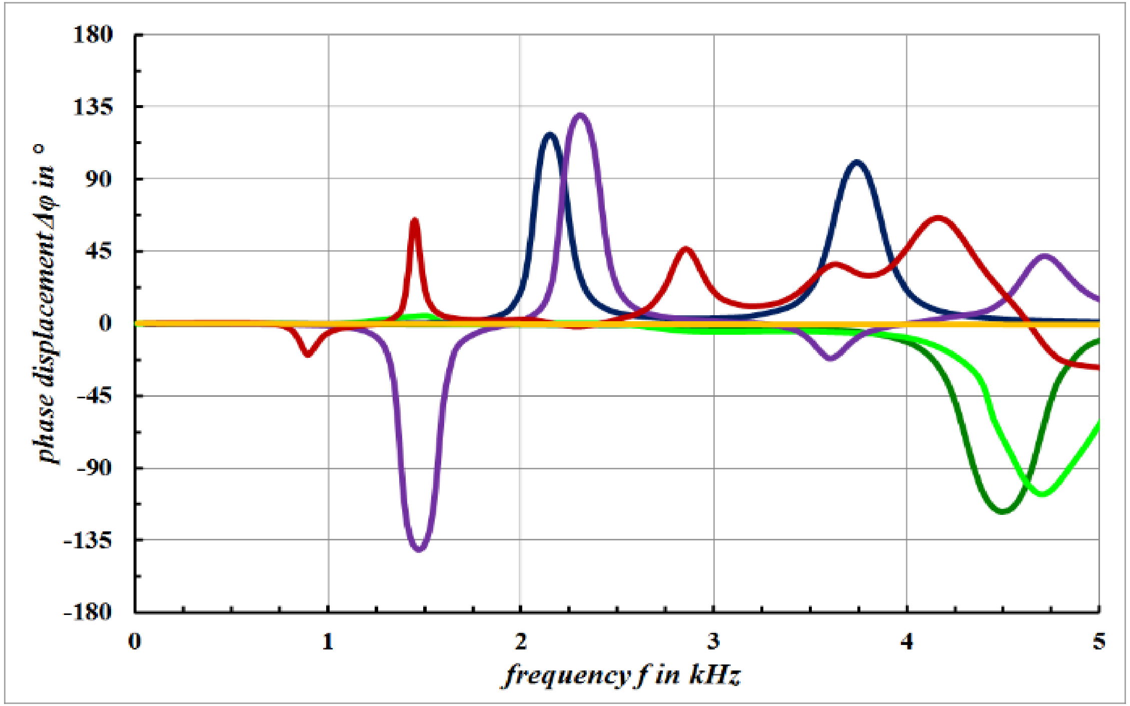
123kV-VT(blue)

245kV-VT(purple)

420kV-CTVT(red)

420kV-RC-divider (yellow)

Frequency Response – Phase Shift Error



Legend
36kV-VT(light green)
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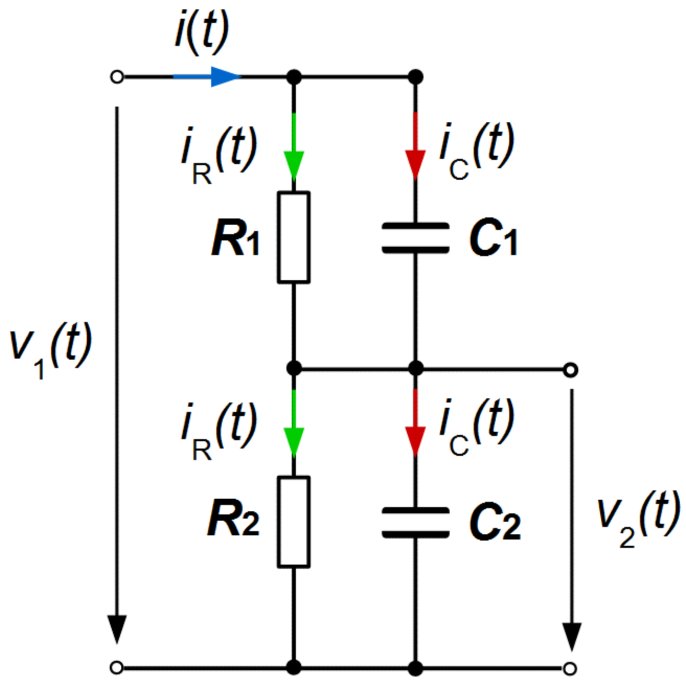
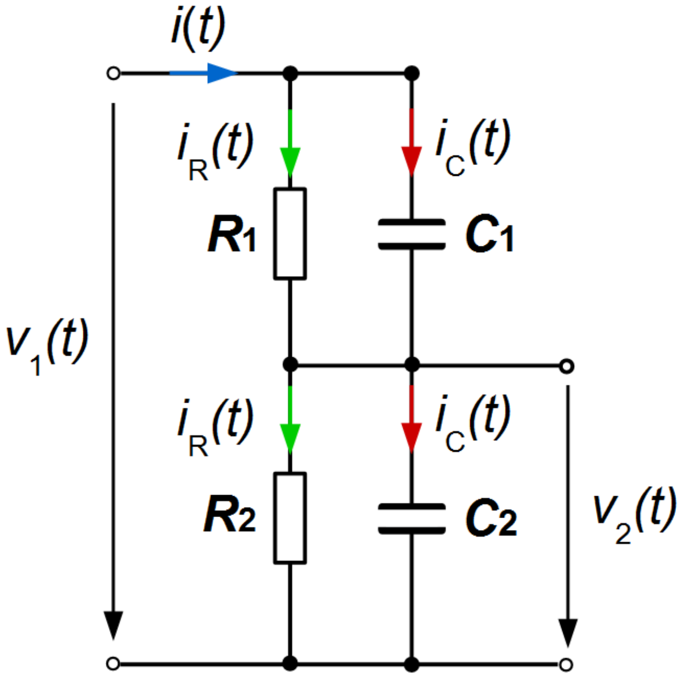
Theoretical Aspects Of RC-Dividers



V_1: Primary voltage
V_2: Secondary voltage
C_1: Primary capacitance
R_1: Primary resistance
C_2: Secondary capacitance
R_2: Secondary resistance
i_C: Capacitive current
i_R: Resistive current

Theoretical Aspects Of RC-Dividers

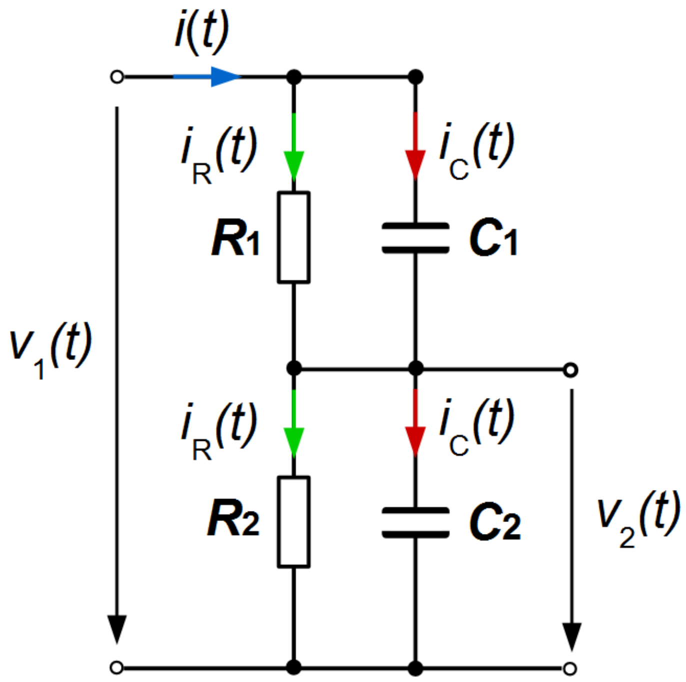


$$\underline{Z}_1 = \frac{R_1}{1 + j\omega C_1 R_1}$$

$$\underline{Z}_2 = \frac{R_2}{1 + j\omega C_2 R_2}$$

$$\underline{Z}_{\text{total}} = \frac{R_1}{1 + j\omega C_1 R_1} + \frac{R_2}{1 + j\omega C_2 R_2}$$

Theoretical Aspects Of RC-Dividers



$$\underline{k}_{\mathrm{C}}(\mathrm{j}\omega) = \frac{C_1}{C_1 + C_2 \cdot \dfrac{(1 + 1/(\mathrm{j}\omega C_2 R_2))}{(1 + 1/(\mathrm{j}\omega C_1 R_1))}}$$

$$\underline{k}_{\mathrm{R}}(\mathrm{j}\omega) = \frac{R_2}{R_2 + R_1 \cdot \dfrac{(1 + \mathrm{j}\omega C_2 R_2)}{(1 + \mathrm{j}\omega C_1 R_1)}}$$

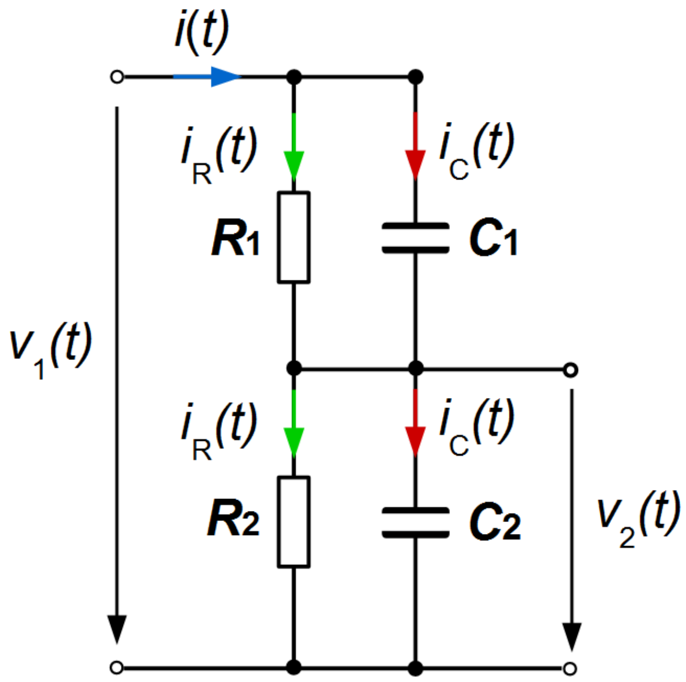
$$f \to \infty$$

$$\frac{Z_2}{Z_{\mathrm{total}}} = \frac{C_1}{C_1 + C_2}$$

$$f \to 0$$

$$\frac{Z_2}{Z_{\mathrm{total}}} = \frac{R_2}{R_2 + R_1}$$

Theoretical Aspects Of RC-Dividers



$$\tau_1 = \tau_2 \;\rightarrow\; R_1 \cdot C_1 = R_2 \cdot C_2$$

1. $\tau_1 > \tau_2$, undercompensated
2. $\tau_1 = \tau_2$, compensated
3. $\tau_1 < \tau_2$, overcompensated

In case 2, the secondary voltage follows the primary voltage with a fixed time delay:

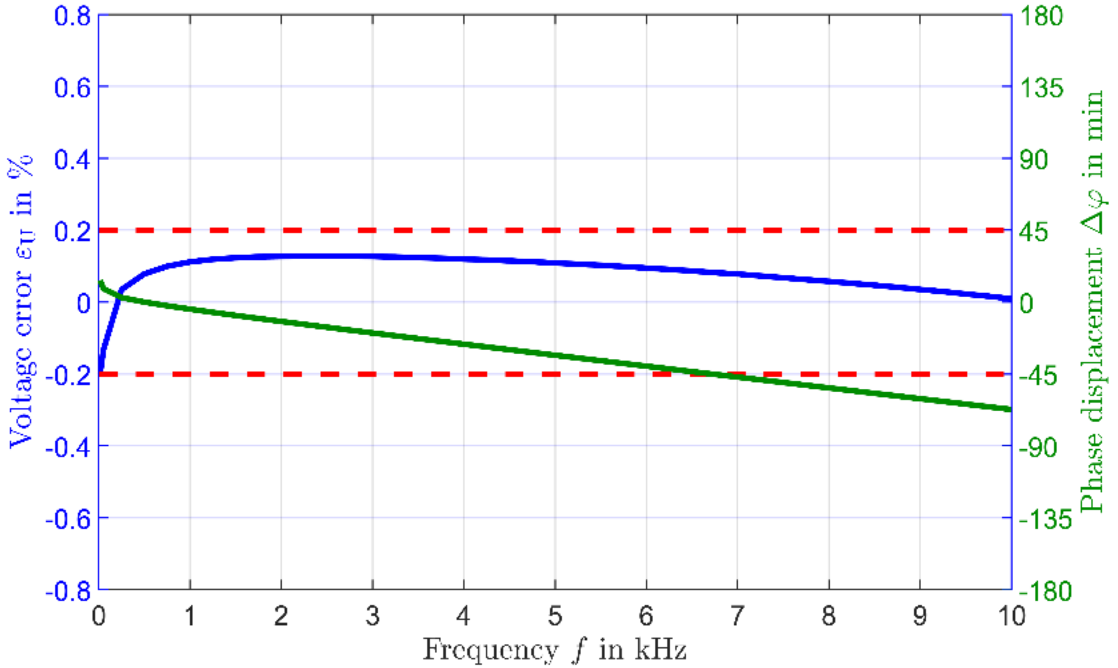
$$T_a = 2.2 \cdot \tau_1 = 2.2 \cdot \tau_2$$

Frequency Response Behavior Of RC-dividers

- For a variety of reasons, it is not possible to perfectly match the primary and secondary components, therefore:
  - $\tau_1 \neq \tau_2 \;\rightarrow\; R_1 \cdot C_1 \neq R_2 \cdot C_2$

- Frequency-dependent error formulas may be derived.

Frequency Response Behavior Of RC-dividers



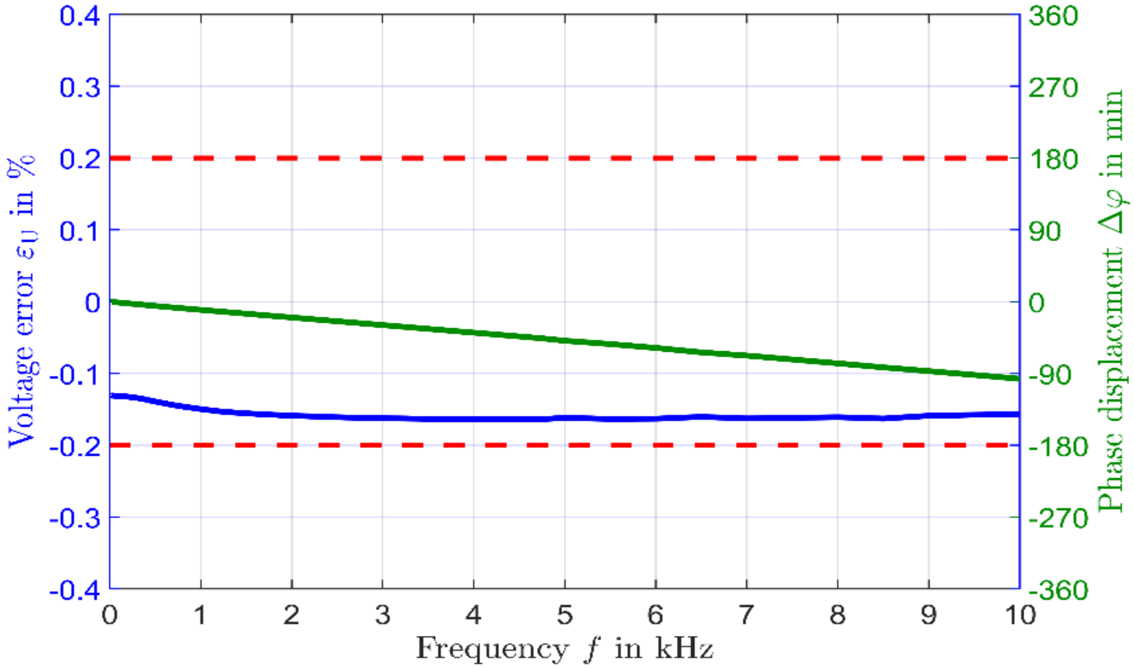
Legend

Type: AIS RC-divider

Voltage accuracy – blue

Phase displacement – green

Frequency Response Behavior Of RC-dividers



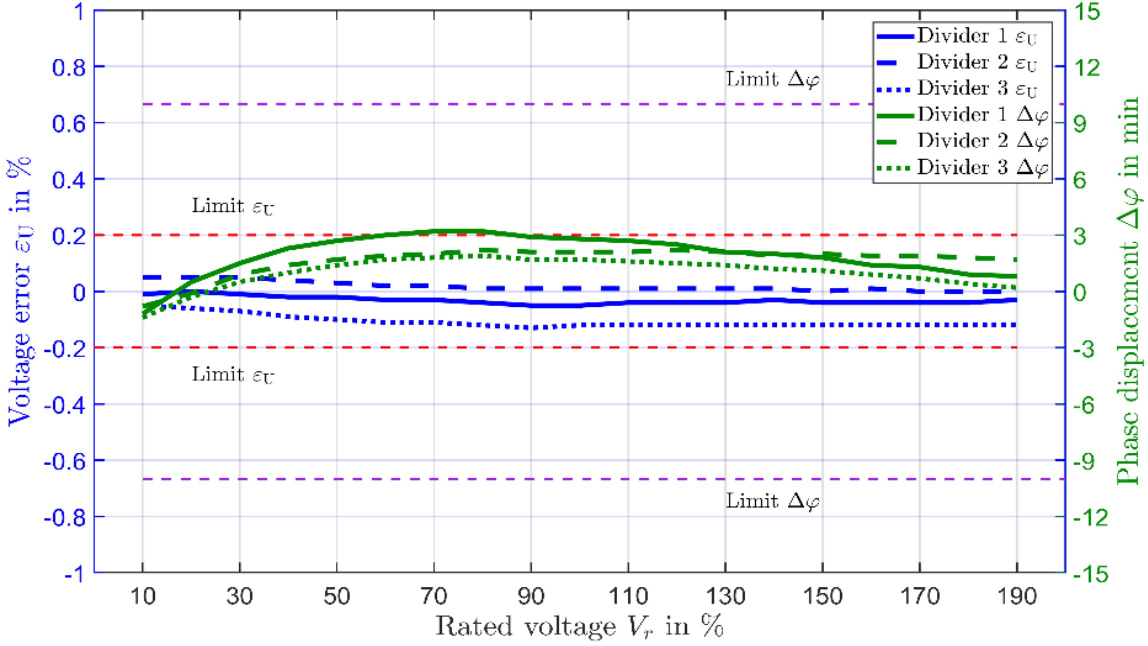
Legend

Type: GIS RC-divider

Voltage accuracy – blue

Phase displacement – green

Frequency Response Behavior Of RC-dividers



Legend

Voltage accuracy – blue

Phase displacement – green

IEC Accuracy Class 0.2

Voltage – Red

Phase displacement – Purple

Frequency Response Behavior Of RC-dividers

Legend

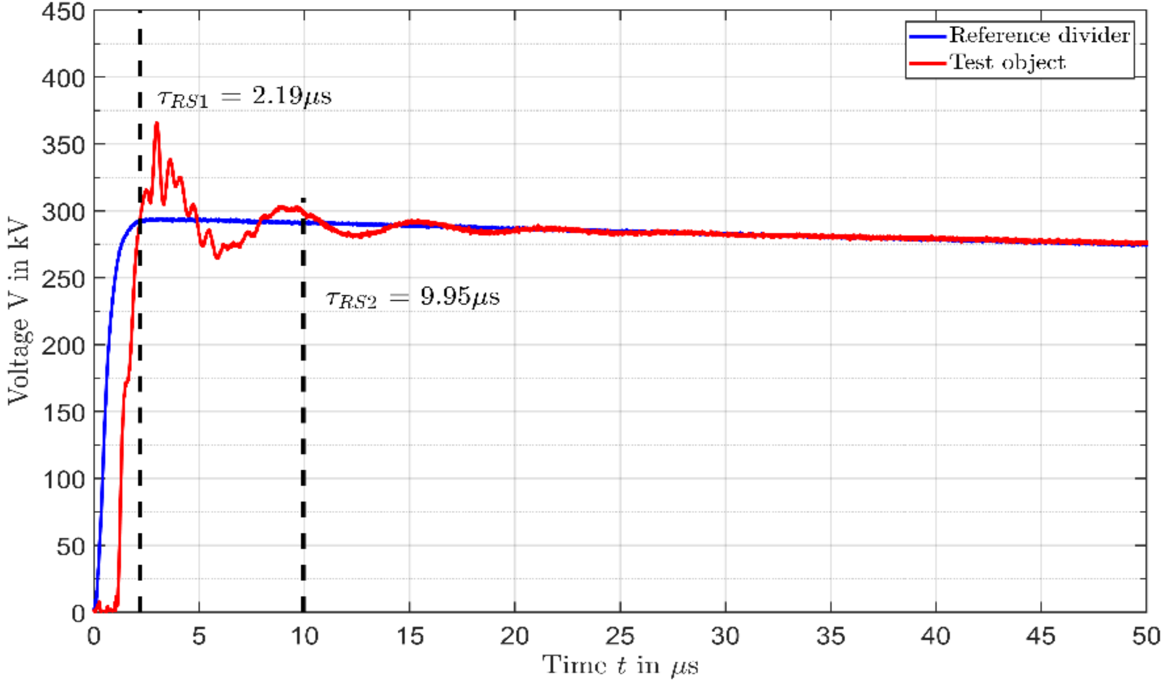
Type: GIS RC-divider

Input Signal: Impulse

Reference – Blue

Measured – Red

Frequency Response Behavior Of RC-dividers



Legend

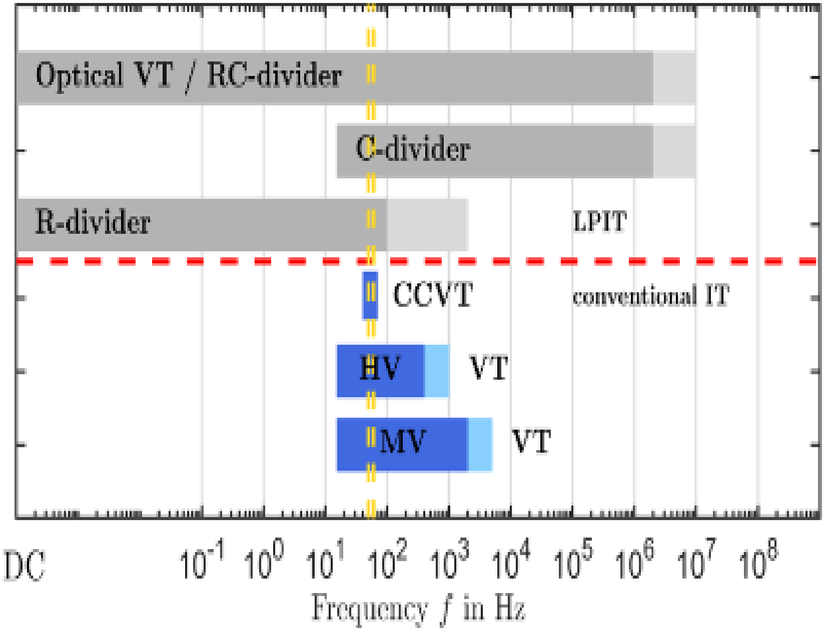
Type: AIS RC-divider

Input Signal: Step Response

Reference – Blue

Measured – Red

Comparisons Between RCVD and CVT



	CVT	RCVD
Measuring performance		
Accuracy at DC	not possible	Very good
Accuracy at sub-harmonics	not usable	Very good
Accuracy at f_R	Very good	Very good
Accuracy at harmonics	not accurate	Very good
Accuracy at transient impulses	Very bad	good
Measuring application	Yes	Yes
Metering application	Yes	Yes
Protection application	Yes	Yes

Conclusions

- The grid is becoming a “more noisy” place.
- Traditional measurement transformers may lack the bandwidth to accurately observe phenomenon on the grid.
- There are new types of measurement transformers which provide adequate frequency response with low measurement error.

- Final thought – present standards may not have accuracy classes which cover all of the necessary functions in the modern grid: revenue metering, protection, power quality measurement, etc.

QUESTIONS?