# CVT TRANSIENTS – CAUSES, EFFECTS, SOLUTIONS

Venkatesh C  Zhiying Zhang  Ilia Voloh
GE Grid Solutions

# Overview

- Historical Overview
- Why we need Ferro-resonance Suppression Circuit
- Understanding Ferro resonance
- CVT Transient Causes
- CVT Transients Effects
- CVT Transients Solutions

# Historical Overview

**1847**
Fuse was recommended to protect telegraph station from lightning strikes

**1890**
First AIEE Protective Relay Conference

**1890**
Direct release Oil CB proposed

**1904**
Protection device with the basic structure of distance relay proposed

**1920**
Ferroresonance devised - two stable frequency operating points coexist

**1921**
Step characteristic was first used

**1936**
CVT term devised

**1948**
Working group fromed to investage transient characteristics of CVT

**1949**
Design improvements to CVT

**1971**
Transient Response investigation

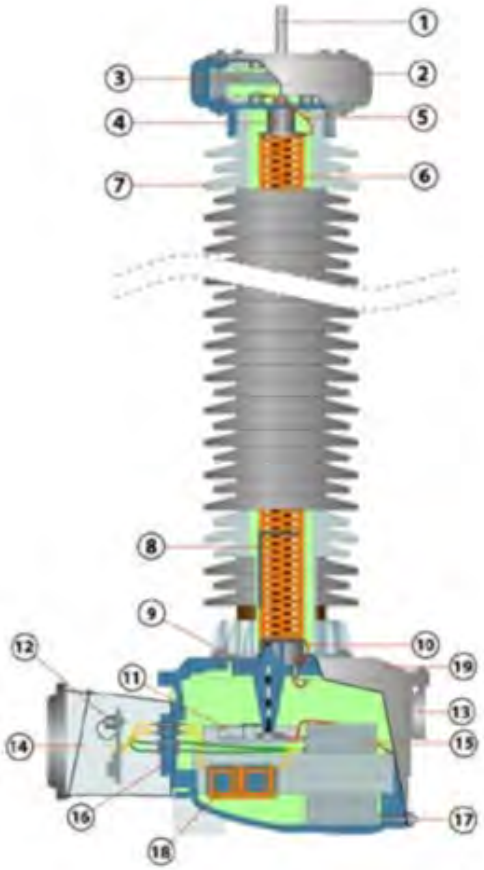
**1981**
IEEE committee report trigerring standard

**1992**
Digital Models proposed

**1997**
Patented Solution 1

**2002**
Patented Solution 2

# Cross Section of CVT

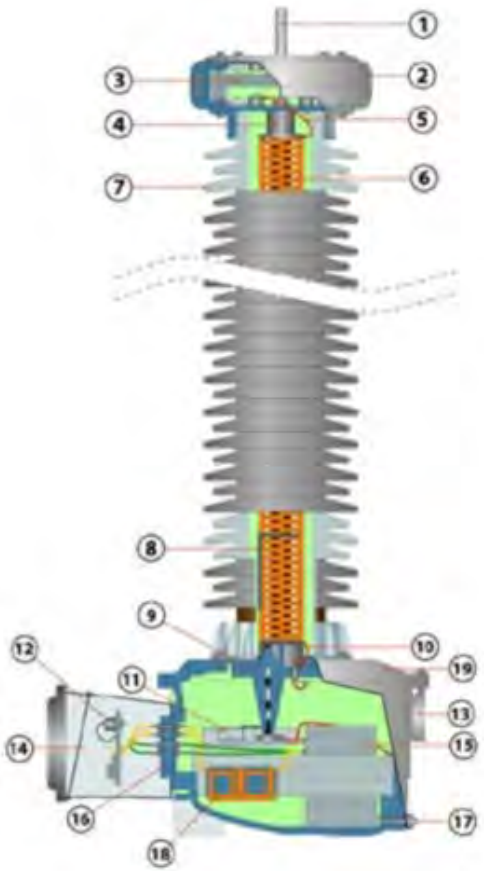



1 - PRIMARY TERMINAL
2 - CAST ALUMINIUM BELLOW HOUSING
3 - STAINLESS STEEL EXPANSION BELLOW
4 - COMPRESSION SPRING
5 - INSULATED VOLTAGE CONNECTION
6 - CAPACITOR ELEMENTS
7 - INSULATOR (PORCELAIN OR SILICON RUBBER)
8 - VOLTAGE DIVIDER TAP CONNECTION
9 - CAST-EPOXY BUSHING
10 - HF TERMINAL CONNECTION
11 - FERRORESONACE SUPPRESSION DEVICE
12 - SECONDARY TERMINALS
13 - OIL LEVEL SIGHT-GLASS
14 - TERMINAL BOX
15 - INTERMEDIATE TRANSFORMER
16 - OIL/AIR BLOCK
17 - OIL DRAIN VALVE
18 - COMPENSATING REACTOR
19 - ALUMINIUM COVER PLATE

Cross section of CVT

Detailed CVT model

# Cross Section of CVT

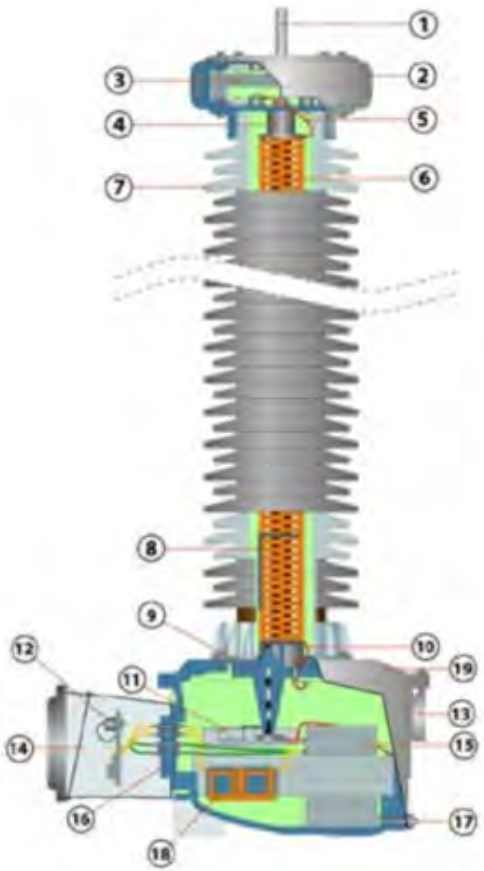


1 - PRIMARY TERMINAL
2 - CAST ALUMINIUM BELLOW HOUSING
3 - STAINLESS STEEL EXPANSION BELLOW
4 - COMPRESSION SPRING
5 - INSULATED VOLTAGE CONNECTION
6 - CAPACITOR ELEMENTS
7 - INSULATOR (PORCELAIN OR SILICON RUBBER)
8 - VOLTAGE DIVIDER TAP CONNECTION
9 - CAST-EPOXY BUSHING
10 - HF TERMINAL CONNECTION
11 - FERRORESONACE SUPPRESSION DEVICE
12 - SECONDARY TERMINALS
13 - OIL LEVEL SIGHT-GLASS
14 - TERMINAL BOX
15 - INTERMEDIATE TRANSFORMER
16 - OIL/AIR BLOCK
17 - OIL DRAIN VALVE
18 - COMPENSATING REACTOR
19 - ALUMINIUM COVER PLATE

Cross section of CVT

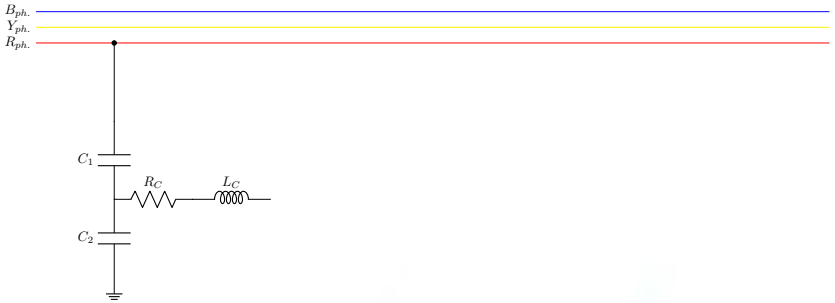
Detailed CVT model

# Cross Section of CVT



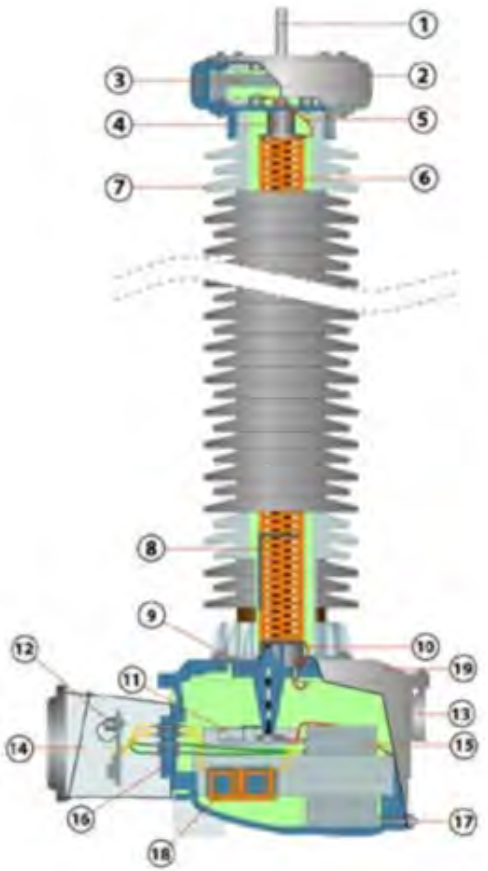
1 - PRIMARY TERMINAL
2 - CAST ALUMINIUM BELLOW HOUSING
3 - STAINLESS STEEL EXPANSION BELLOW
4 - COMPRESSION SPRING
5 - INSULATED VOLTAGE CONNECTION
6 - CAPACITOR ELEMENTS
7 - INSULATOR (PORCELAIN OR SILICON RUBBER)
8 - VOLTAGE DIVIDER TAP CONNECTION
9 - CAST-EPOXY BUSHING
10 - HF TERMINAL CONNECTION
11 - FERRORESONACE SUPPRESSION DEVICE
12 - SECONDARY TERMINALS
13 - OIL LEVEL SIGHT-GLASS
14 - TERMINAL BOX
15 - INTERMEDIATE TRANSFORMER
16 - OIL/AIR BLOCK
17 - OIL DRAIN VALVE
18 - COMPENSATING REACTOR
19 - ALUMINIUM COVER PLATE

Cross section of CVT



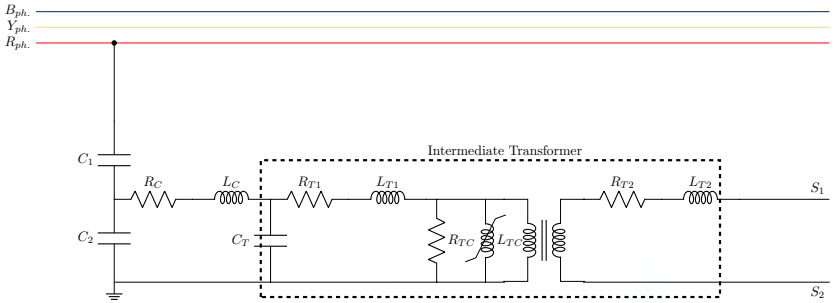

Detailed CVT model

# Cross Section of CVT



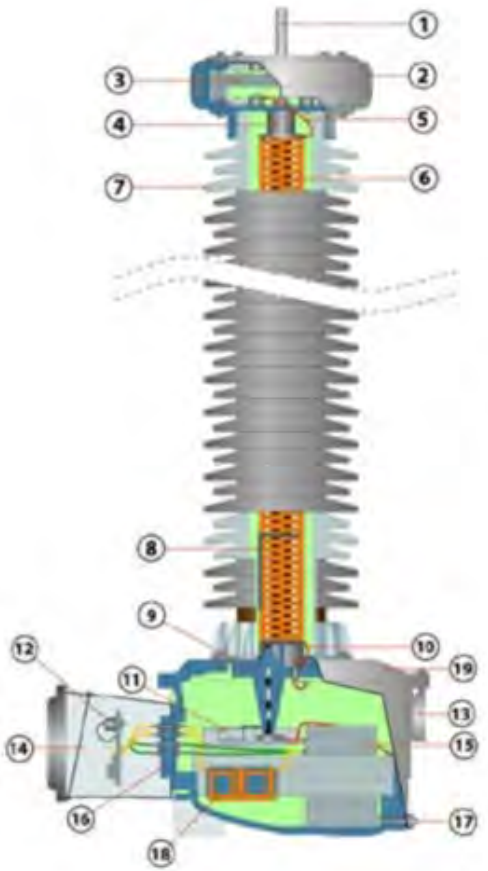
1 - PRIMARY TERMINAL
2 - CAST ALUMINIUM BELLOW HOUSING
3 - STAINLESS STEEL EXPANSION BELLOW
4 - COMPRESSION SPRING
5 - INSULATED VOLTAGE CONNECTION
6 - CAPACITOR ELEMENTS
7 - INSULATOR (PORCELAIN OR SILICON RUBBER)
8 - VOLTAGE DIVIDER TAP CONNECTION
9 - CAST-EPOXY BUSHING
10 - HF TERMINAL CONNECTION
11 - FERRORESONACE SUPPRESSION DEVICE
12 - SECONDARY TERMINALS
13 - OIL LEVEL SIGHT-GLASS
14 - TERMINAL BOX
15 - INTERMEDIATE TRANSFORMER
16 - OIL/AIR BLOCK
17 - OIL DRAIN VALVE
18 - COMPENSATING REACTOR
19 - ALUMINIUM COVER PLATE

Cross section of CVT



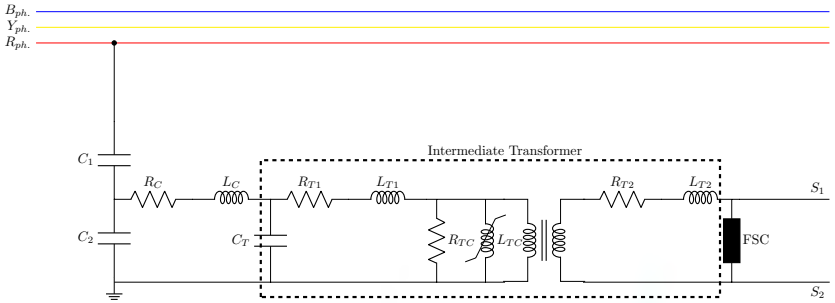

Detailed CVT model

# Cross Section of CVT



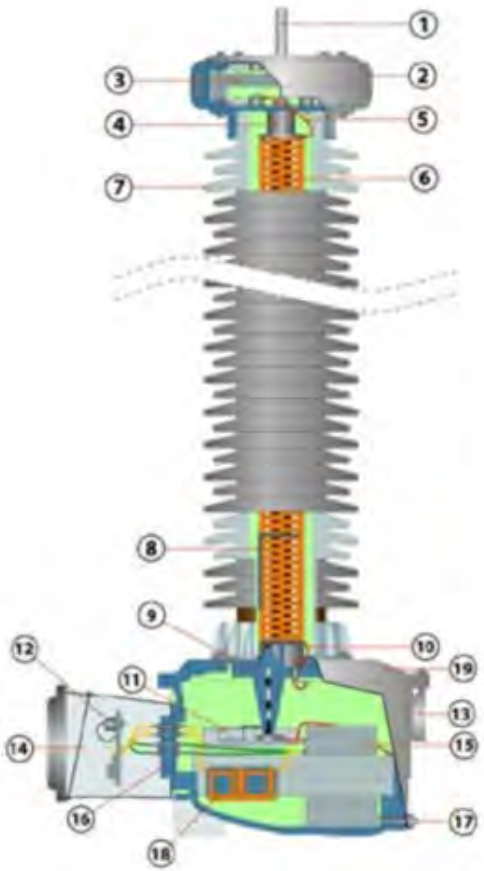
1 - PRIMARY TERMINAL
2 - CAST ALUMINIUM BELLOW HOUSING
3 - STAINLESS STEEL EXPANSION BELLOW
4 - COMPRESSION SPRING
5 - INSULATED VOLTAGE CONNECTION
6 - CAPACITOR ELEMENTS
7 - INSULATOR (PORCELAIN OR SILICON RUBBER)
8 - VOLTAGE DIVIDER TAP CONNECTION
9 - CAST-EPOXY BUSHING
10 - HF TERMINAL CONNECTION
11 - FERRORESONACE SUPPRESSION DEVICE
12 - SECONDARY TERMINALS
13 - OIL LEVEL SIGHT-GLASS
14 - TERMINAL BOX
15 - INTERMEDIATE TRANSFORMER
16 - OIL/AIR BLOCK
17 - OIL DRAIN VALVE
18 - COMPENSATING REACTOR
19 - ALUMINIUM COVER PLATE

Cross section of CVT

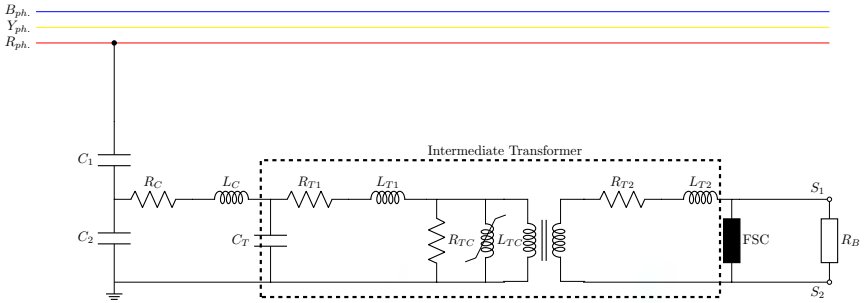



Detailed CVT model

# Cross Section of CVT

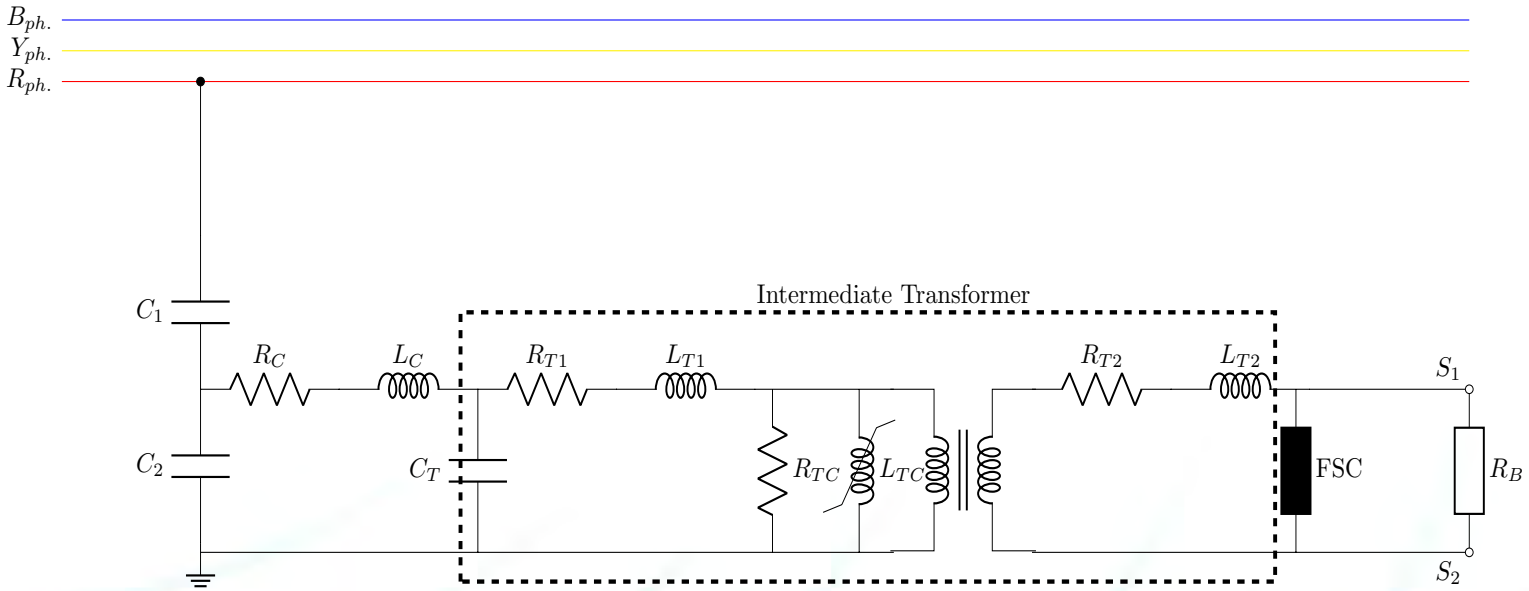



Cross section of CVT



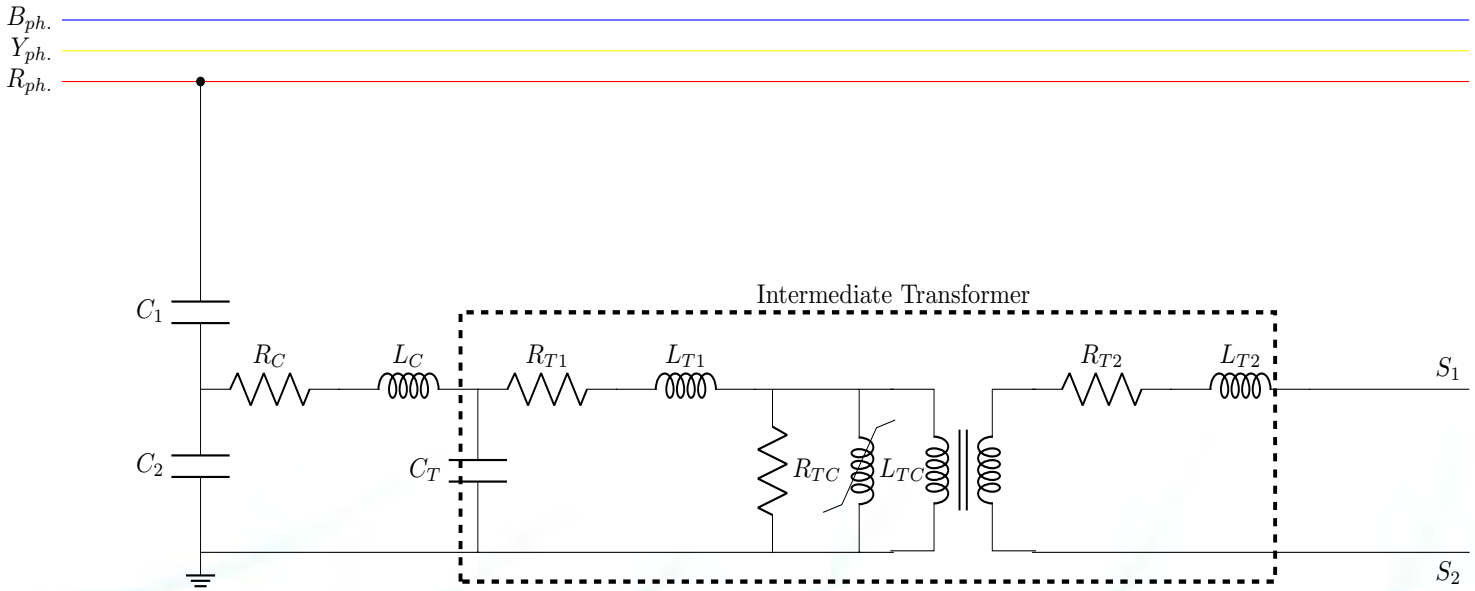

Detailed CVT model

# Why we need Ferro Resoance Suppression Circuit?



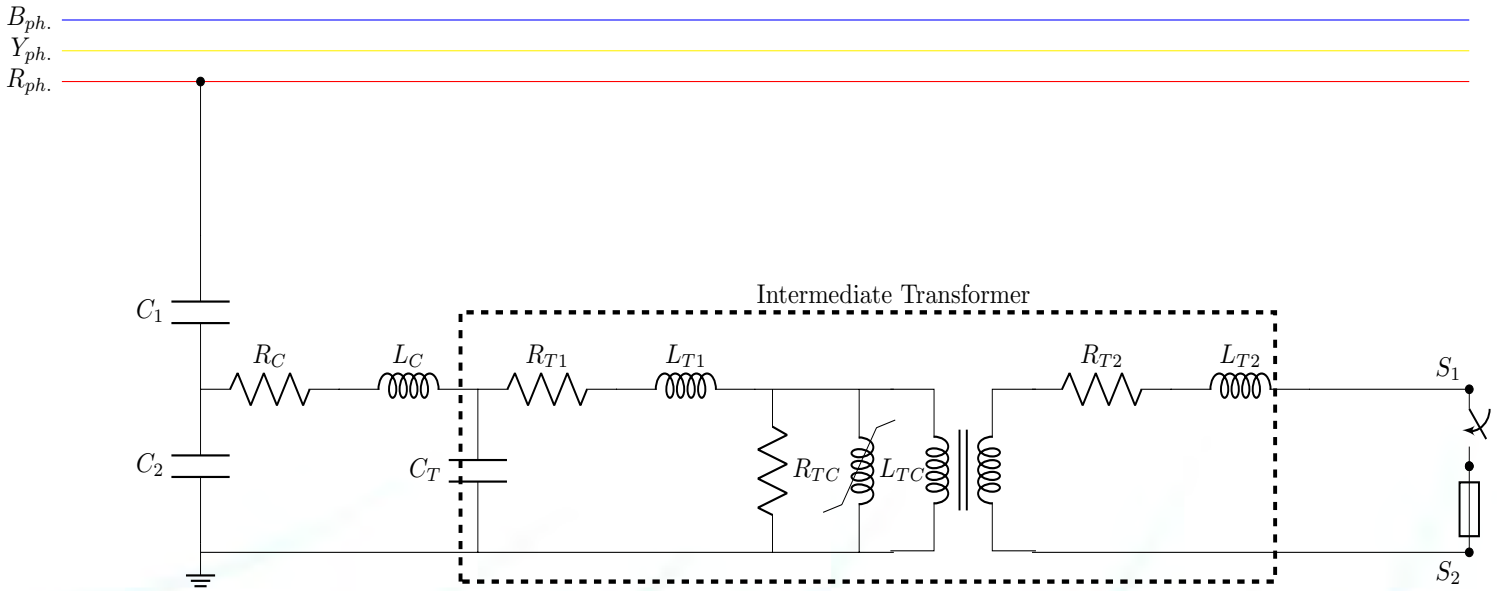

Detailed CVT model

# Why we need Ferro Resoance Suppression Circuit?



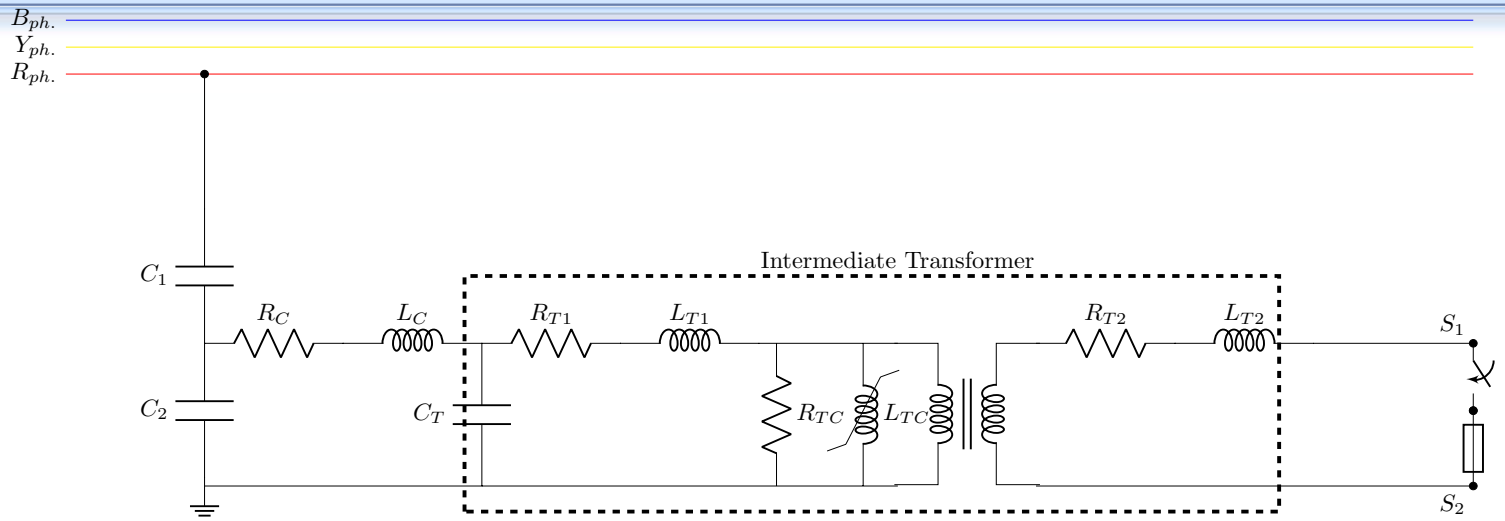

Detailed CVT model

# Why we need Ferro Resoance Suppression Circuit?

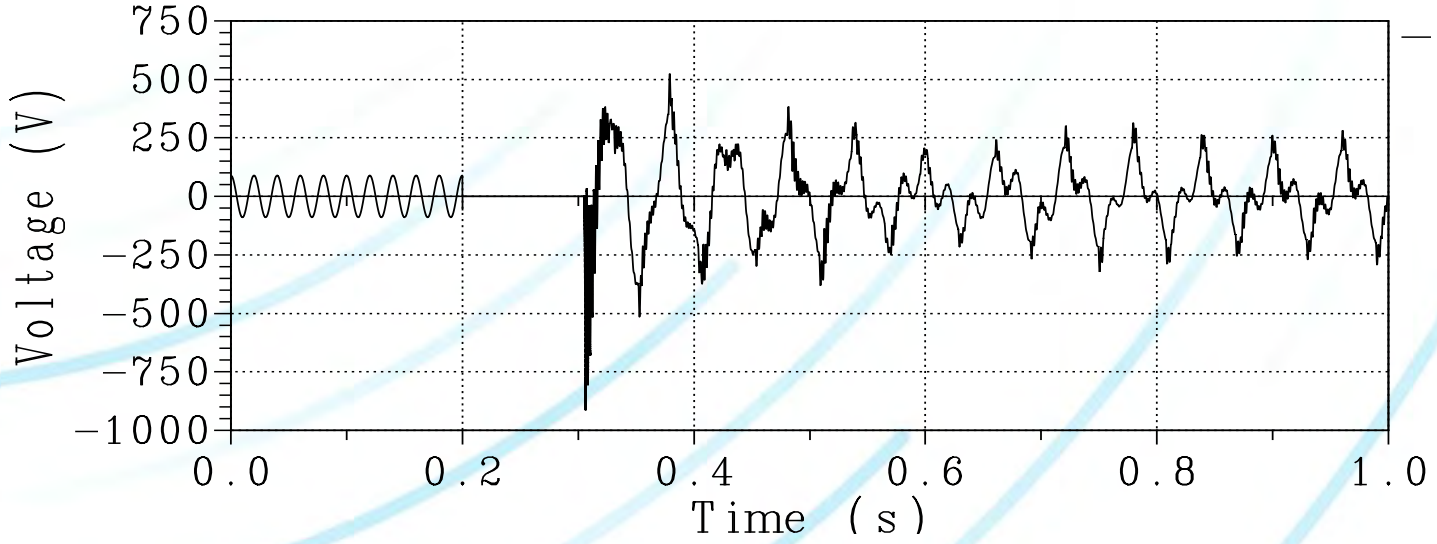



Detailed CVT model

# Why we need Ferro Resoance Suppression Circuit?

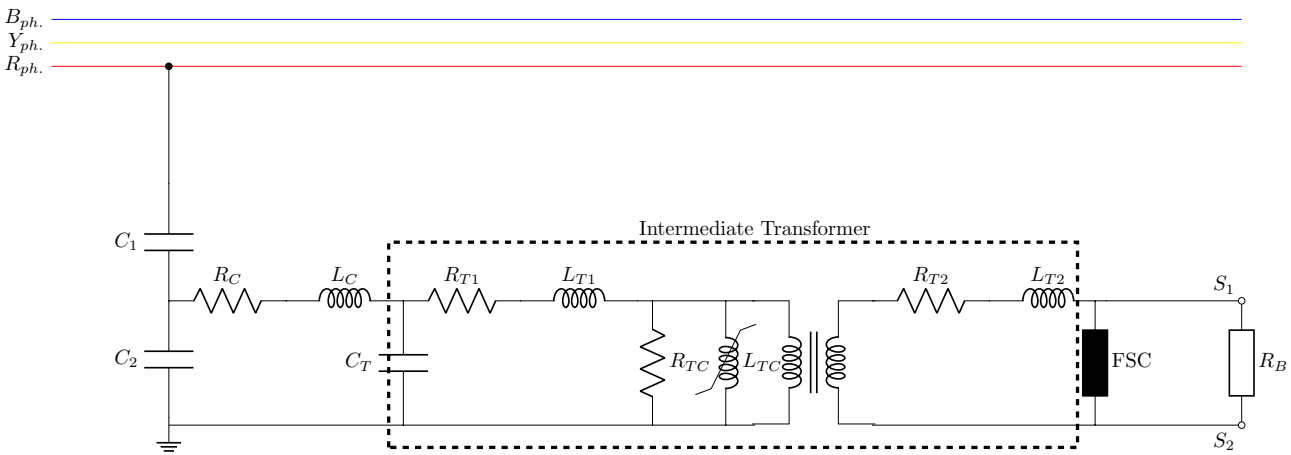



Detailed CVT model

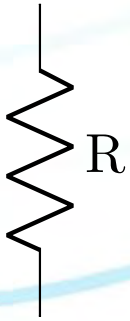



Ferro resoanance

# Type of Ferro-resonance suppression circuit

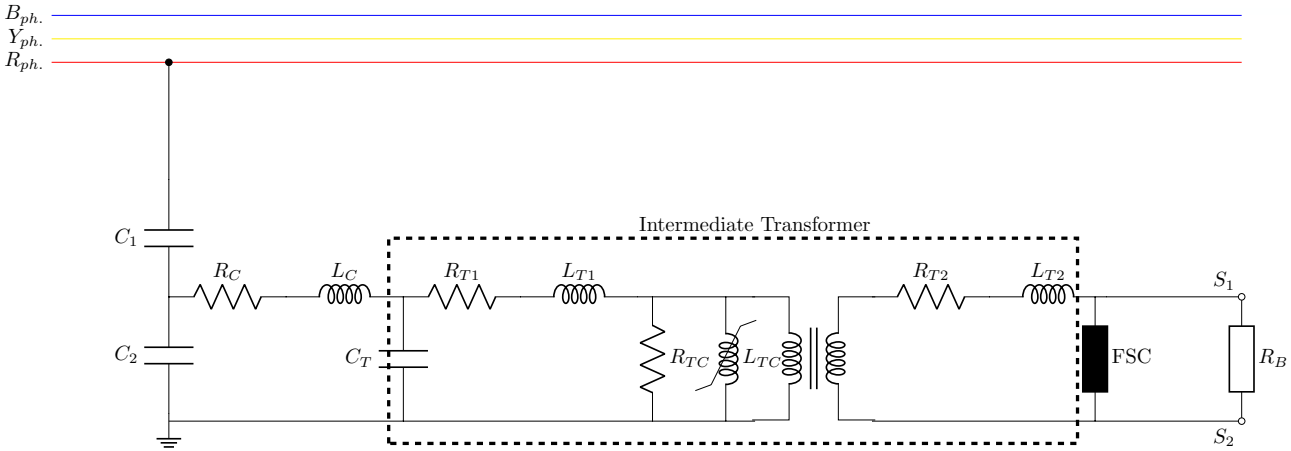



Detailed CVT model

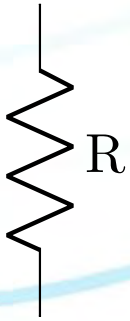



Resistor

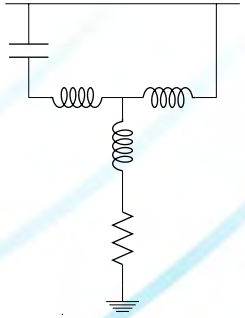
# Type of Ferro-resonance suppression circuit




Detailed CVT model

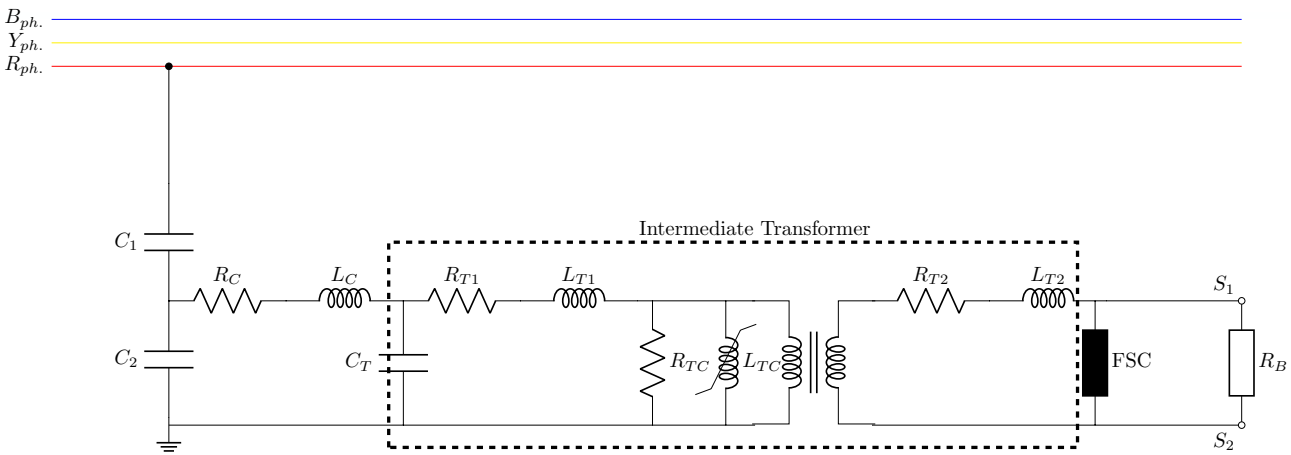



Resistor

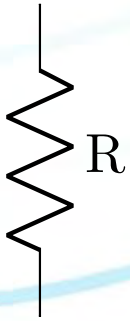


Type-1 FSC

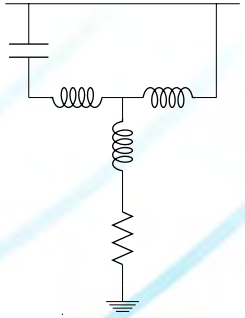
# Type of Ferro-resonance suppression circuit



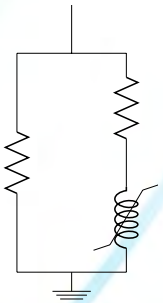

Detailed CVT model




Resistor

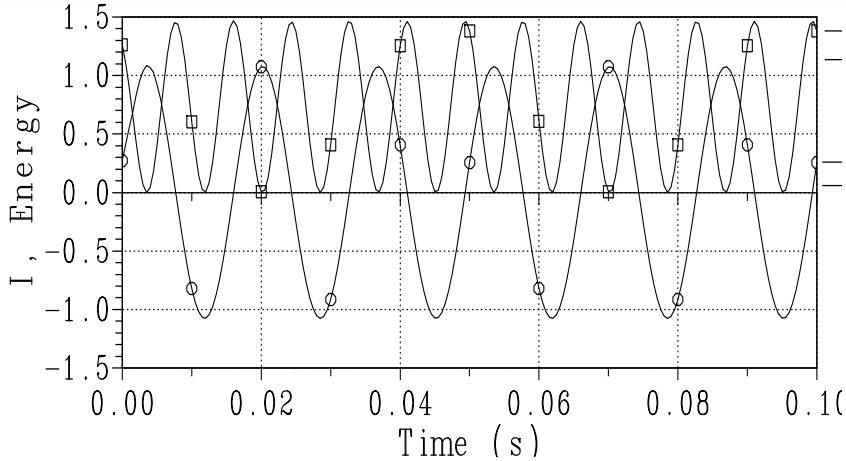


Type-1 FSC

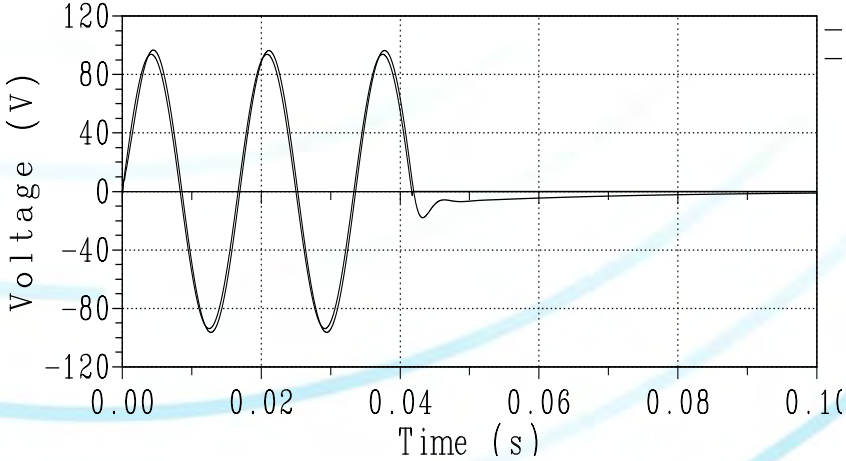


Type-2 FSC

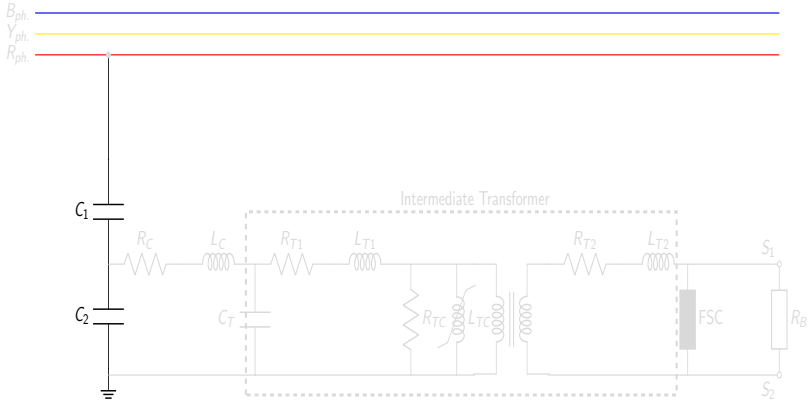
# CVT Transients : Cause 1 - Point on Wave



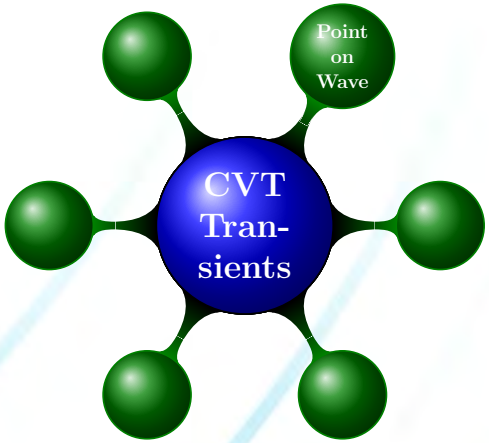

C - Energy (Square mark, scaled)




Fault at zero crossing

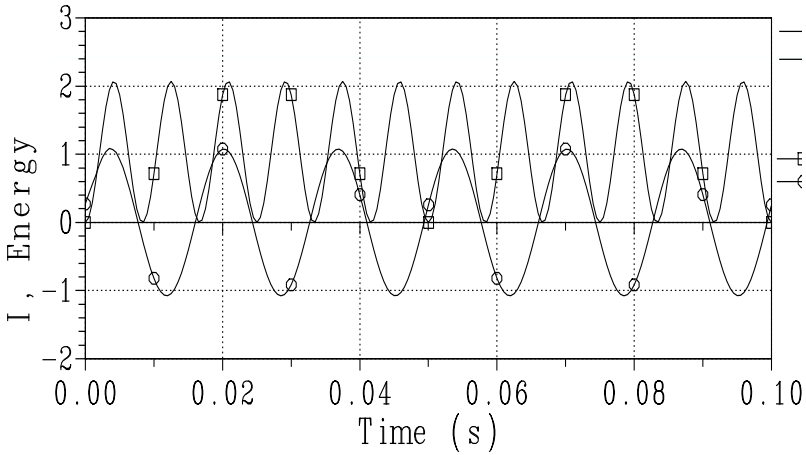



Detailed CVT model

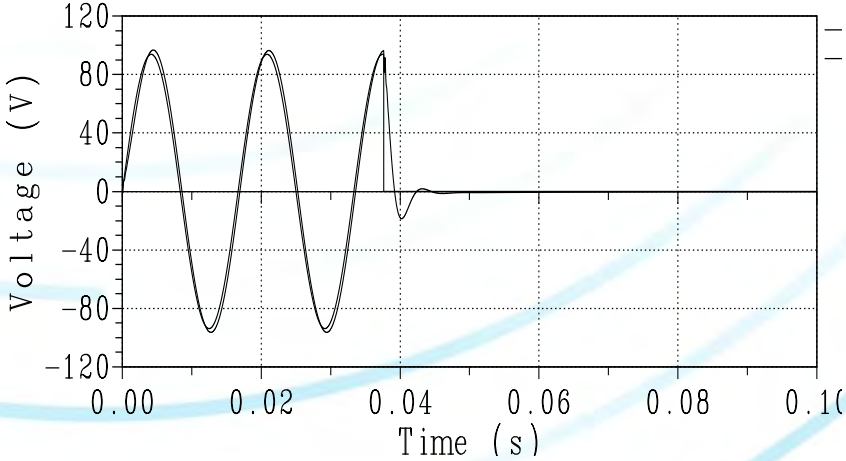



Causes

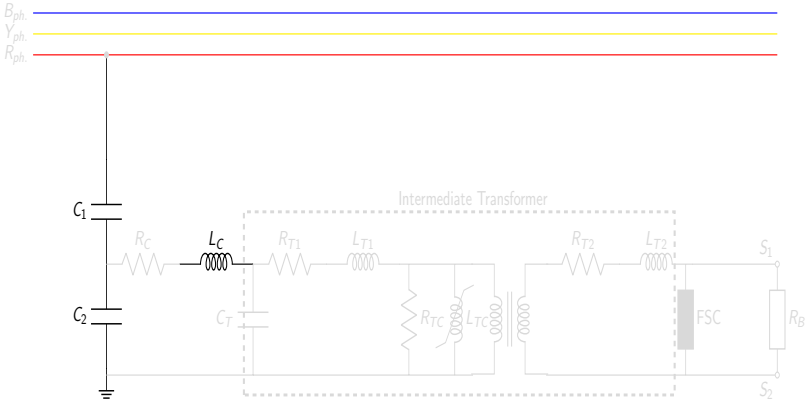
# CVT Transients : Cause 1 - Point on Wave (Contd.)



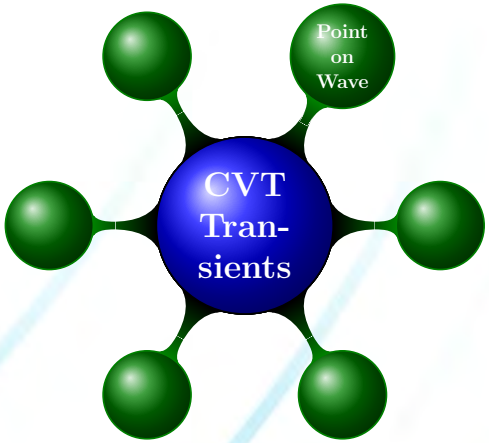

L - Energy (Square mark, scaled)




Fault at peak

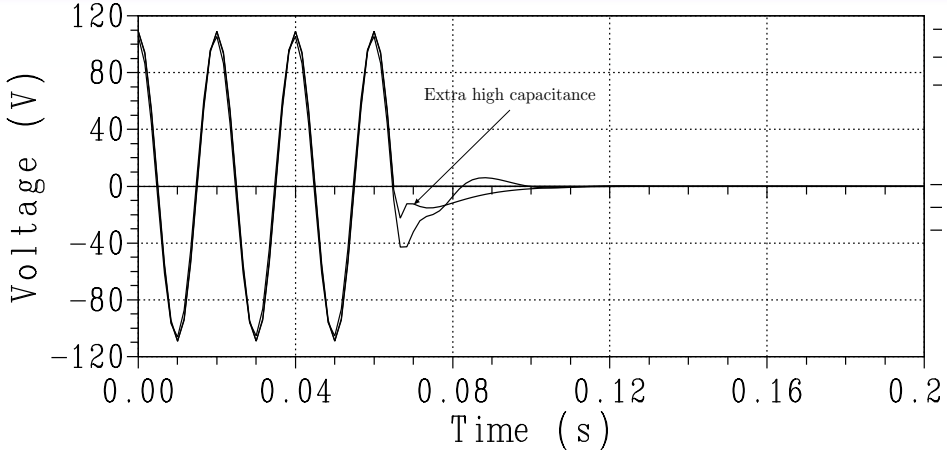



Detailed CVT model

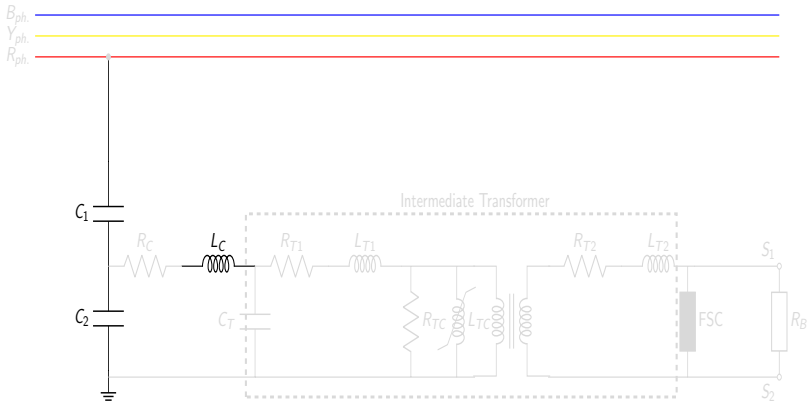



Causes

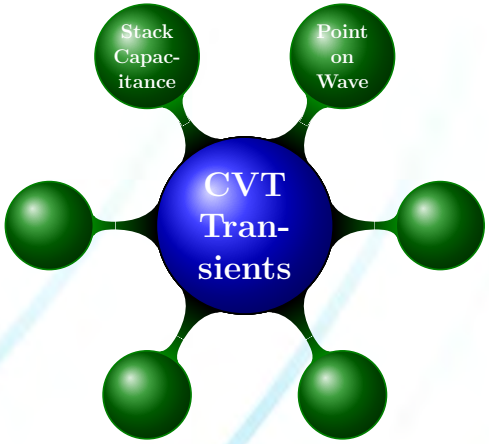
# CVT Transients : Cause 2 - Stack Capacitance




Impact of stack capacitance on CVT transients



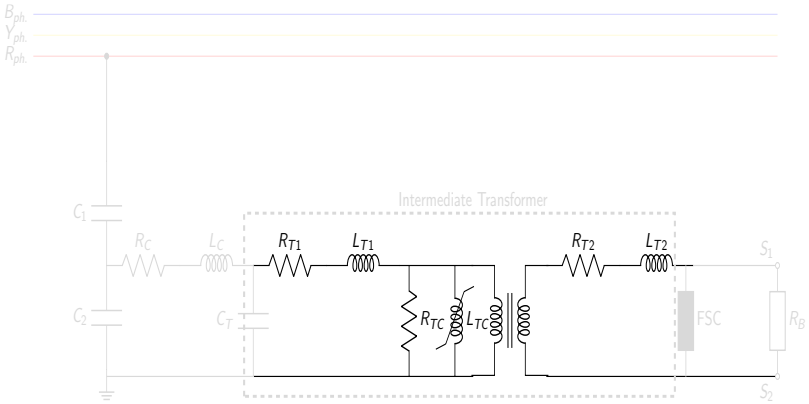

Detailed CVT model




Causes

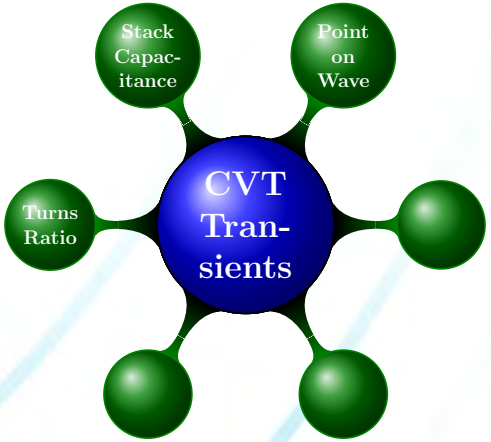
| | |
|---|---|
| High C | Low magnitude more duration |
| Low C | High magnitude less duration |

# CVT Transients : Cause 3 - Turns Ratio



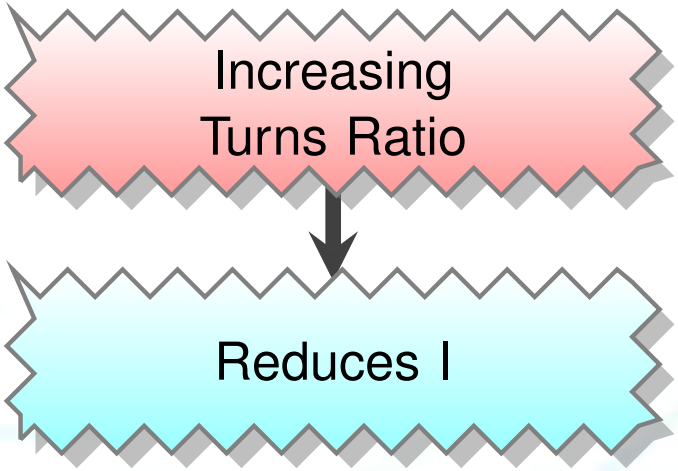

Increasing Turns Ratio

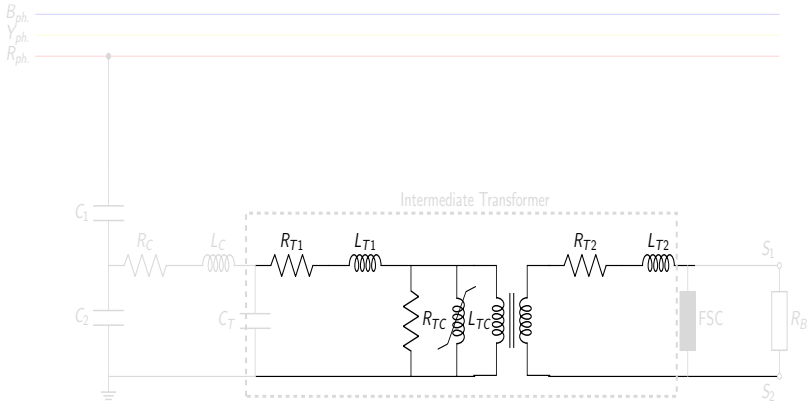
Detailed CVT model



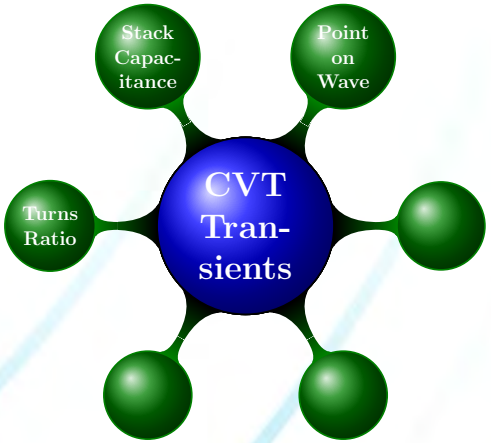

Causes

# CVT Transients : Cause 3 - Turns Ratio




Detailed CVT model




Causes

# CVT Transients : Cause 3 - Turns Ratio

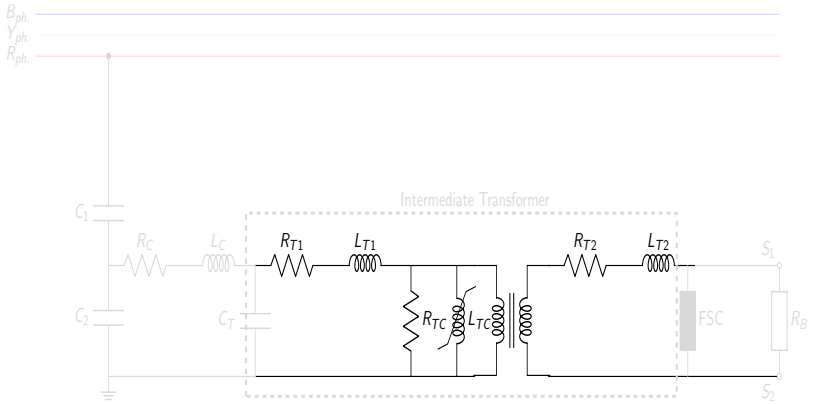
Increasing Turns Ratio

↓

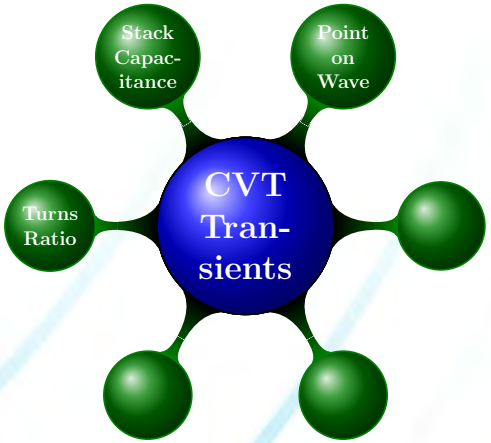
Reduces I

↓

Reduces $V = IX_C$

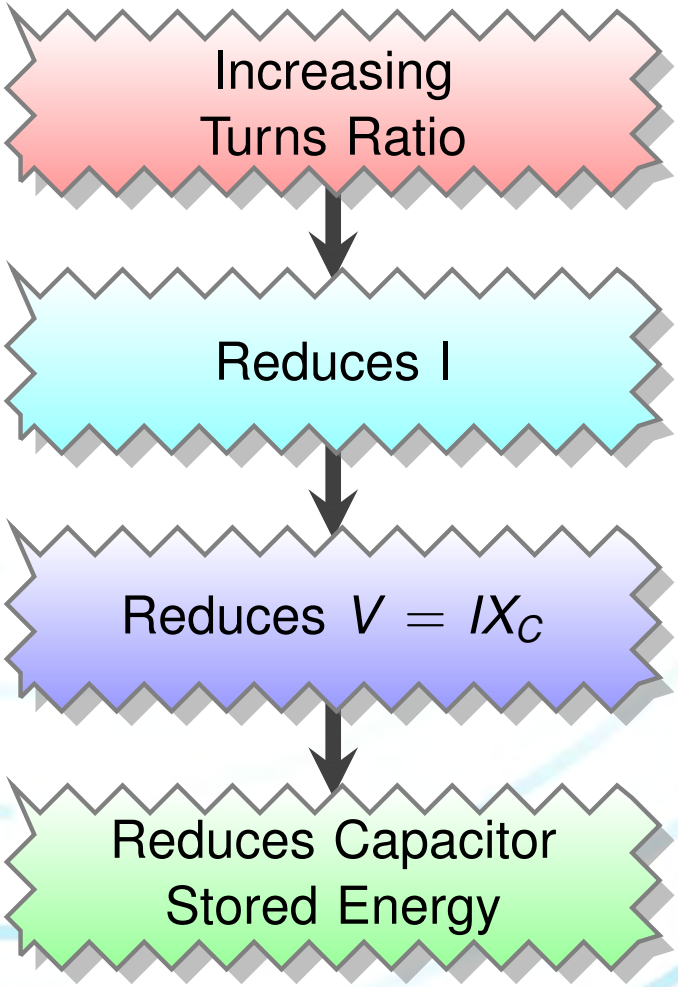


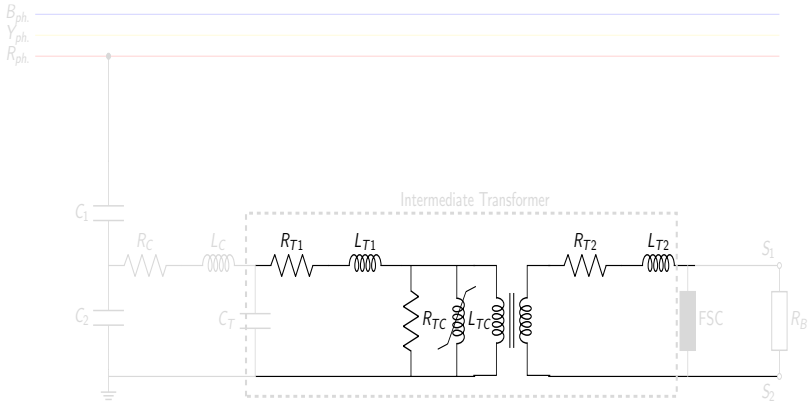

Detailed CVT model



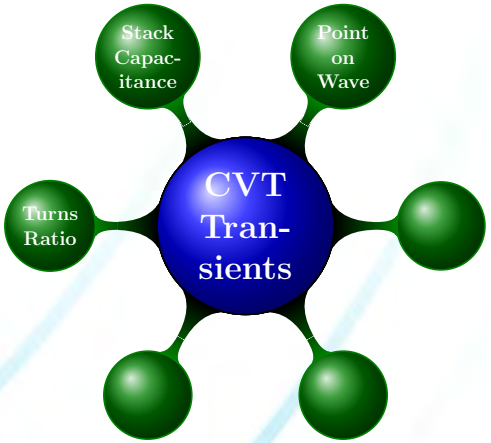

Causes

# CVT Transients : Cause 3 - Turns Ratio



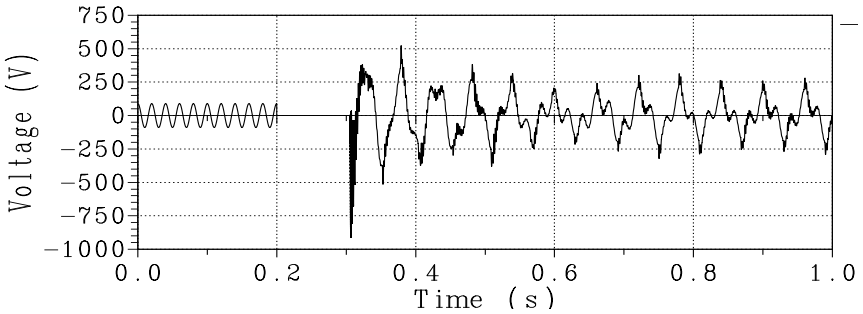




Detailed CVT model

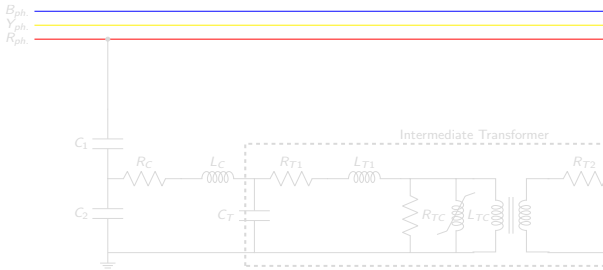



Causes

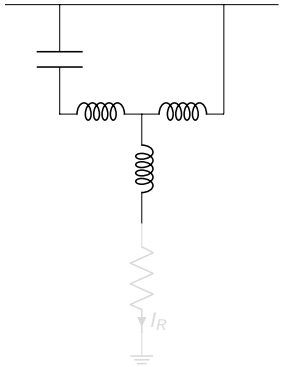
# CVT Transients : Cause 4 - Type 1 FSC



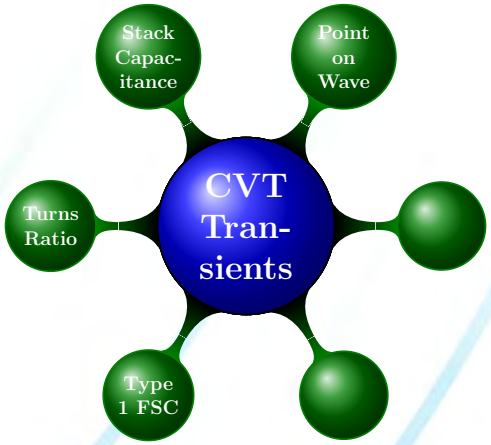

FSC test - Without FSC



Detailed CVT model

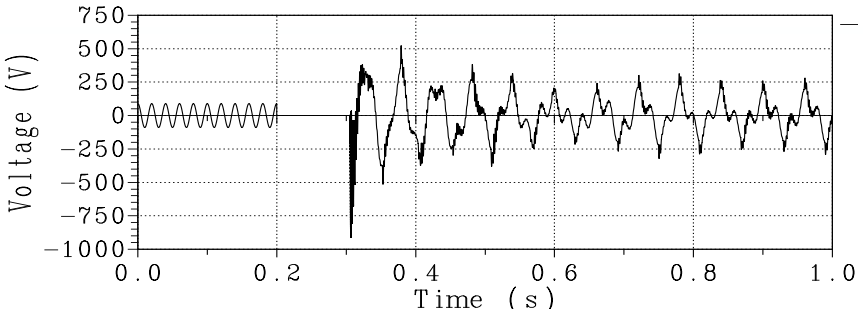


Type 1 FSC

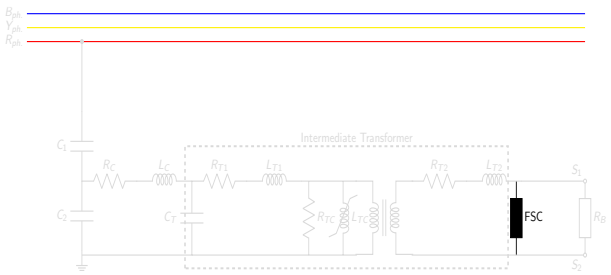



Causes

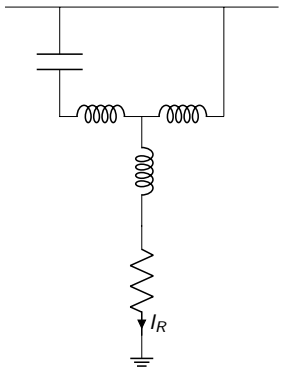
# CVT Transients : Cause 4 - Type 1 FSC

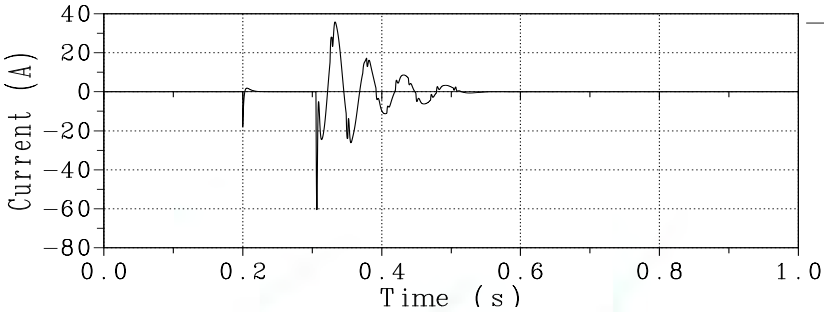



FSC test - Without FSC



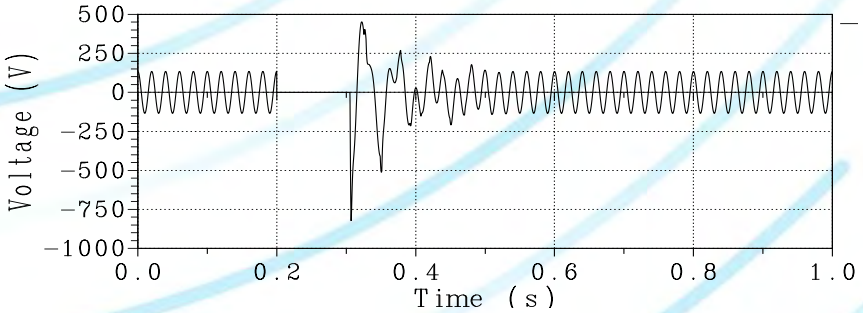

Detailed CVT model



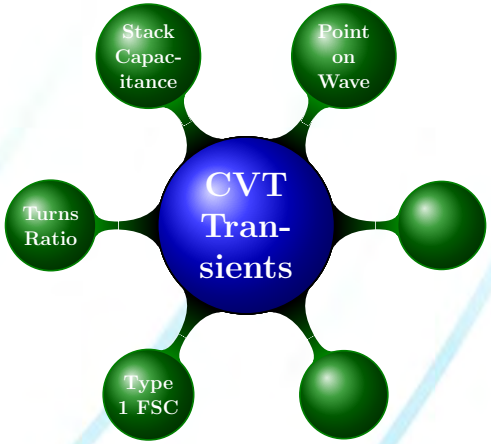




Current through resistor $I_R$

Type 1 FSC

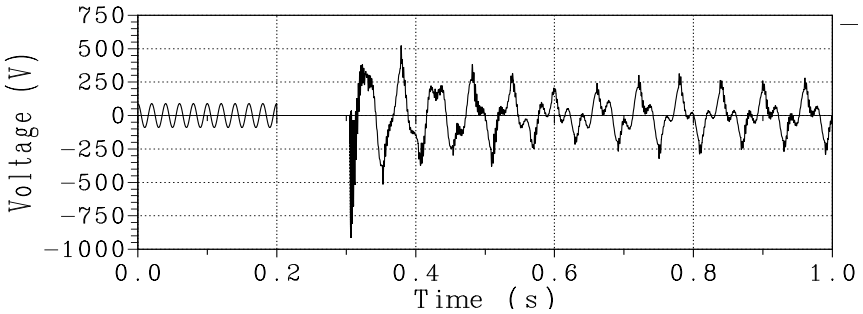



FSC test - With Type 1 FSC

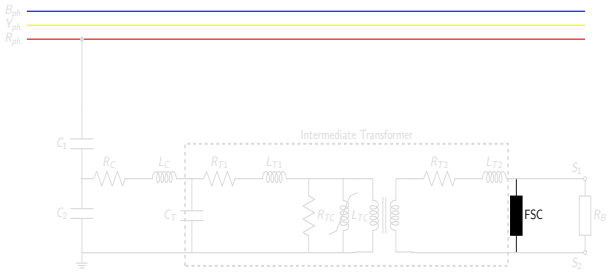



Causes

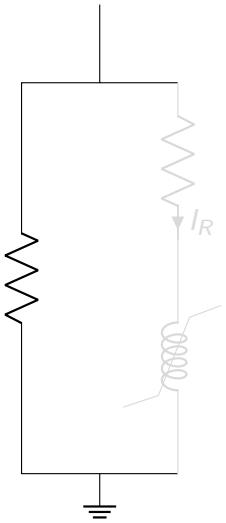
# CVT Transients : Cause 5 - Type 2 FSC



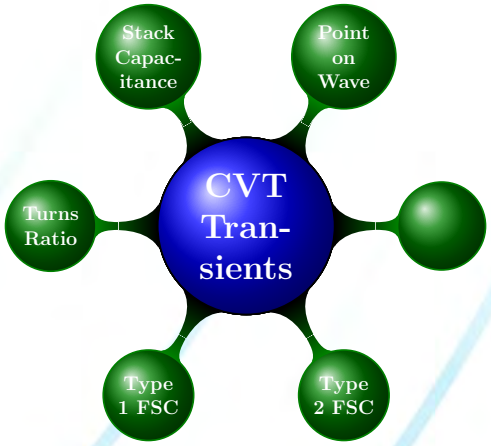

FSC test - Without FSC




Detailed CVT model

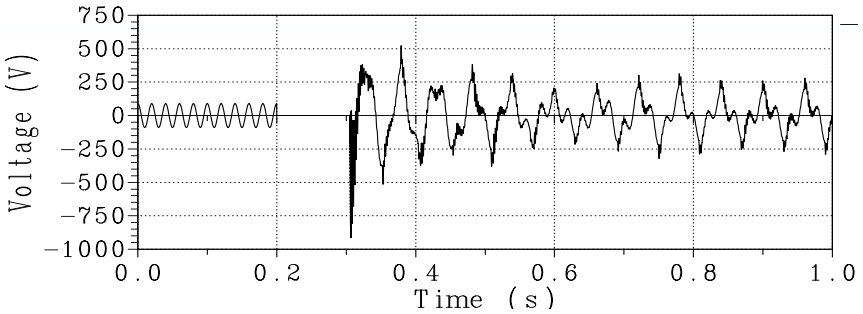



Type 2 FSC

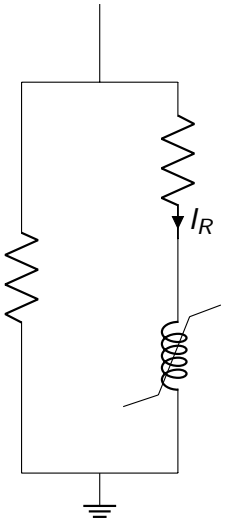


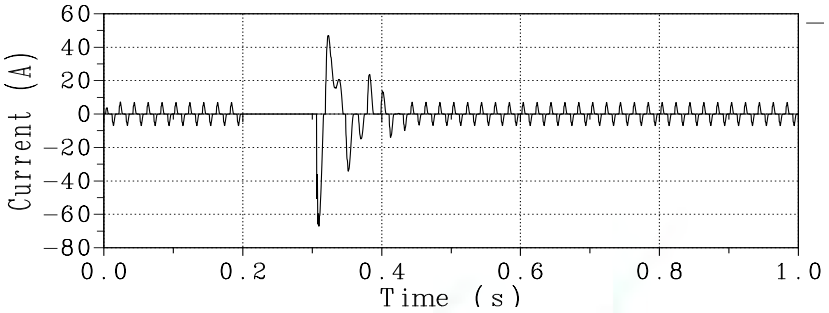

Causes

# CVT Transients : Cause 5 - Type 2 FSC

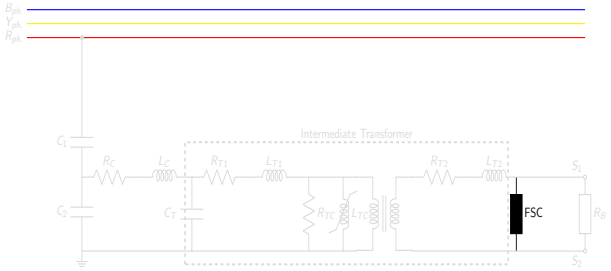



FSC test - Without FSC



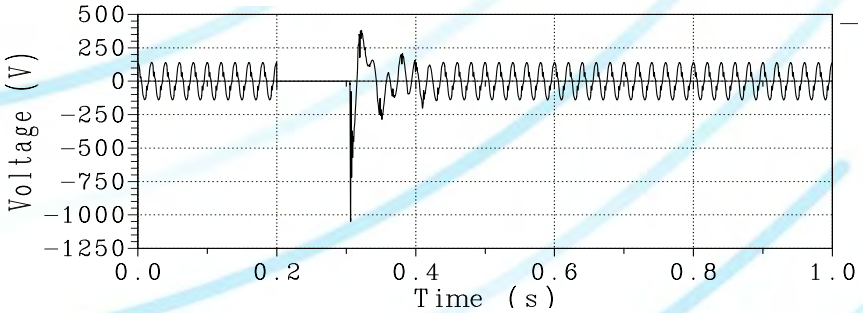




Current through resistor $I_R$

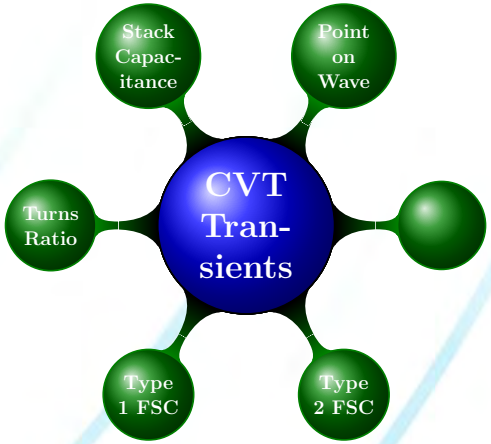



Detailed CVT model

Type 2 FSC

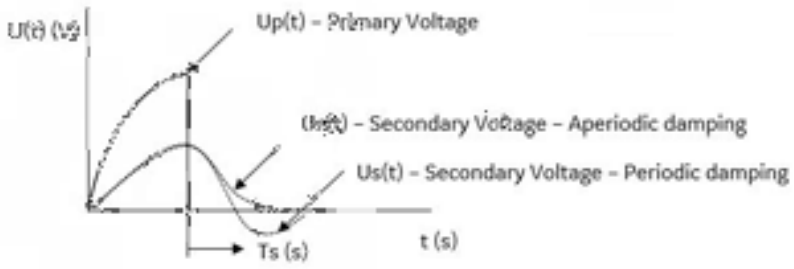



FSC test - With Type 2 FSC




Causes

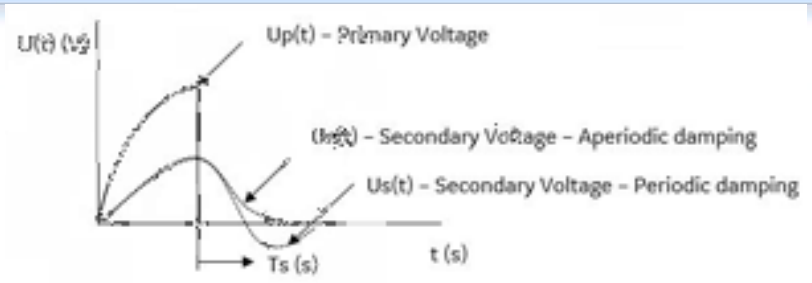
# CVT Transients : Transient Response Test Ratio (TSTR)




Transient response of CVT

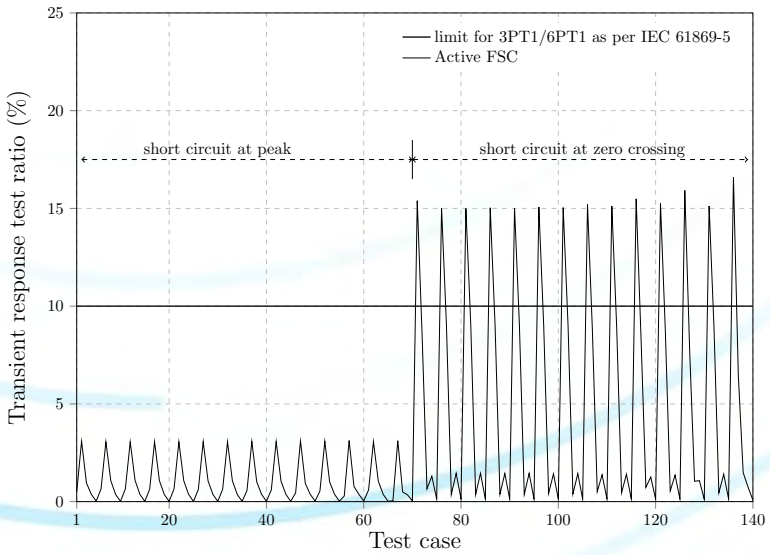
$$TSTR = \frac{|U_s(t)|}{\sqrt{2}U_s} \times 100\%$$

# CVT Transients : Transient Response Test Ratio (TSTR)

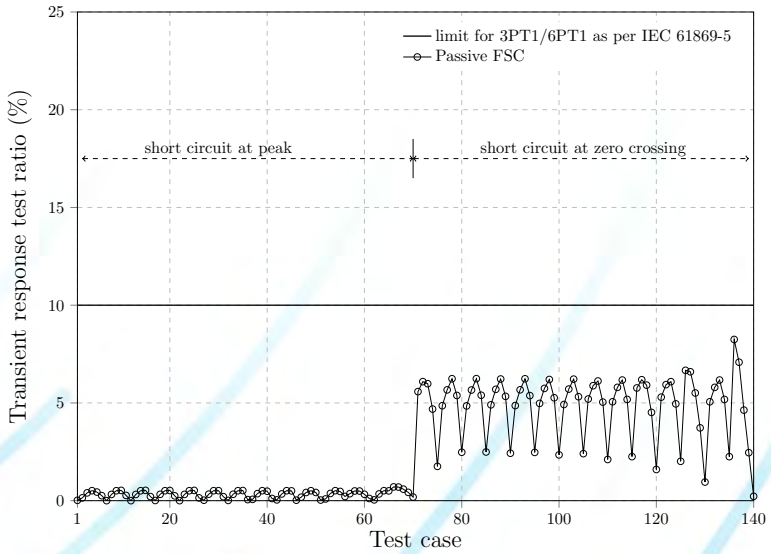



$$TSTR = \frac{|U_s(t)|}{\sqrt{2}U_s} \times 100\%$$

Transient response of CVT

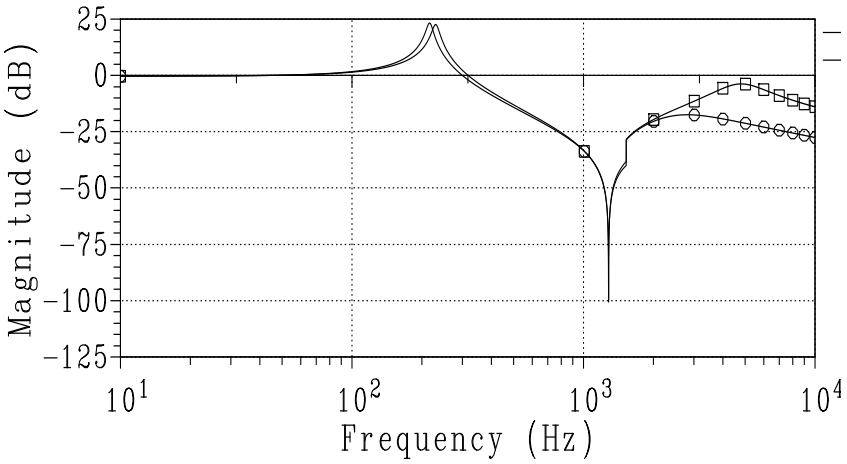



TSTR - Type 1 FSC

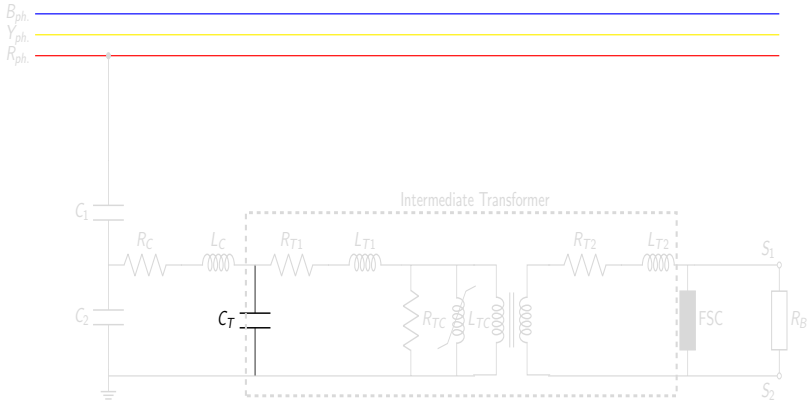



TSTR - Type 2 FSC

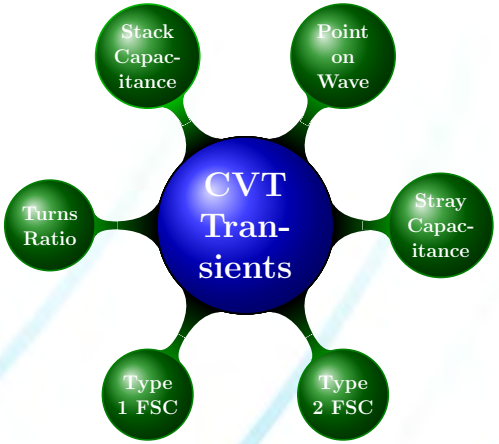
# CVT Transients : Cause 6 - Stray Capacitance




Impact of primary winding stray capacitance

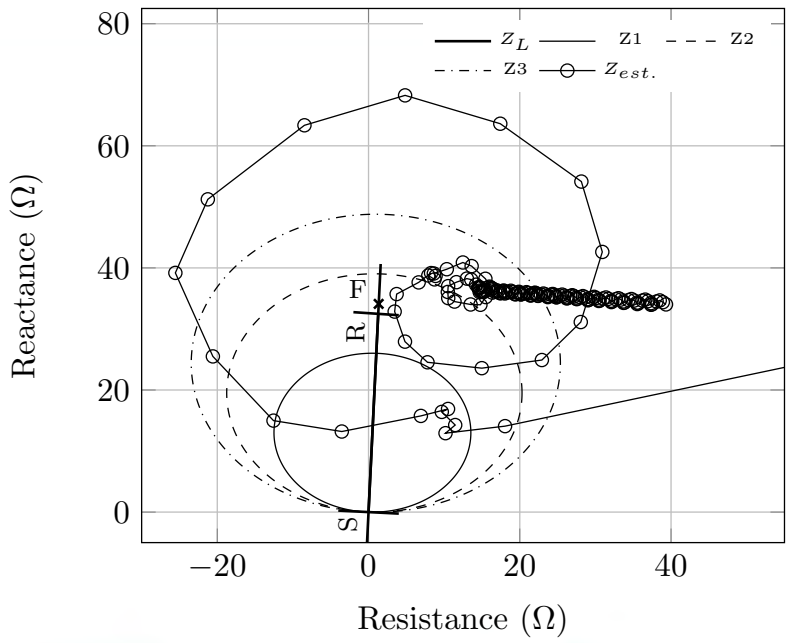



Detailed CVT model

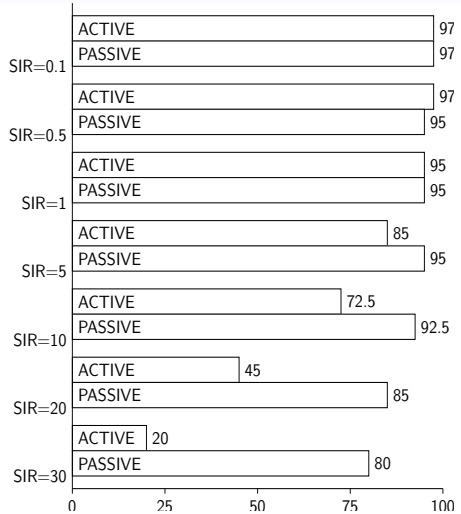



Causes

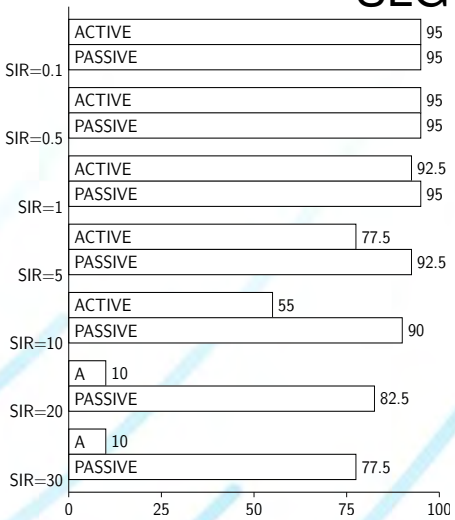
# CVT Transients : Effects



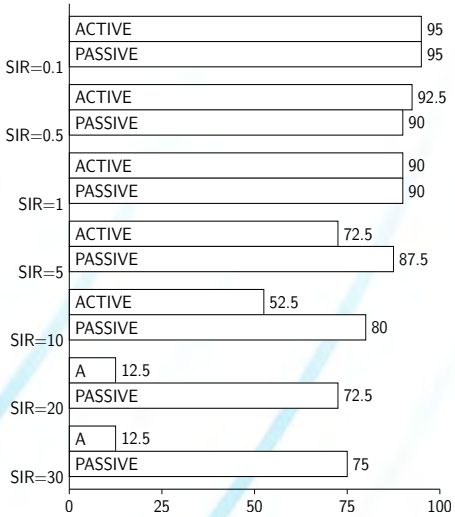

Impedance plot for SIR 30




SLG




LLG



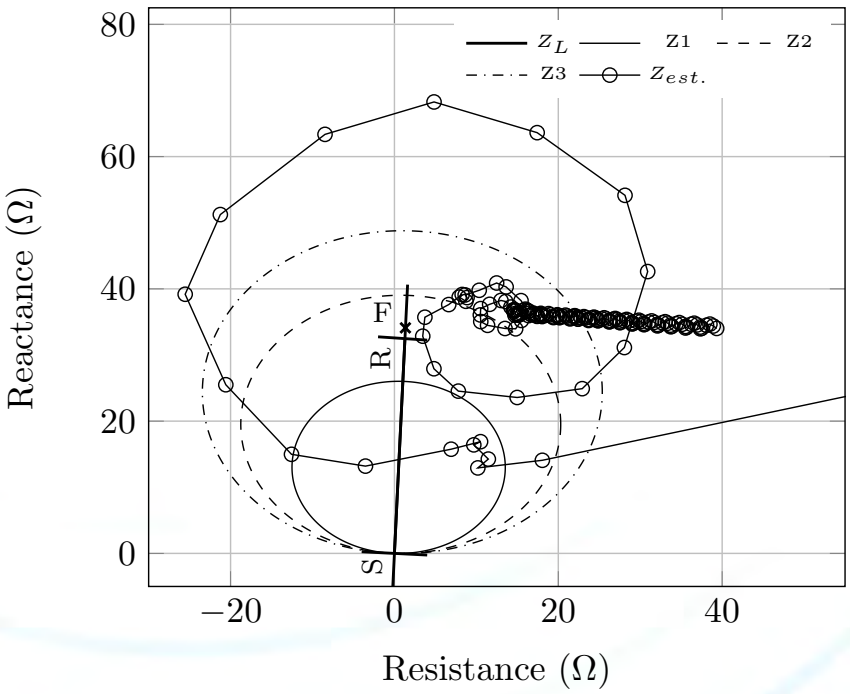

3PH

SLG — Single line to Ground Fault

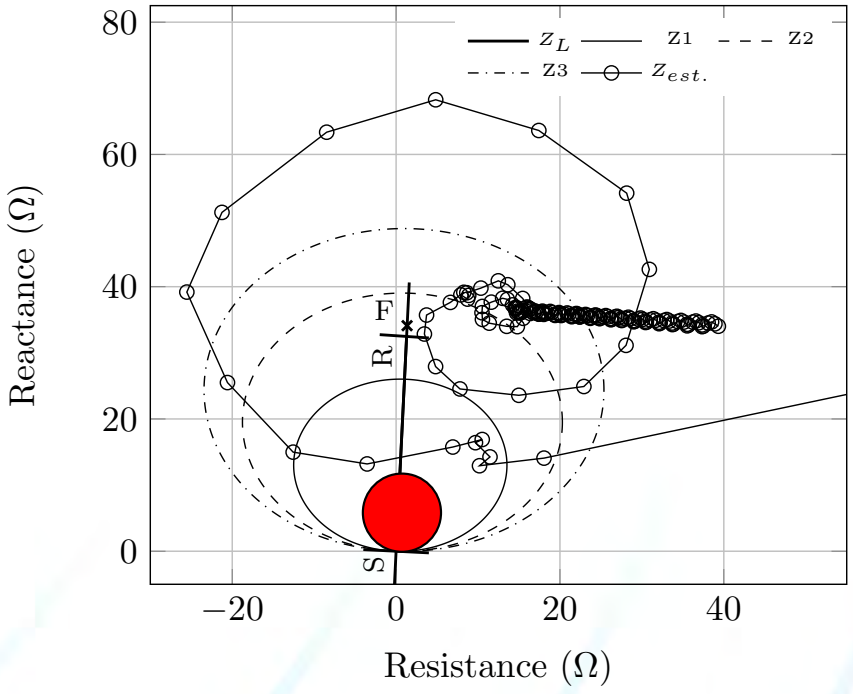
LLG — Line to line to Ground Fault

3PH — Three phase fault

# CVT Transients : Solution 1 - Reach Reduction

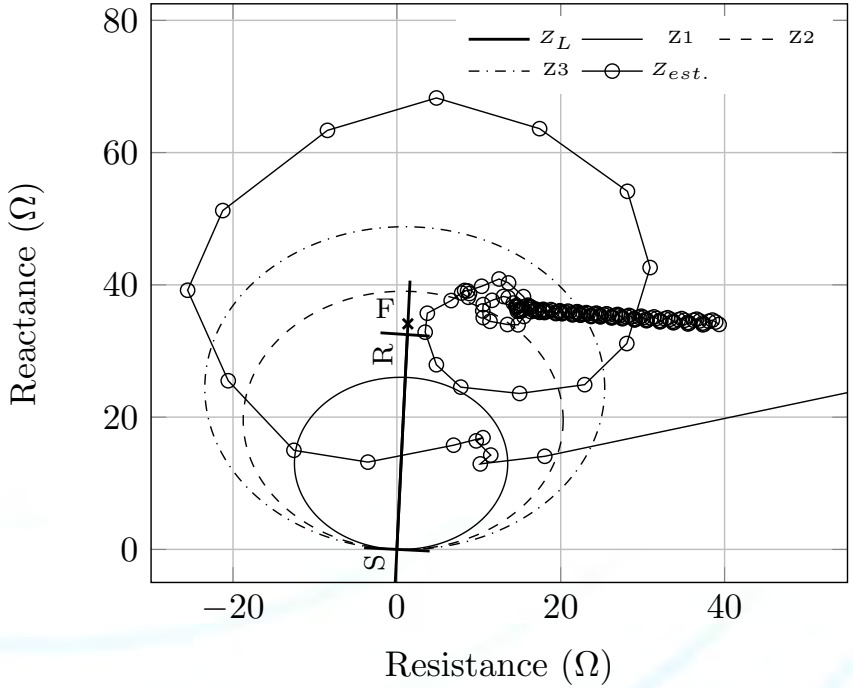



Impedance plot for SIR 30

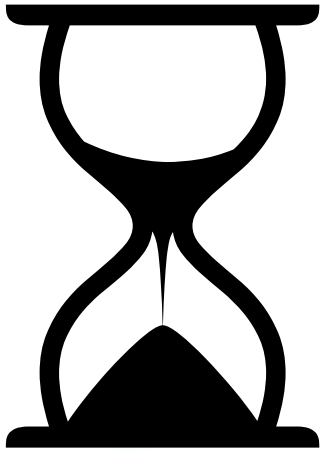



Reach reduction

# CVT Transients : Solution 2 - Fixed Time Delay

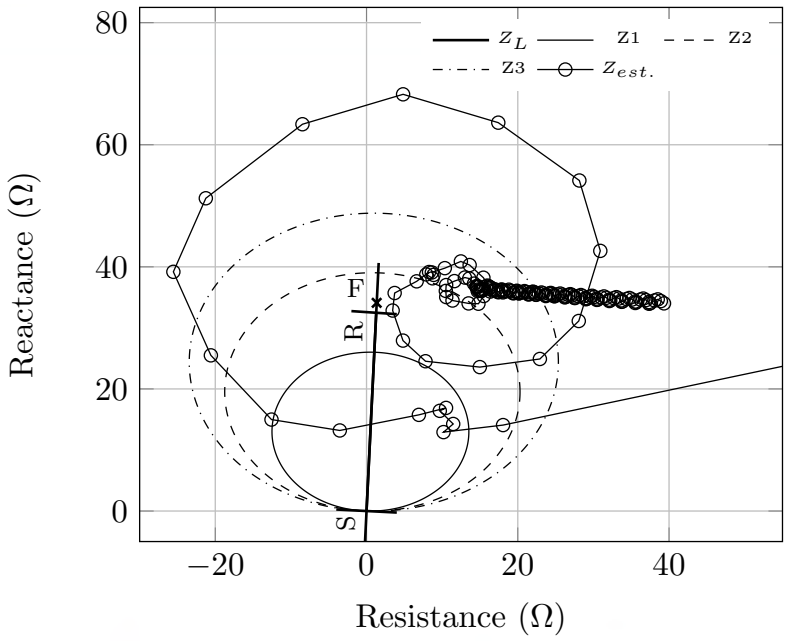



Impedance plot for SIR 30

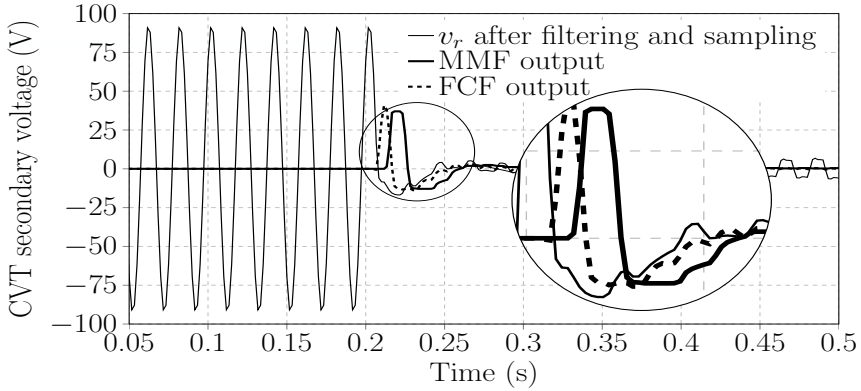


Fixed delay

# CVT Transients : Solution 3a - Adaptive Time Delay



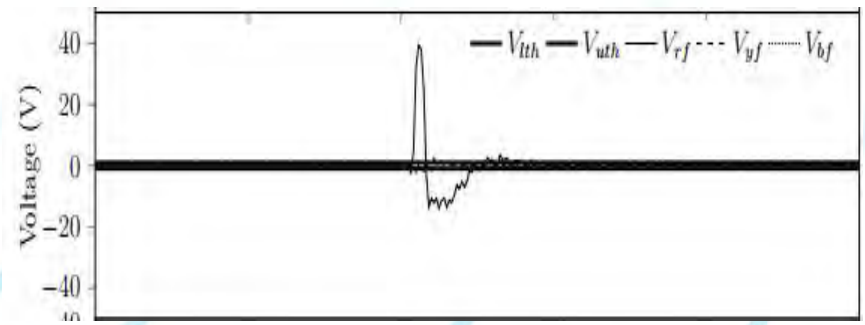

Impedance plot for SIR 30




Filtered information

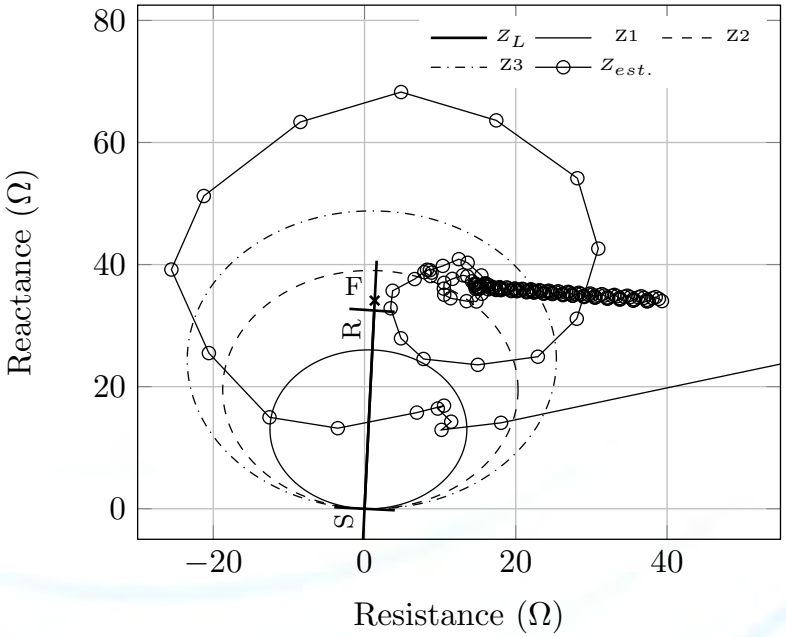
MMF — Mathematical Morphology

FCF — Feed Forward Comb Filter

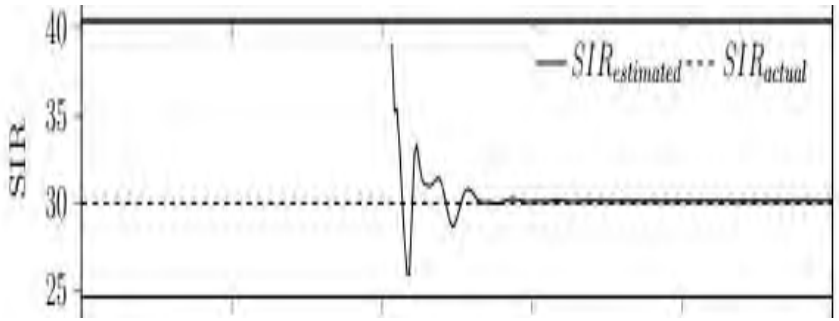



CVT Transient

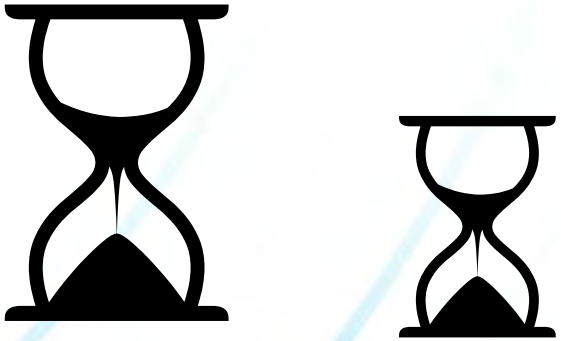
# CVT Transients : Solution 3b - Adaptive Time Delay




Impedance plot for SIR 30

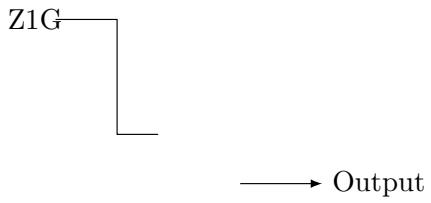


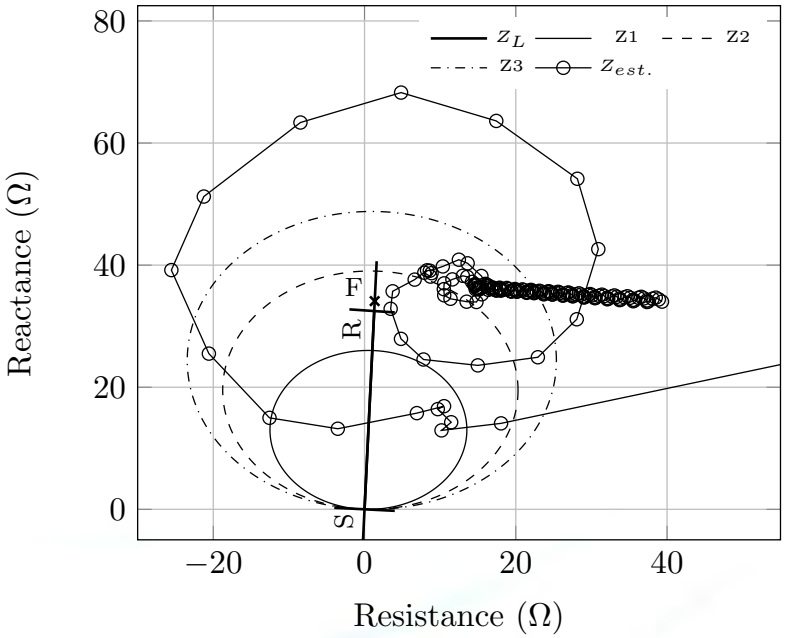

Estimated SIR



Adaptive delay

# CVT Transients : Solution 4 - Patented Technique 1



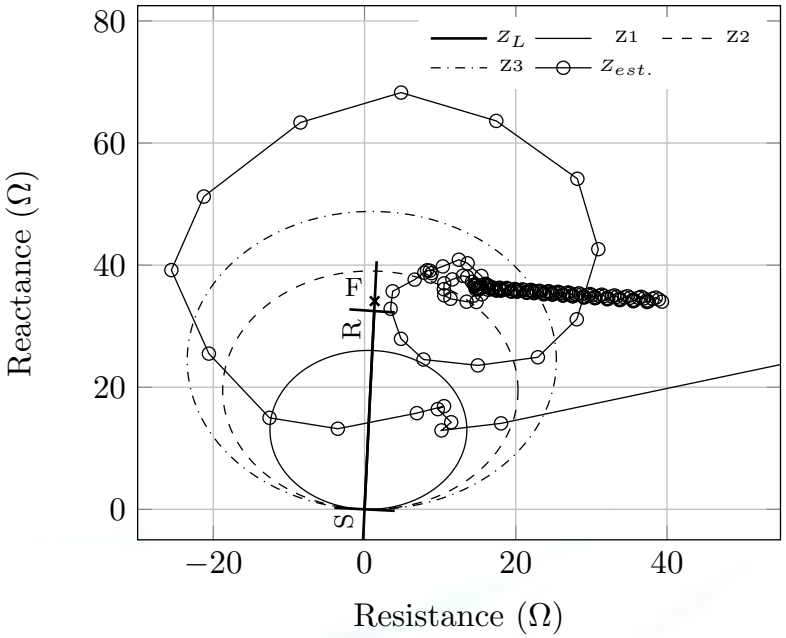




Impedance plot for SIR 30

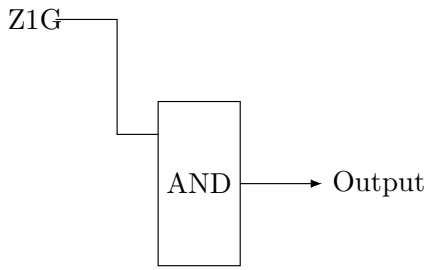
Patent

System for detection of transients in CVT

# CVT Transients : Solution 4 - Patented Technique 1



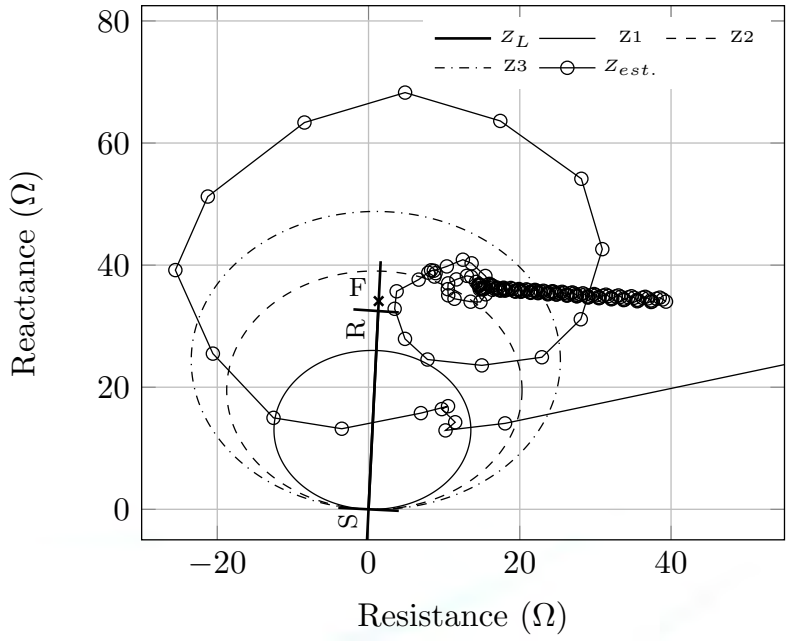

Impedance plot for SIR 30



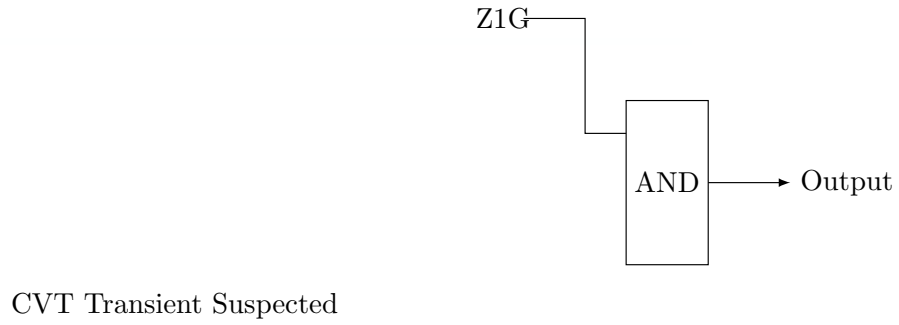

Patent

System for detection of transients in CVT

# CVT Transients : Solution 4 - Patented Technique 1



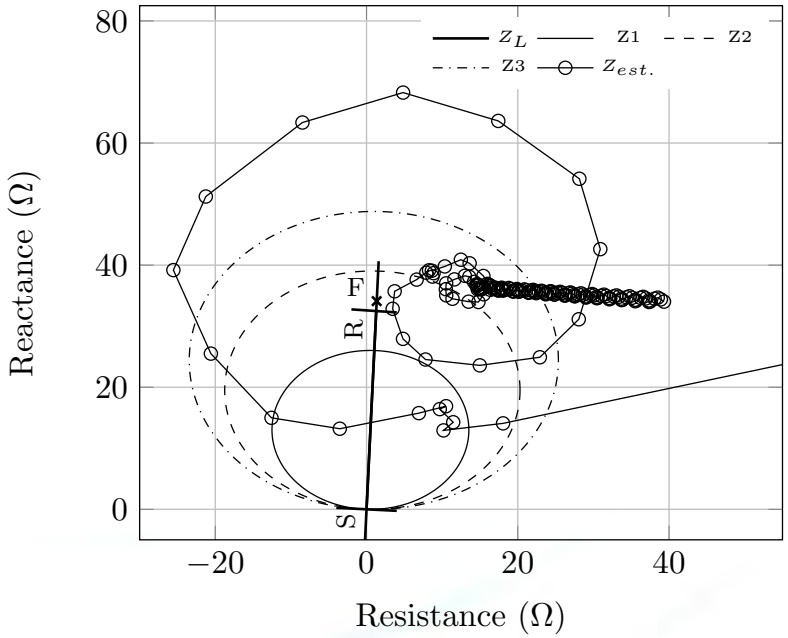

Impedance plot for SIR 30



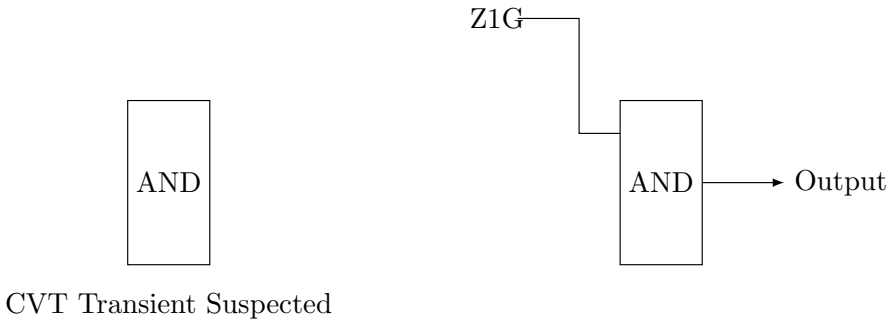

Patent

System for detection of transients in CVT

# CVT Transients : Solution 4 - Patented Technique 1



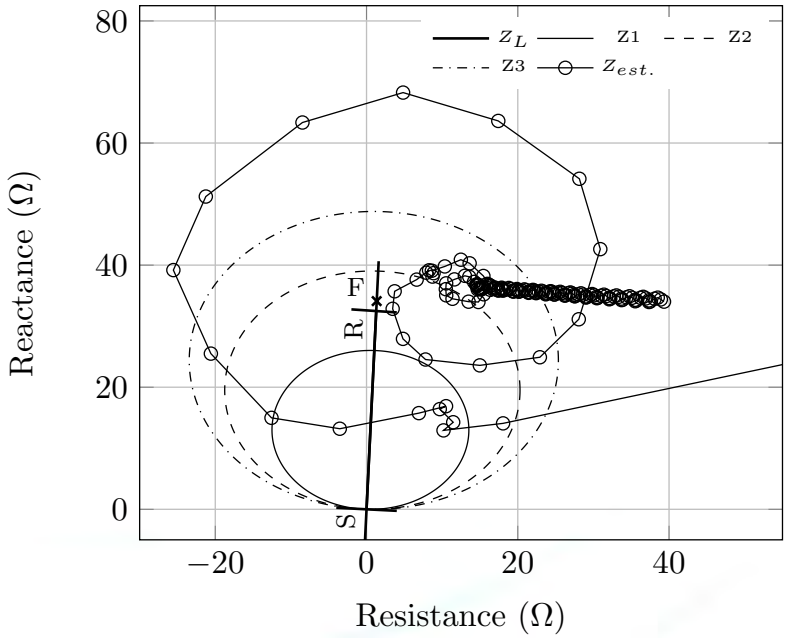

Impedance plot for SIR 30



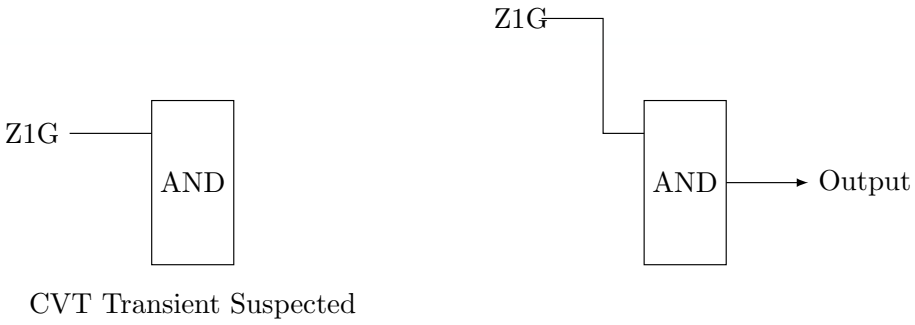

Patent

System for detection of transients in CVT

# CVT Transients : Solution 4 - Patented Technique 1



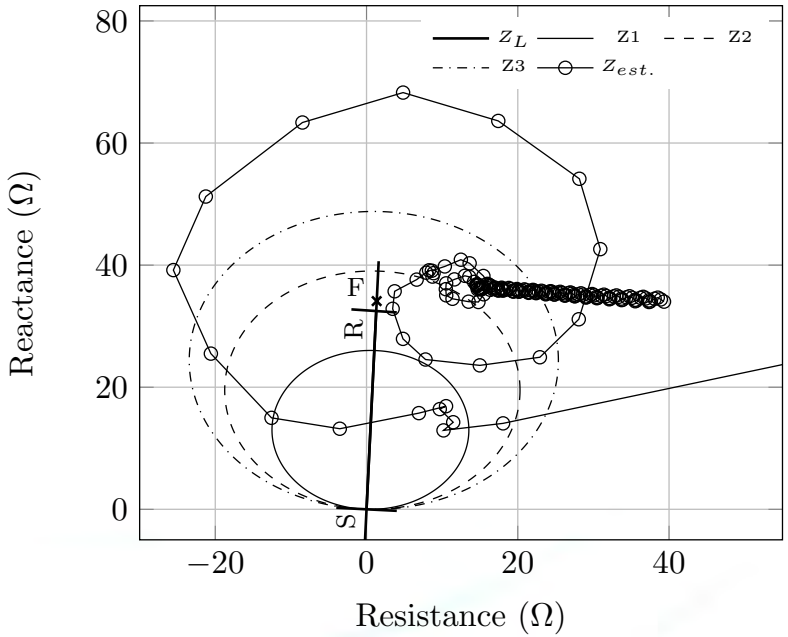

Impedance plot for SIR 30



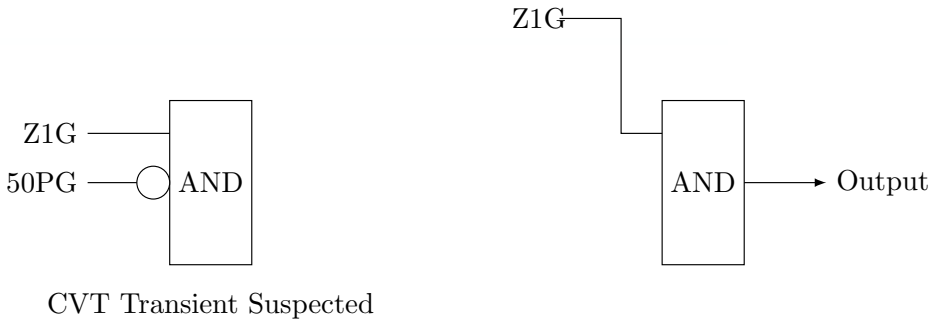

Patent

System for detection of transients in CVT

# CVT Transients : Solution 4 - Patented Technique 1



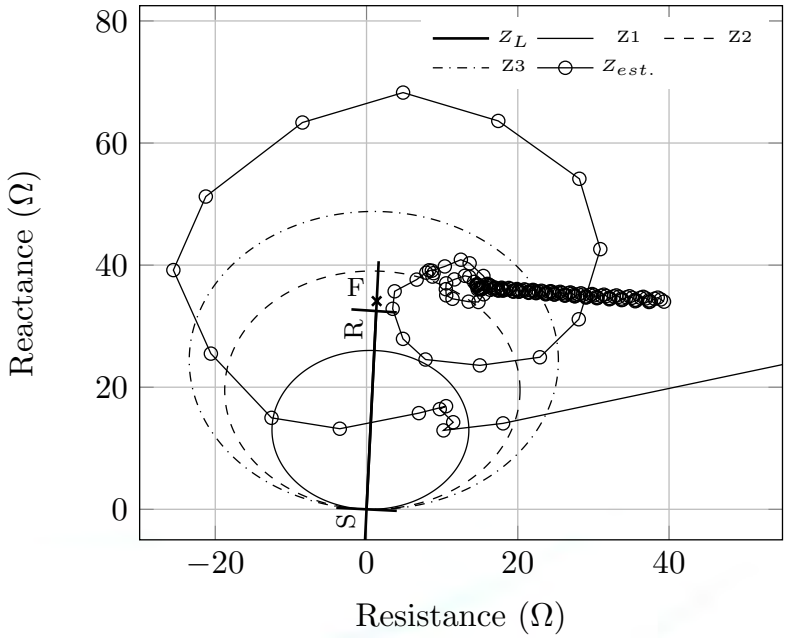

Impedance plot for SIR 30



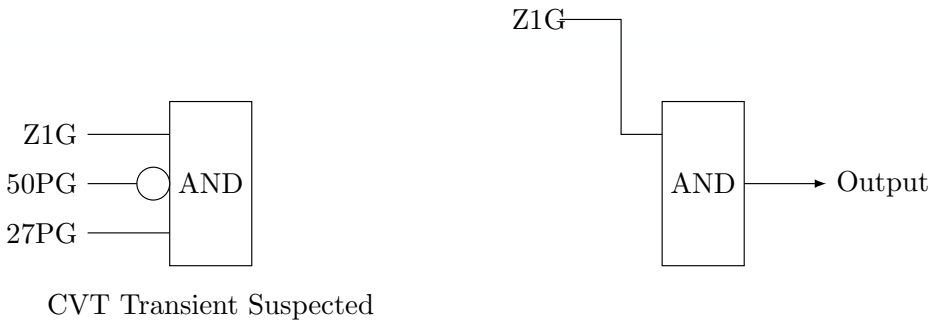

Patent

System for detection of transients in CVT

# CVT Transients : Solution 4 - Patented Technique 1



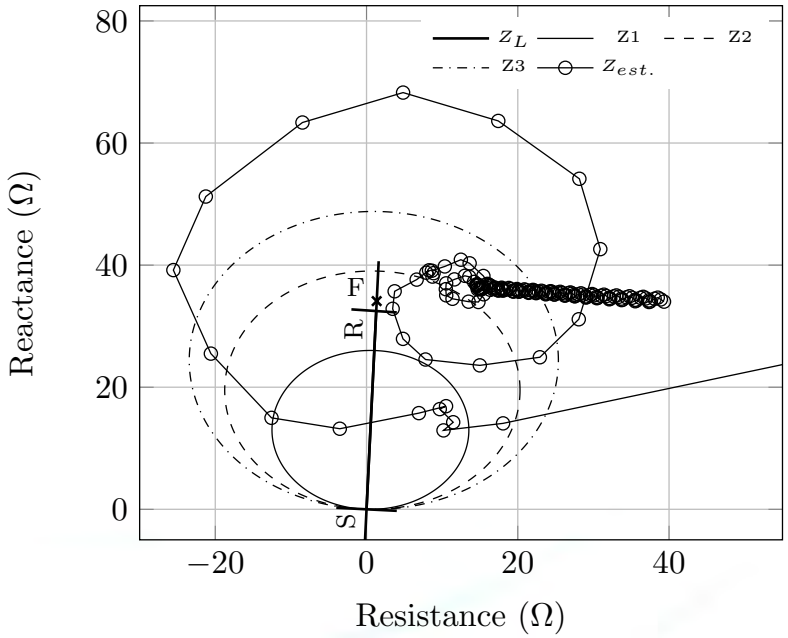

Impedance plot for SIR 30



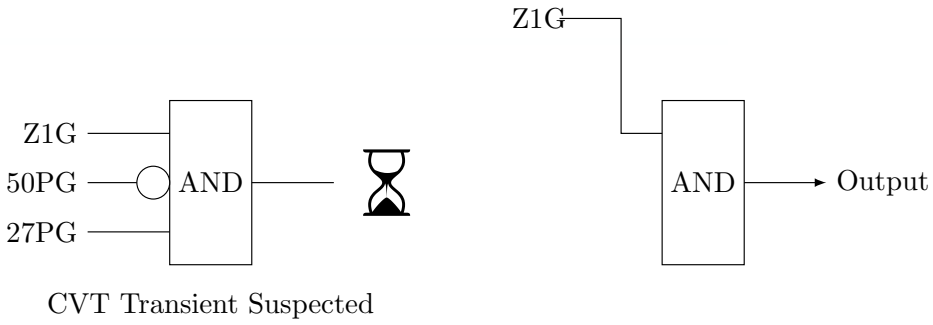

Patent

System for detection of transients in CVT

# CVT Transients : Solution 4 - Patented Technique 1



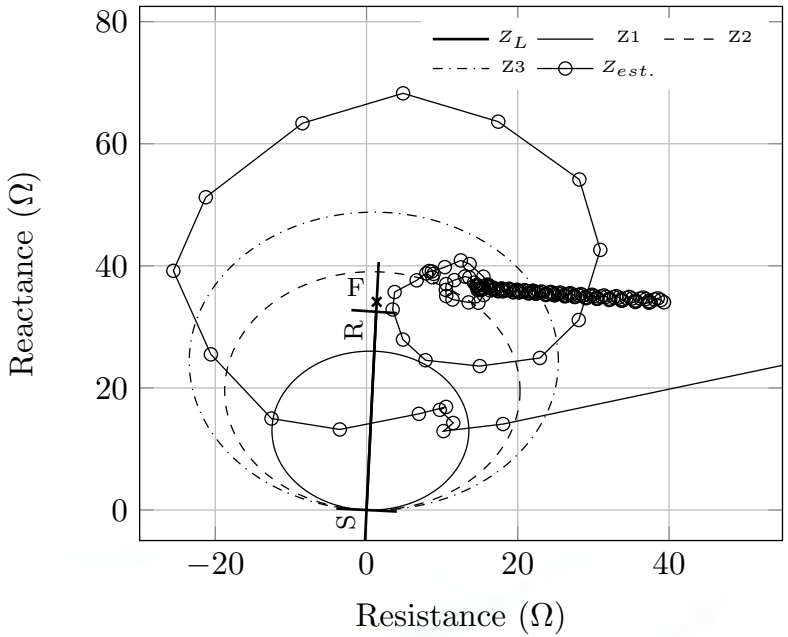

Impedance plot for SIR 30



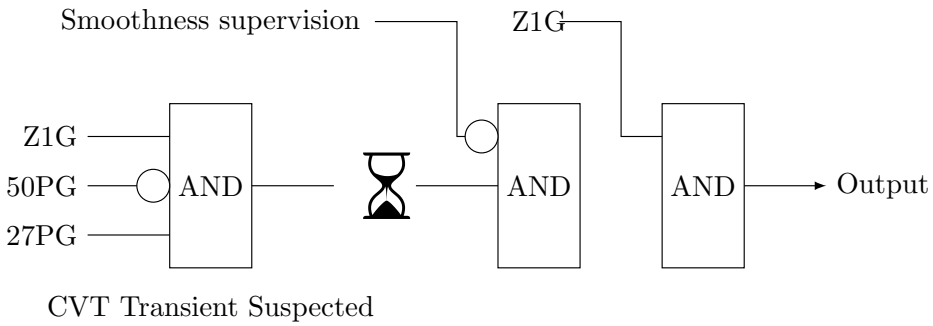

Patent

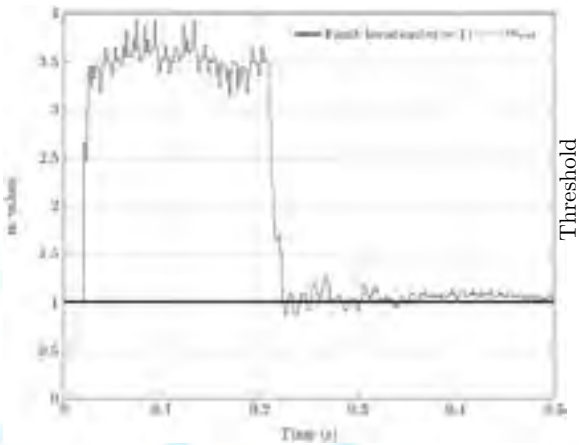
System for detection of transients in CVT

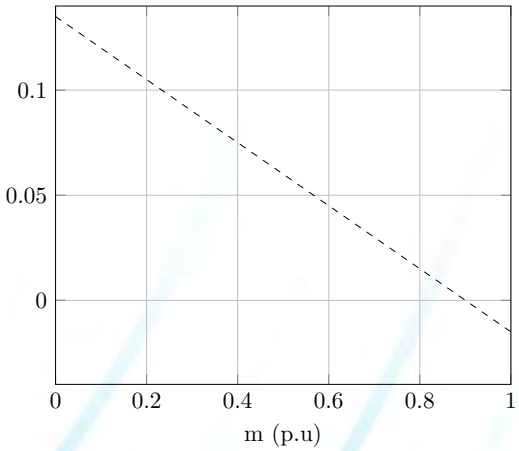
# CVT Transients : Solution 4 - Patented Technique 1




Impedance plot for SIR 30



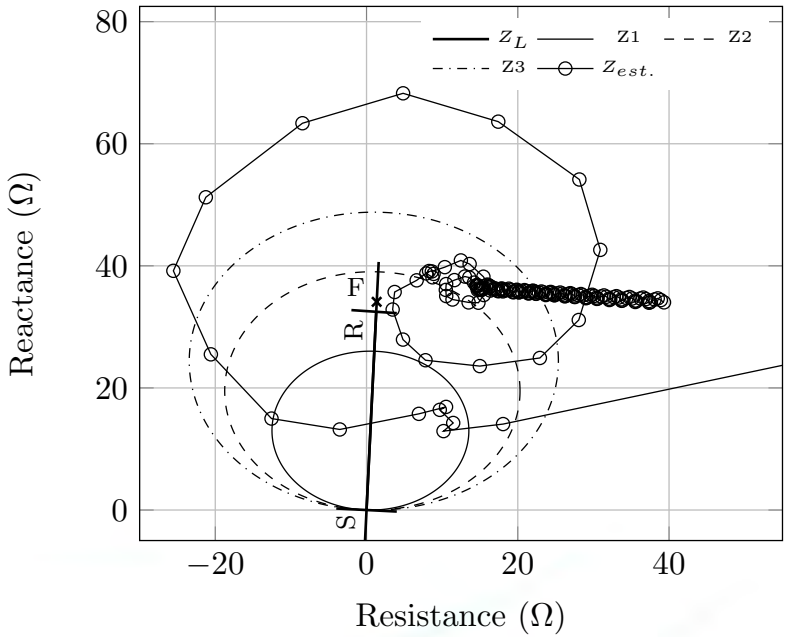





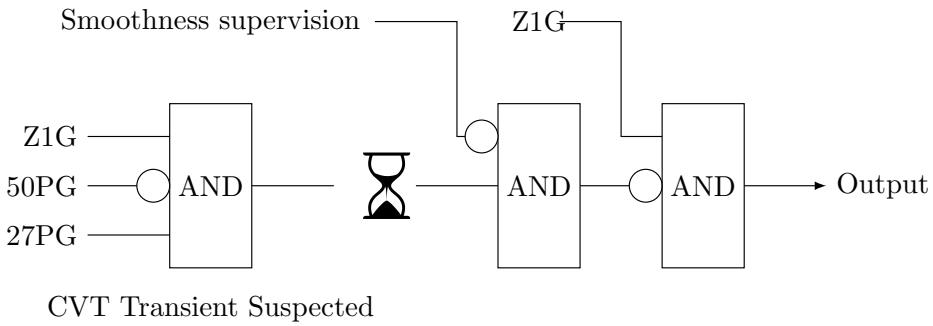

Patent

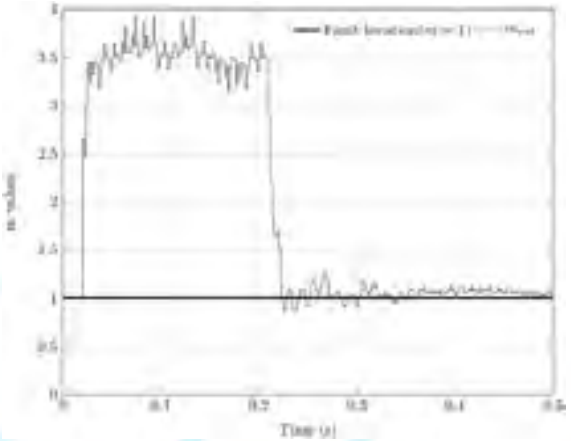
System for detection of transients in CVT

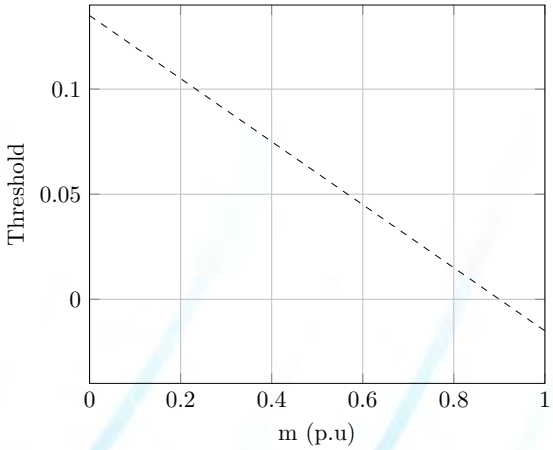
# CVT Transients : Solution 4 - Patented Technique 1




Impedance plot for SIR 30



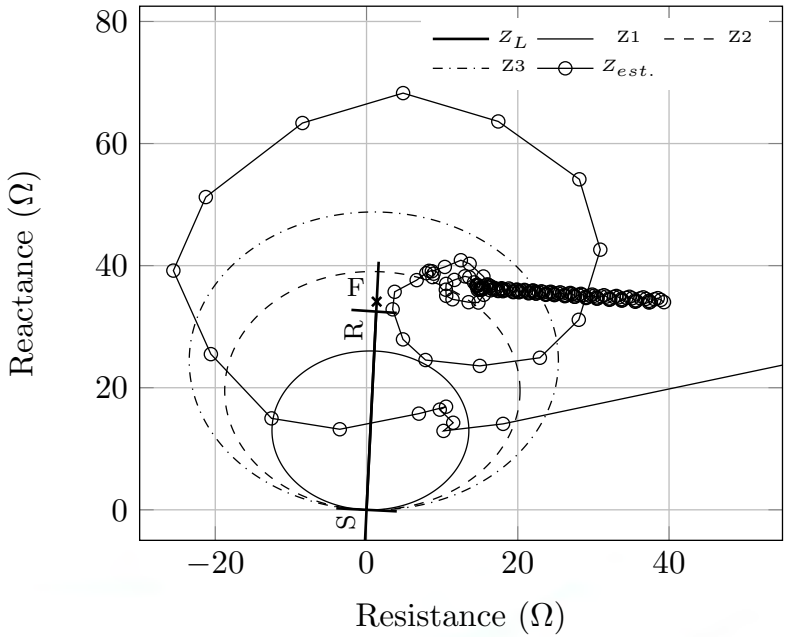





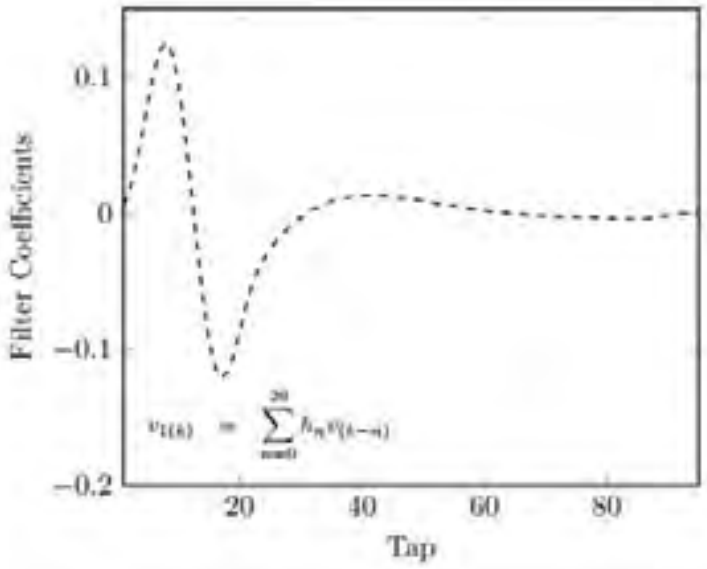

Patent

System for detection of transients in CVT

# CVT Transients : Solution 5 - Patented Technique 2



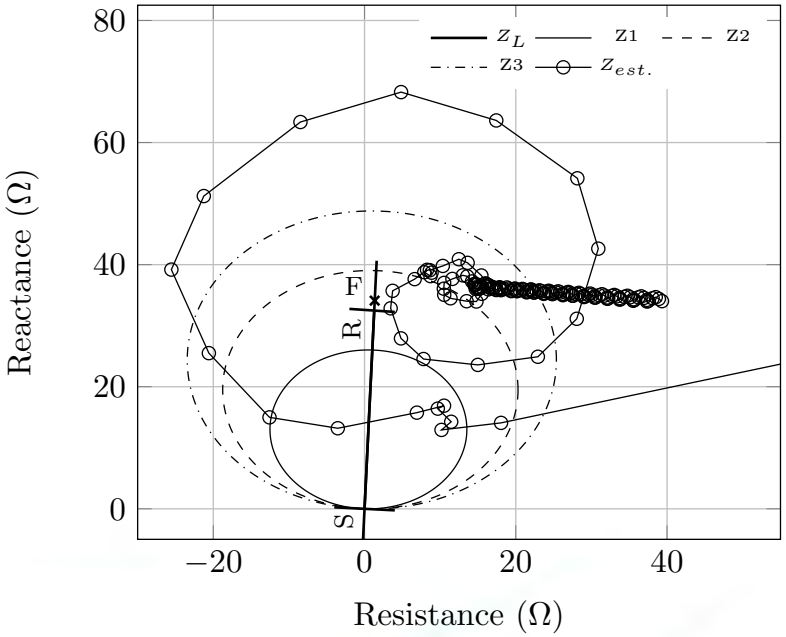

Impedance plot for SIR 30



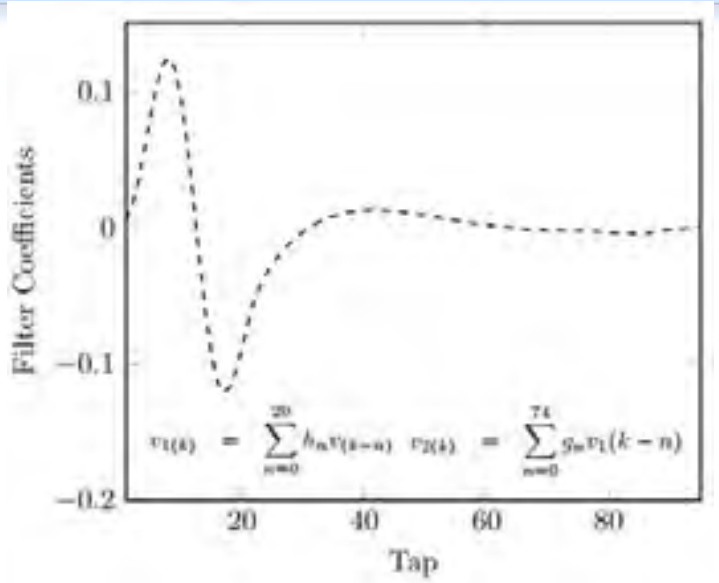

Patent

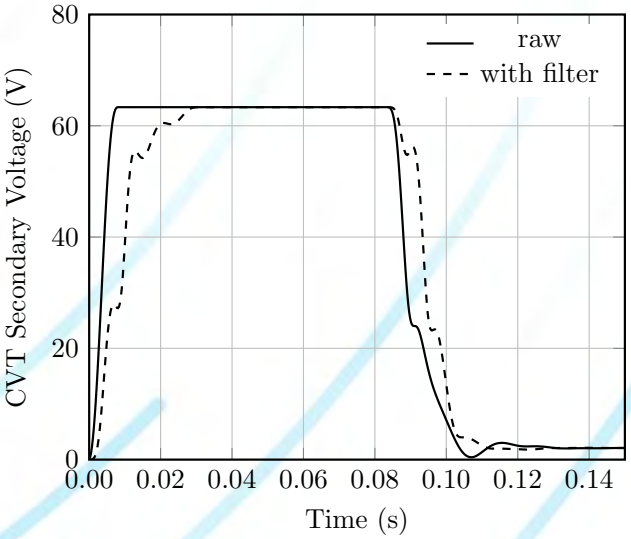
CVT transient filter

# CVT Transients : Solution 5 - Patented Technique 2




Impedance plot for SIR 30




Patent

CVT transient filter

Thank You

Questions?