Many thanks to Emmanuele, Michal, Federica and the GSI-team for the support!

Transients in SIS100 - Simulation at CERN

Dimitri Delkov

02.07.2020

1. Introduction to the Project
2. SIS 100 Circuit
3. Controller in PSpice for Power Supply
4. Simulation Results
5. Conclusion and Further Work

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1. Introduction to the Project

Collaboration with CERN and GSI/FAIR

GSI-Team:

Department: Superconducting Magnets (SCM)

- Group: Magnet Electrical Systems (MES)

Group Leader: Piotr Szwangruber

Employee: Vivien Raginel,

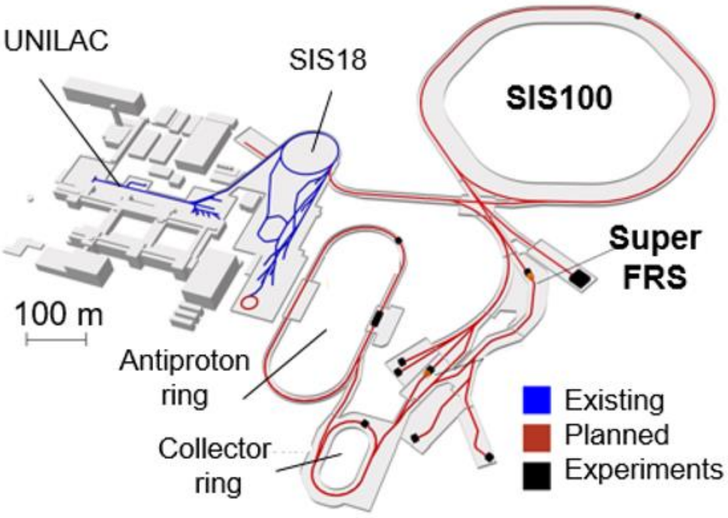
Two years project to investigate the transients in the new accelerator (SIS100 Circuit).

1. Introduction to the Project

FAIR: Facility for Antiprotonand Ion Researach.

Three acceleration levels:

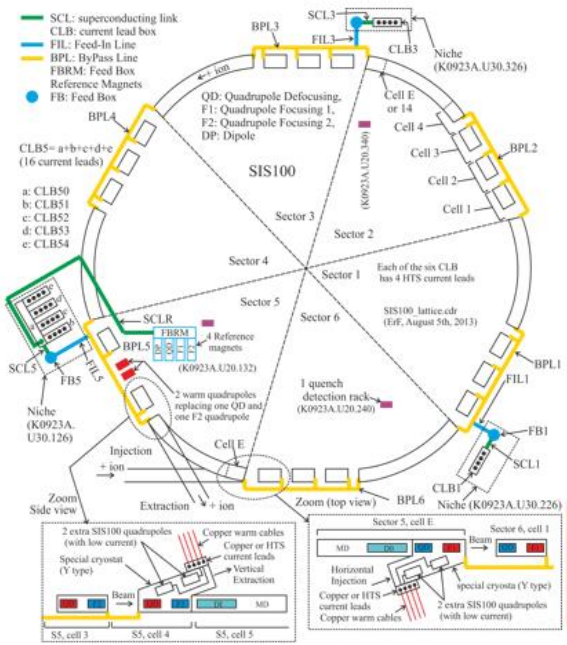
1. UNILAC (linear accelerator), 20% speed of light
2. SIS18 (ring accelerator), 90% speed of light
3. SIS100 (ring accelerator)



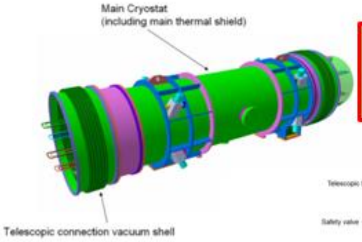
Source: GSI, Piotr presentation at GSI meeting

1. Introduction to the Project

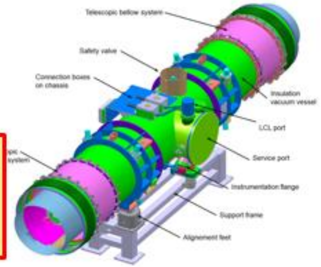
SIS100 = **S**chwer**i**onen**s**ynchrotron 100 [Tm] = Heavy ion synchrotron (beam rigidity*) 100 [Tm]



- Hexagonal, circumference 1083.60 m
- Superconducting (magnet) accelerator
- Max. dipole field 1.9 T
- Ultra High Vacuum (10-11mbar)
- Adsorption by cold vacuum chamber (10 – 15 K)



Dipole Module
- dipole magnet
- BB system



Quad. Doublet Module
- 2 x quad
- BB system
- Corr. magnets

Source: GSI, Piotr presentation at GSI meeting

The SIS100 circuit is not a perfect ring.

- linear and
- curved parts

1. Introduction to the Project

Construction

Private photo, 19.02.2020

1. Introduction to the Project

Accelerator	Circumference (km)	B_{dipole} (T)	$B\rho$ (T·m)	$\frac{dB_{\text{dipole}}}{dt}$ (T/s)	Years of operation
Tevatron	6.300	4.4	$3.3 \cdot 10^3$	0.29	1987-2011
HERA	6.336	4.682	-	0.007	1992-2007
Nuclotron	0.252	1.98	45	2	1993-
RHIC	3.834	3.45	839.5	0.07	2000-
LHC	27	8.36	$23 \cdot 10^3$	0.008	2009-
SIS100	1.0836	1.9	100	4	2026-
SIS300	1.0836	4.5	300	1	-

Source: GSI, Piotr presentation at GSI meeting

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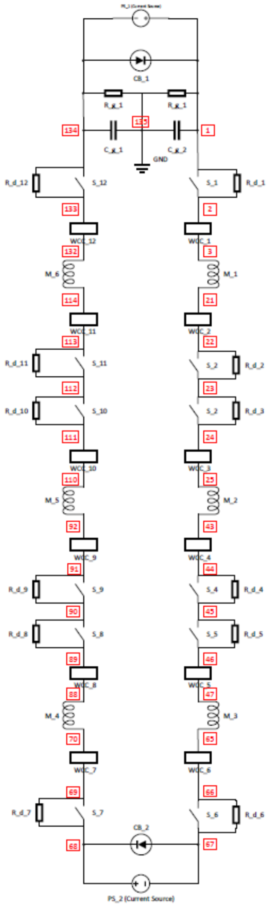
2. SIS100 Circuit

The circuit contains of

- 12 Energy Extraction Systems
- 2 Power Supplies
- 6 Magnet Packets (18 Magnets)
- 2 Crowbars
- 2 Gronding Resistors
- 2 Grounding Capacitors
- 12 WCC Cable Models



$M \cong Magnets$

$PS \cong Power\ Supply$

$CB \cong Crowbar$

$Rd \cong Resistor\ and\ Protection\ System$

$R_{WCC} \cong Resistor\ Water\ Cooled\ Cable$

$Rg \cong Grounding\ Resistor$

$C_{WCC} \cong Capacitor\ Water\ Cooled\ Cable$

$C_g \cong Grounding\ Capacitor$

2. SIS100 Circuit

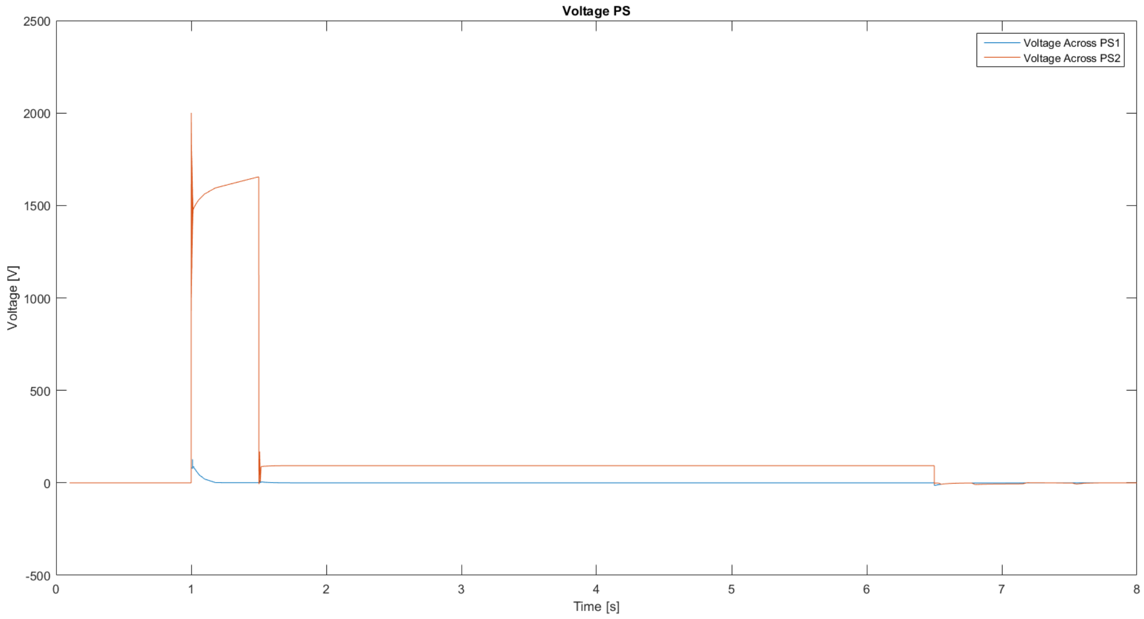
List of Parameters

Parameters	Value	Unit
Current I_n	13.2	kA
Grounding Resistor R_g	≈ 10	kΩ
Inductance of one Magnet L_m	0.55	mH
Resistor EE R_d	67	mΩ
Resistor WCC1	0.425	mΩ
Resistor WCC2	0.3	mΩ
Capacitor WCC1	$4.24 \cdot 10^{-8}$	F
Capacitor WCC2	$3 \cdot 10^{-8}$	F
Grounding Capacitor C_g	$\approx 5 \cdot 10^{-6}$	F
Capacitance Magnet C_m	$\approx 10 \cdot 10^{-9}$	F

CERN

2. SIS100 Circuit

Power Supply Problem in PSpice



- The two voltages across the current power supplies are different
- In reality the voltages should be almost same

<u>Conclusion:</u>
PSPICE do not know how to distribute the voltage!

<u>Possible solution:</u>
Replace the current source through a voltage source.

2. SIS100 Circuit

Power Supply Problem in PSpice

1. Approach: Approximate the voltage source trough

$$V = R \cdot i + L\frac{di}{dt}.$$

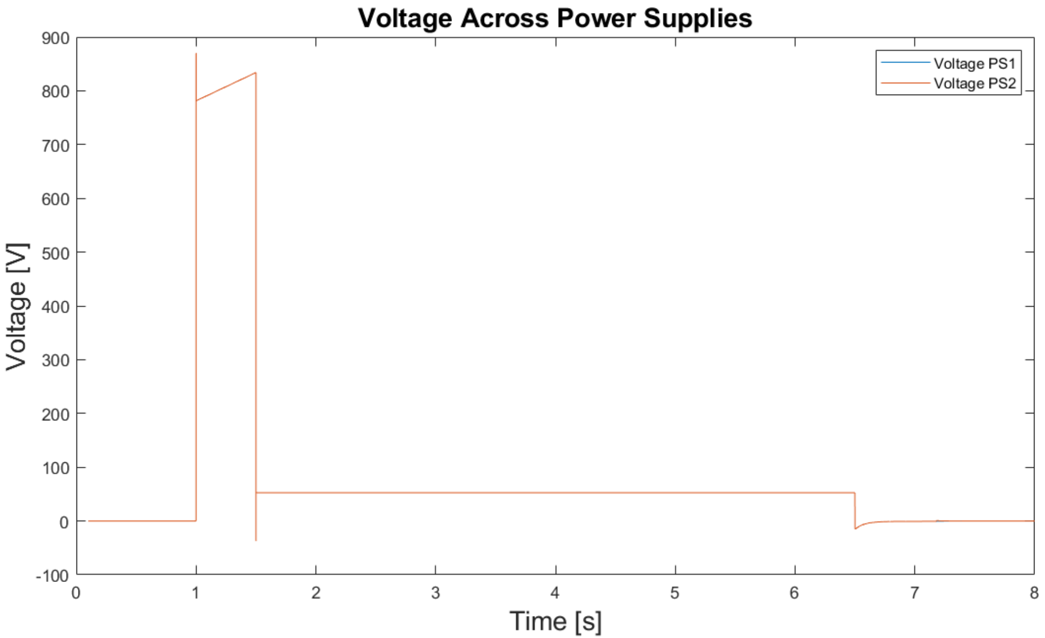
The resistance R and the inductance L are calculated with the formulas

$$R = R_{warm} + 4R_{WCC1} + 8R_{WCC2} + 12\left(50\mu\Omega + \frac{R_{Branch}}{3} + 50\mu\Omega\right)$$

$$L = 108 \cdot L_{magnet} + 12\left(10\mu H + \frac{L_{Branch}}{3} + 10\mu H\right).$$

2. SIS100 Circuit

Power Supply Problem in PSpice

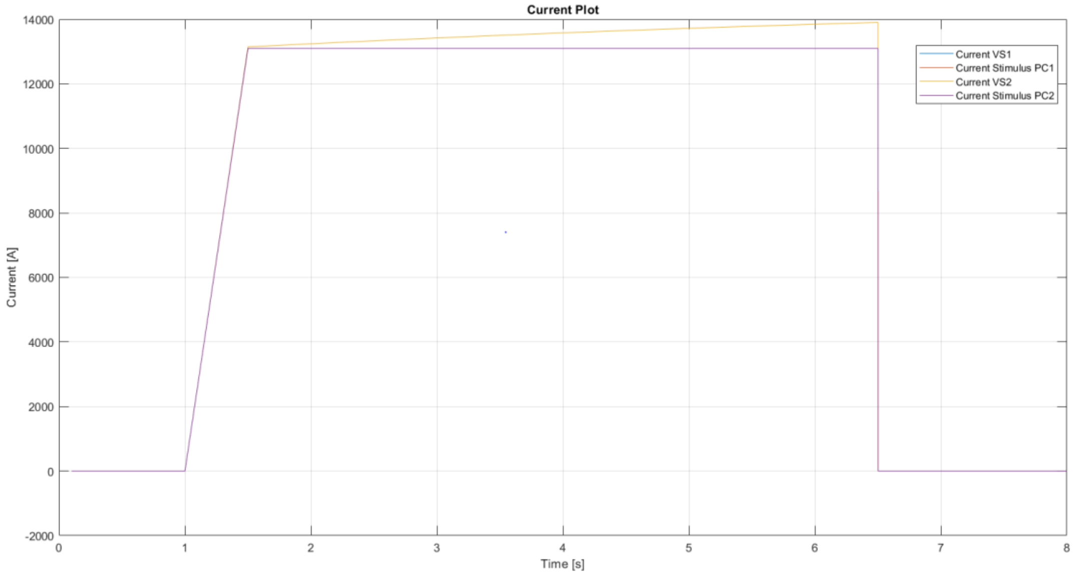


– The two voltages across the current power supplies are now quite the same

2. SIS100 Circuit

Power Supply Problem in PSpice

1. Approach



– Through the approximation of the voltage source, the currents are different

Conclusion:
Approximation is not suitable for the SIS100 circuit!

Possible solution:
A controller is needed.

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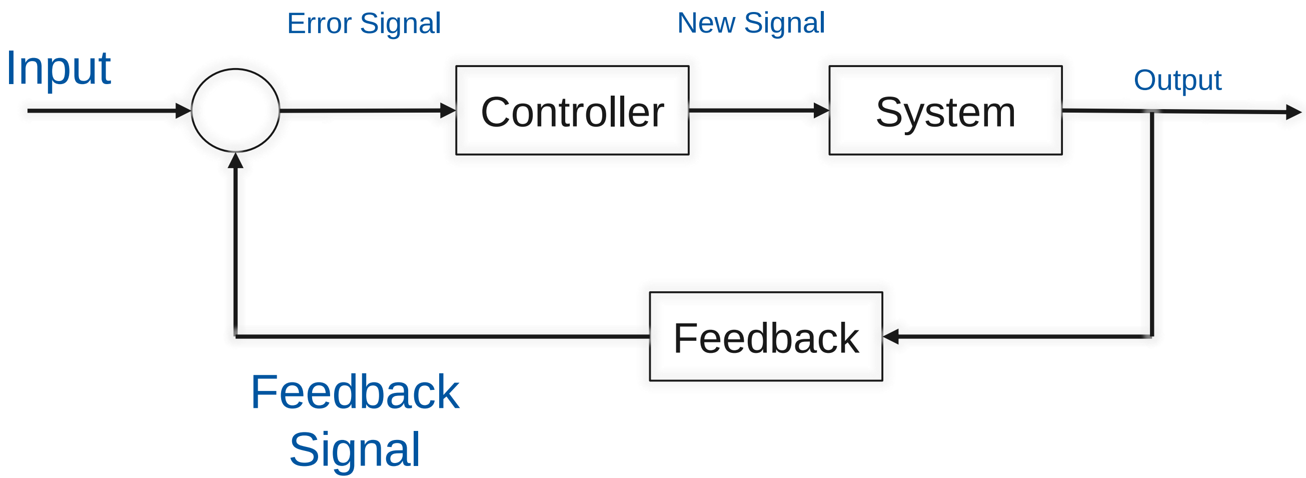
3. Controller in PSpice for Power Supply

Shematic of a controller

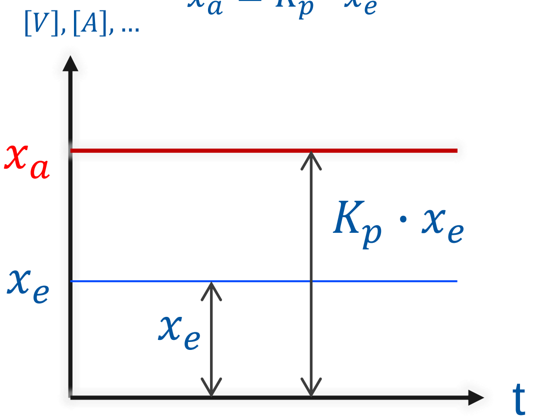


3. Controller in PSpice for Power Supply

Controller Types:

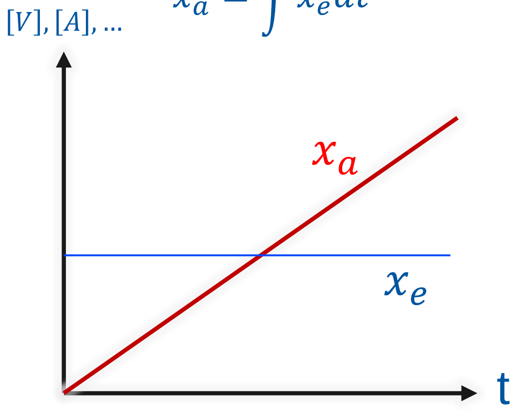
P-Controller

$$x_a = K_p \cdot x_e$$



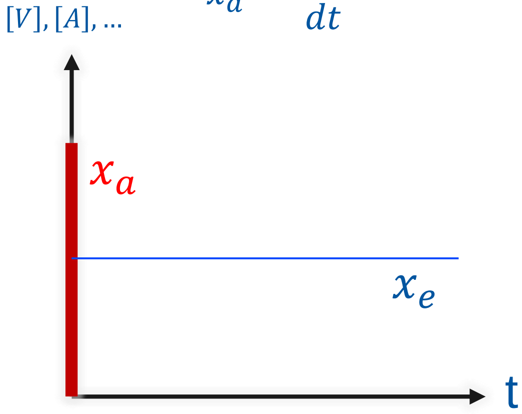
I-Controller

$$x_a = \int x_e dt$$



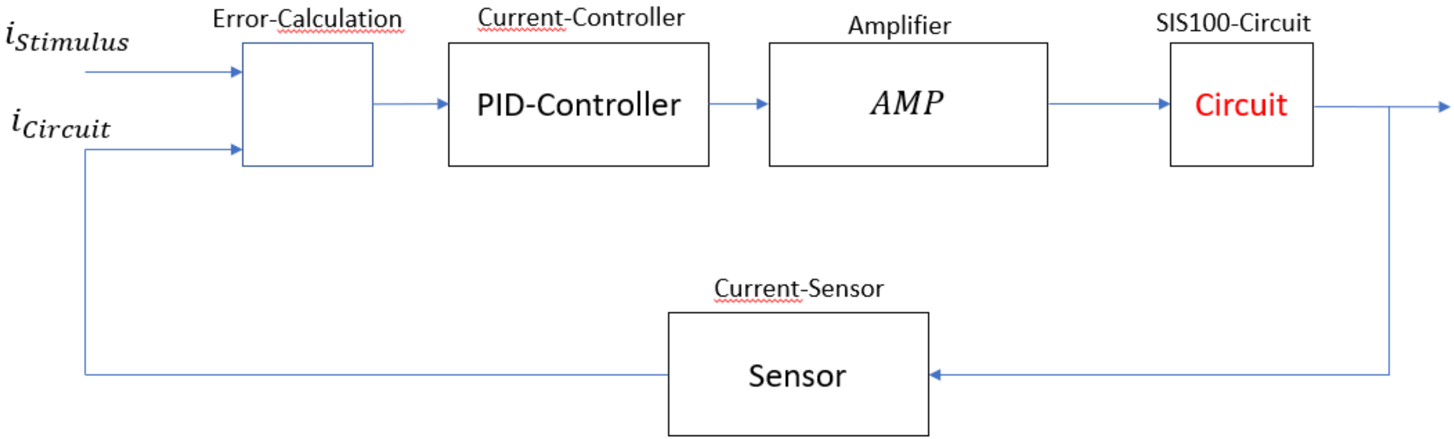
D-Controller

$$x_a = \frac{dx_e}{dt}$$



3. Controller in PSpice for Power Supply

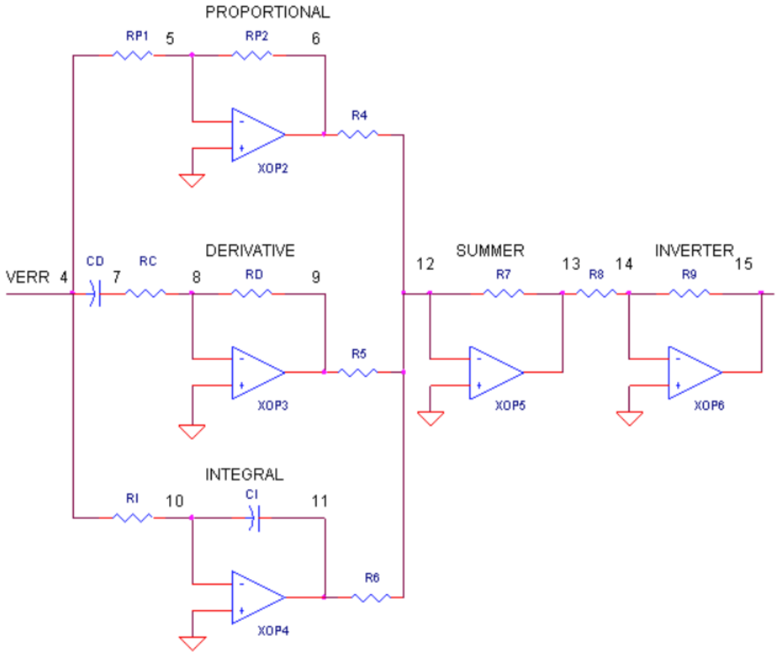
Controll Circuit for SIS100



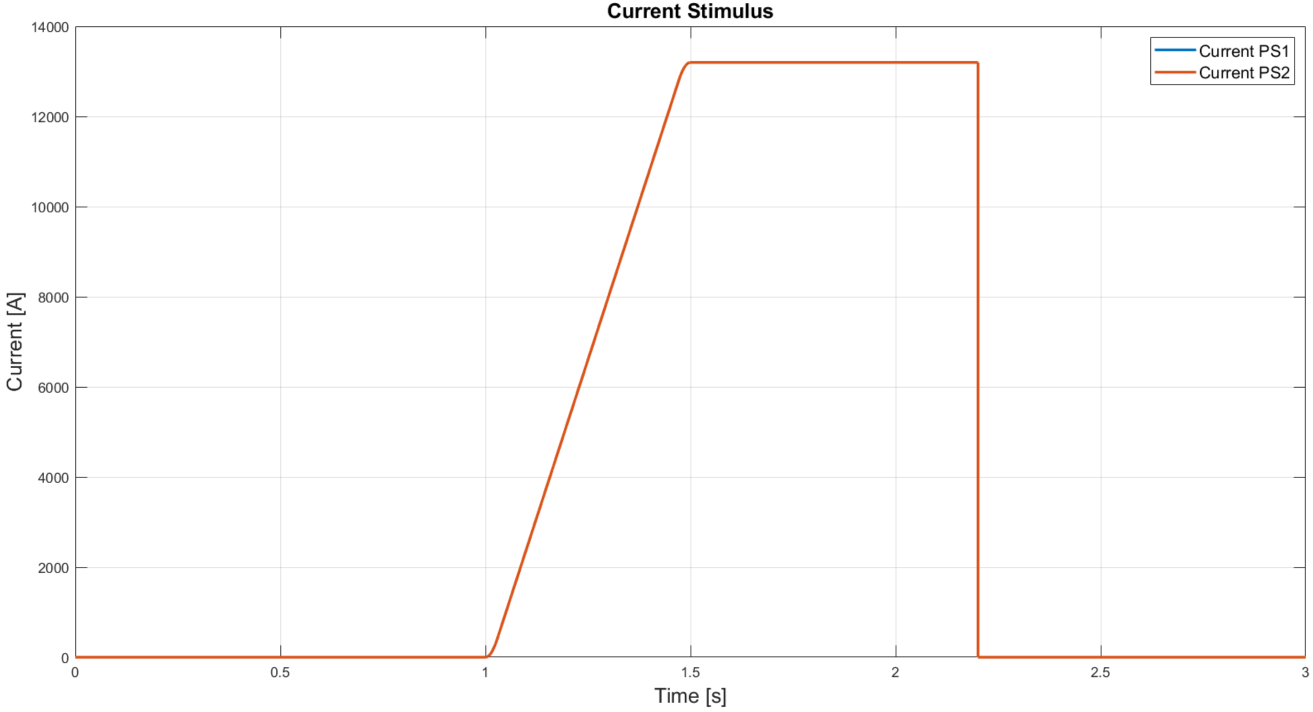
3. Controller in PSpice for Power Supply

Controll Circuit for SIS100

– Realization in PSpice



3. Controller in PSpice for Power Supply



Time to reach the nominal current
$\underline{t = 0{,}5\ s}$

Power abort at $\underline{t = 2{,}201\ s}$

EE open at $\underline{t = 2{,}205\ s}$

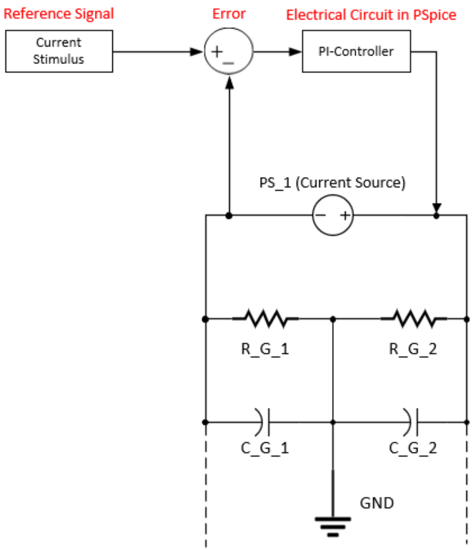
max di/dt = 28000 A/s

Stimulus curve:

- Parabolic ($\Delta t = 0{,}0286\ s$)
- Linear ($\Delta t = 0{,}4428\ s$)
- Parabolic ($\Delta t = 0{,}0286\ s$)
- Constant (nominal current)

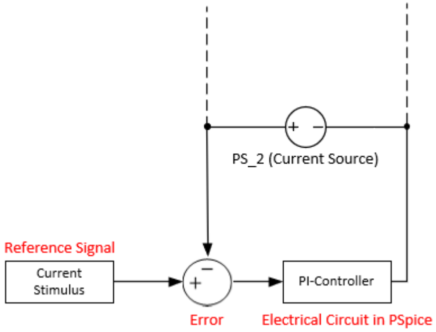
3. Controller in PSpice for Power Supply

Power Converter 1

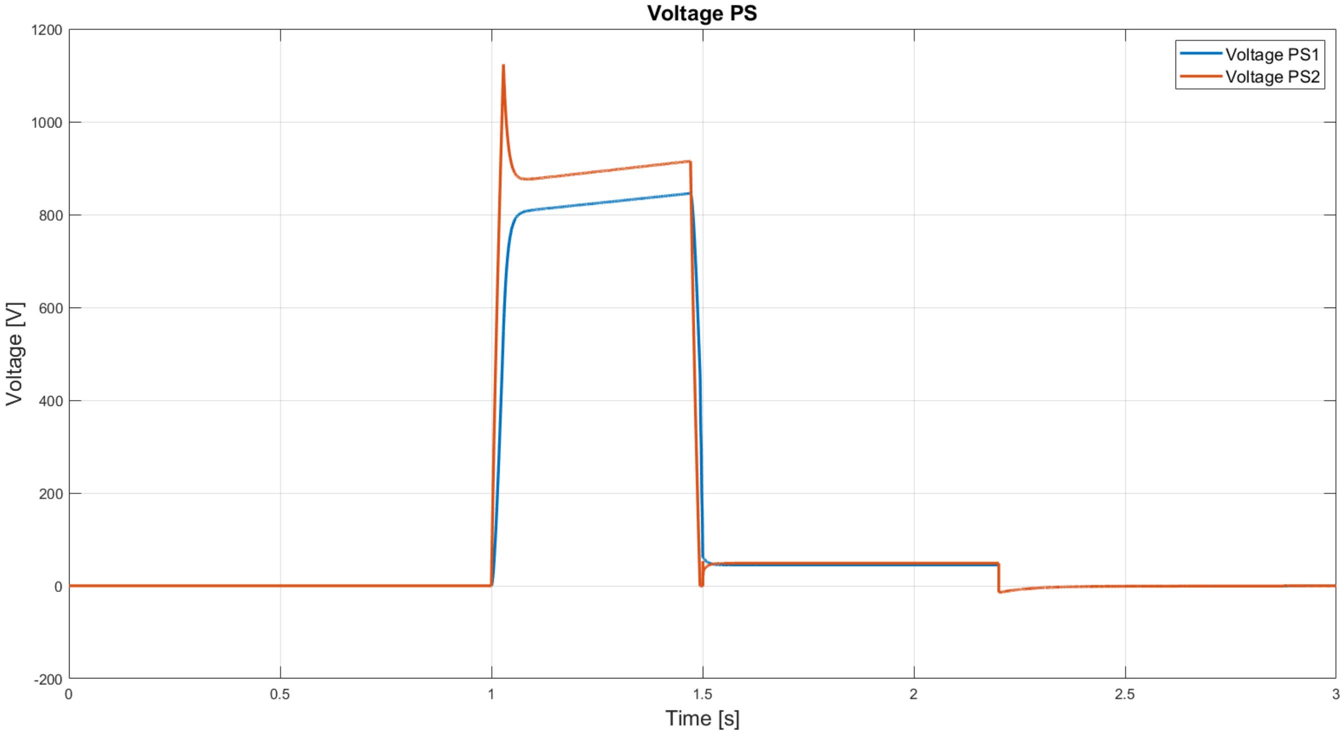


Power Converter 2

- one controller for each power supply
- due to stability reasons only PI controller is applied



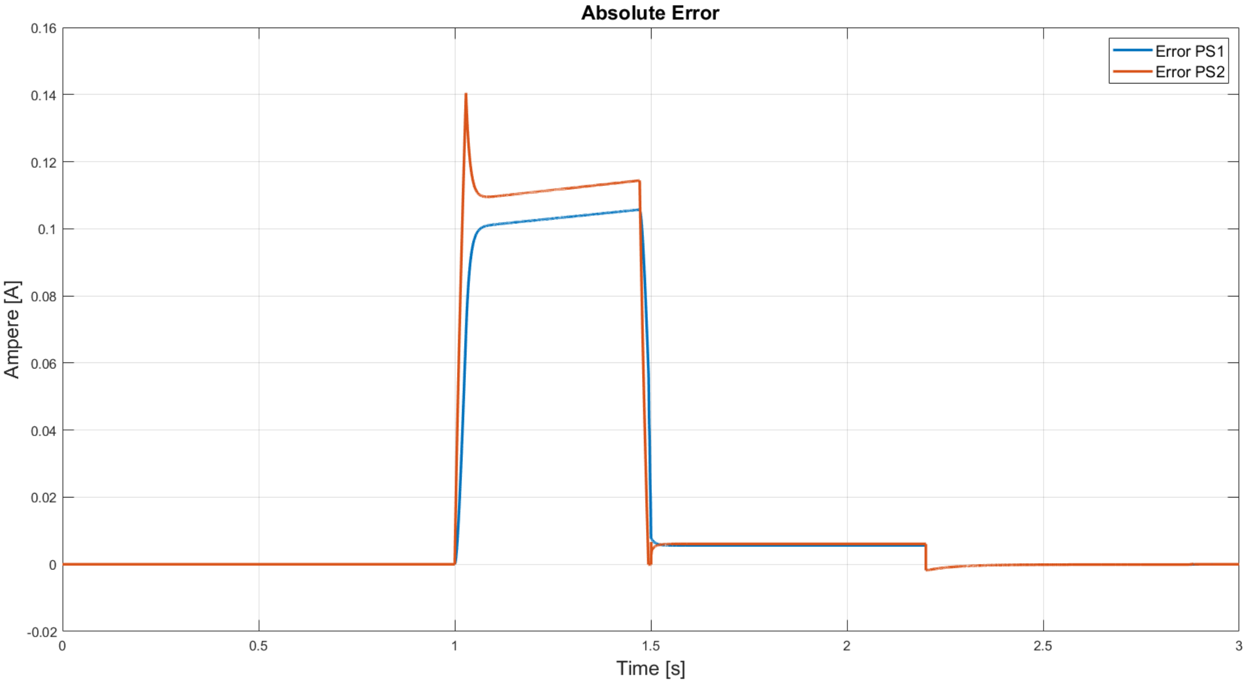
3. Controller in PSpice for Power Supply



- voltage across the two power supplies
- one overshoot in PS2

can be a problem in the operation mode of the SIS100 circuit

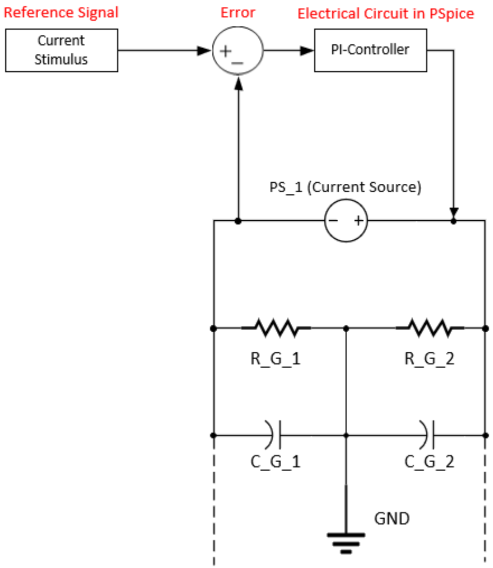
3. Controller in PSpice for Power Supply



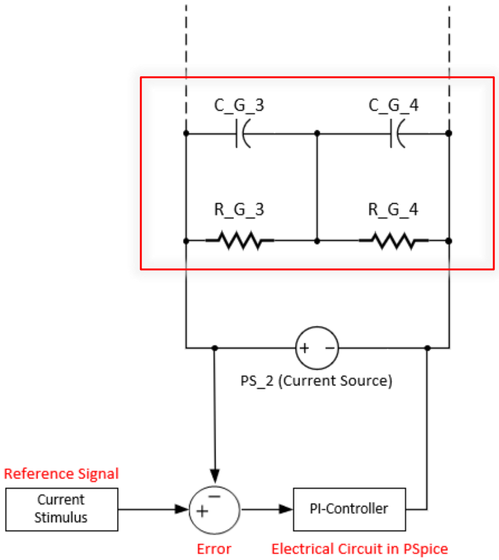
- the propotional part of the controller is dominant
- the behavior is quite the same as for the voltage across the two power supplies
- the I-component of the controller is small

3. Controller in PSpice for Power Supply

Power Converter 1

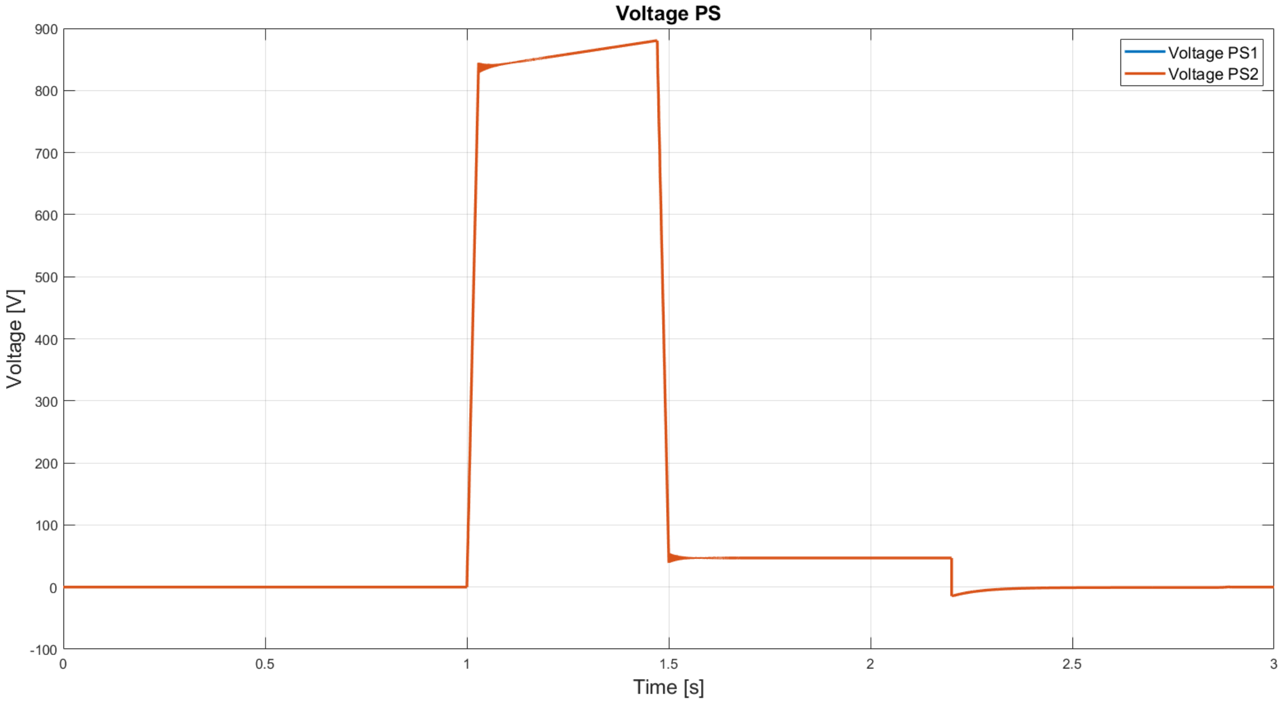


Power Converter 2



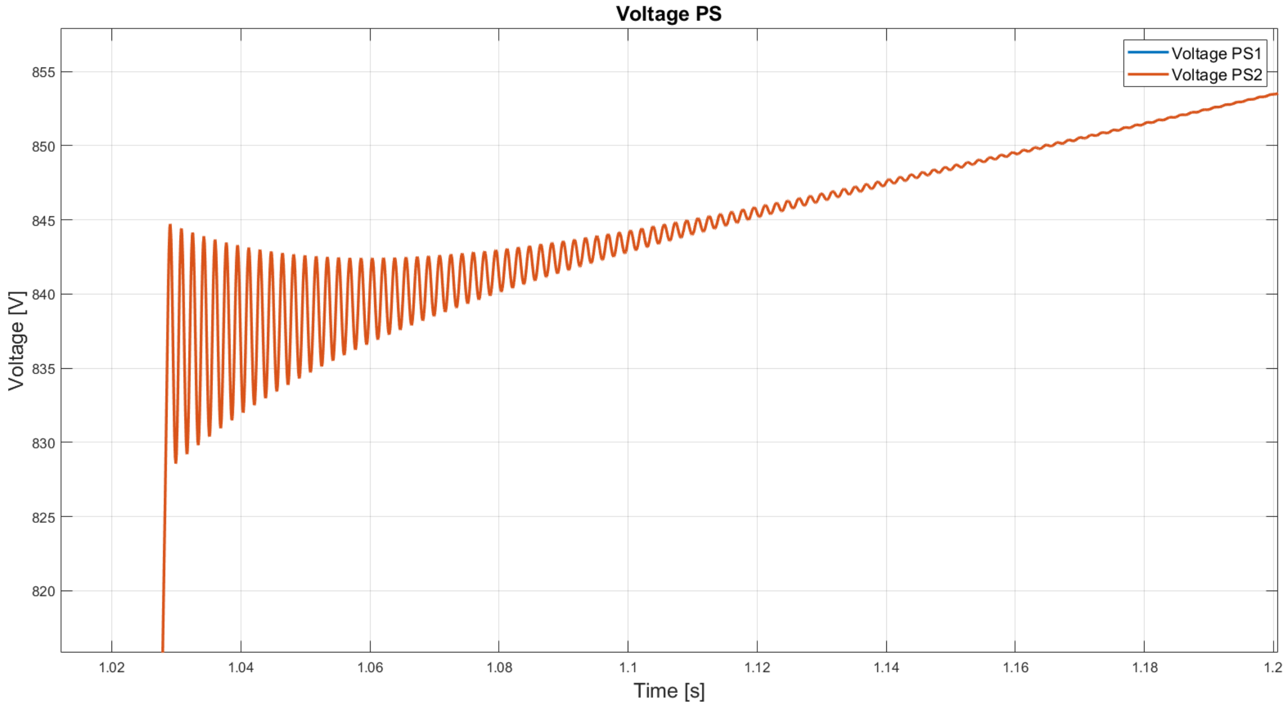
→ To make the circuit more symmetrical.

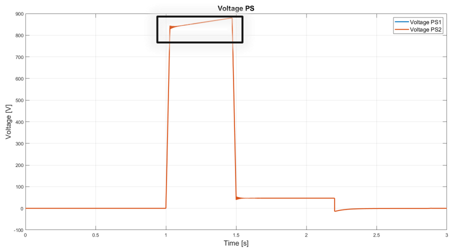
3. Controller in PSpice for Power Supply



- no overshots
- the two curves are quite identical

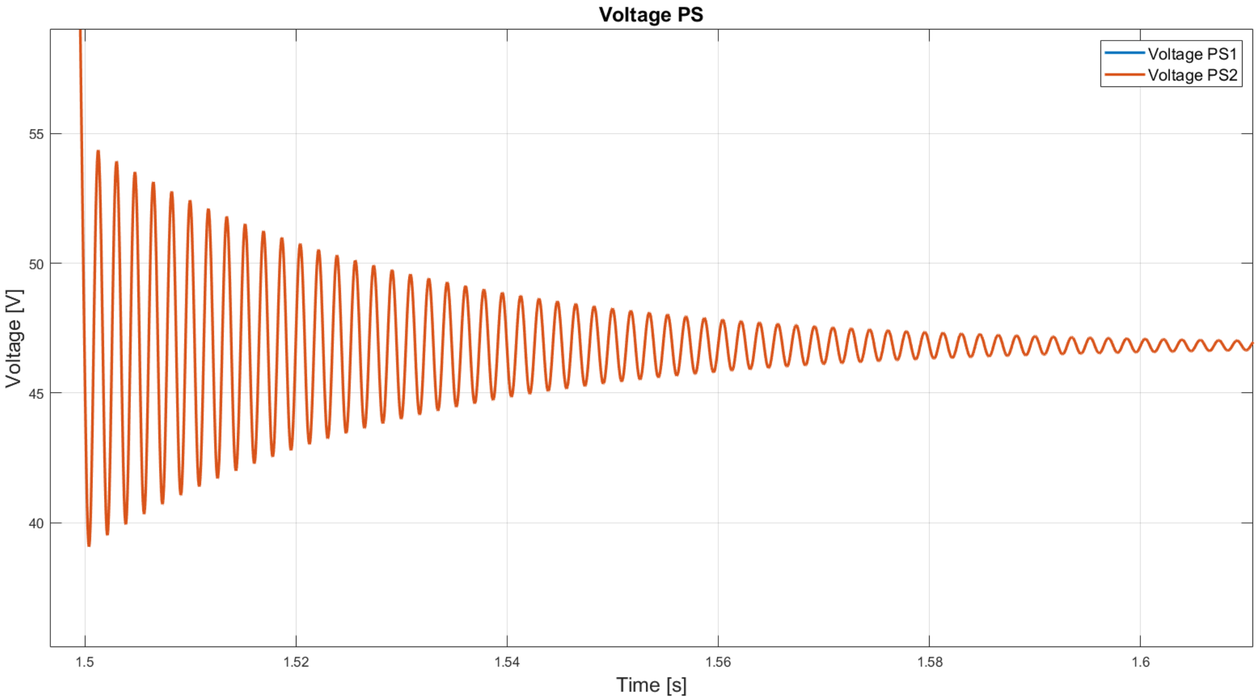
3. Controller in PSpice for Power Supply

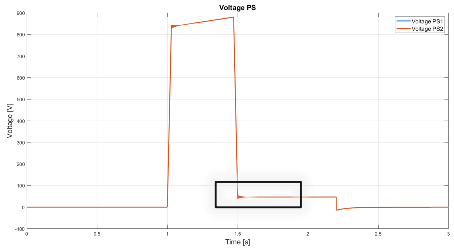




$$f \approx 588{,}23\ Hz$$

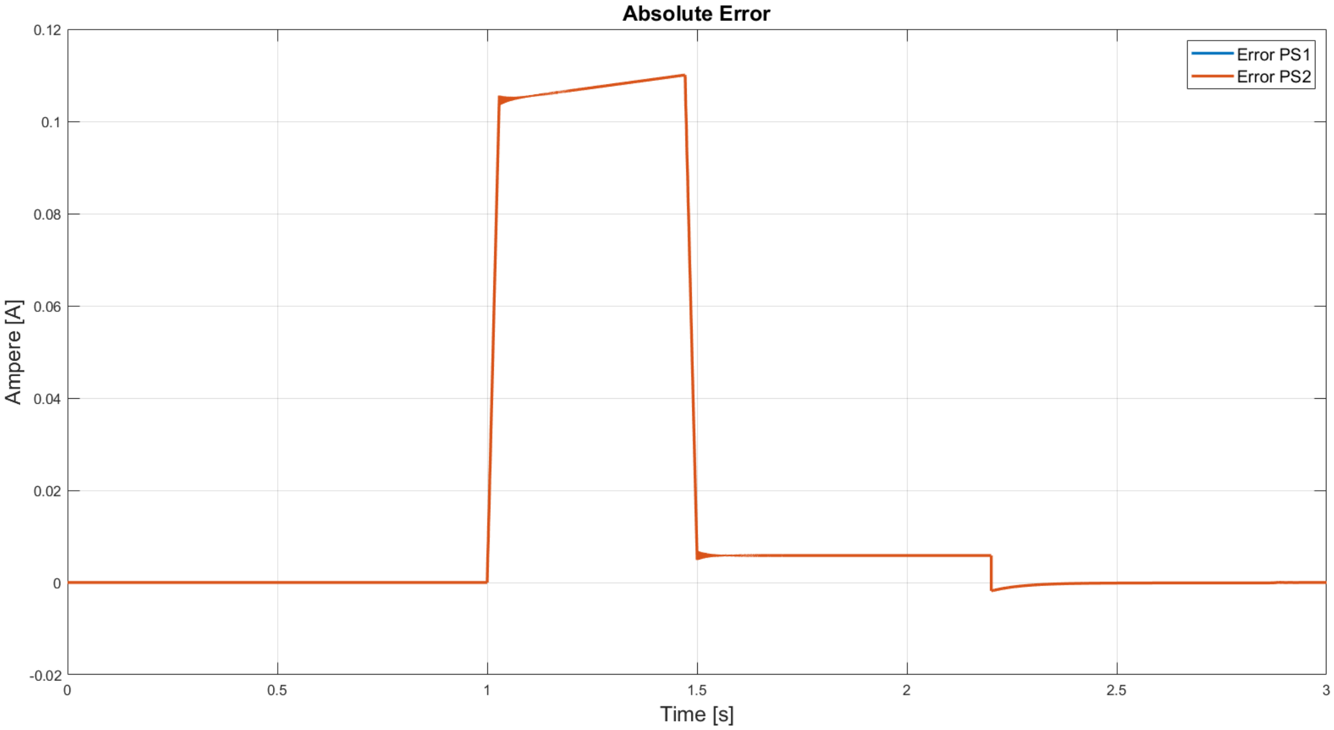
3. Controller in PSpice for Power Supply





$$f \approx 588{,}23\ Hz$$

3. Controller in PSpice for Power Supply



– the absolute error is also quite identical

↓

Under the threshold of 120 mA

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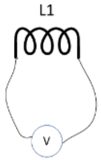
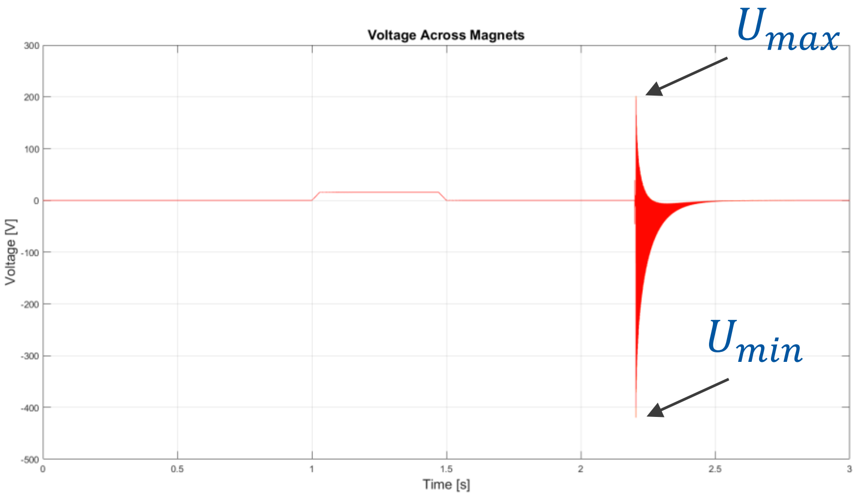
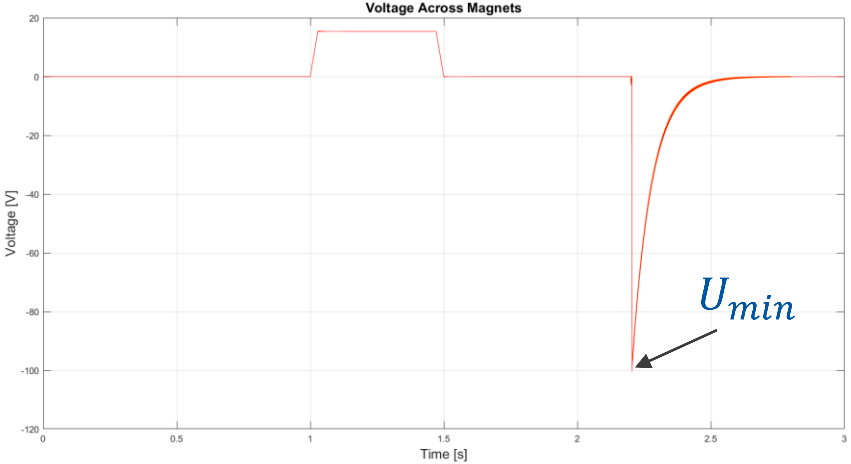
4. Simulation Results



Voltage ascross each magnet



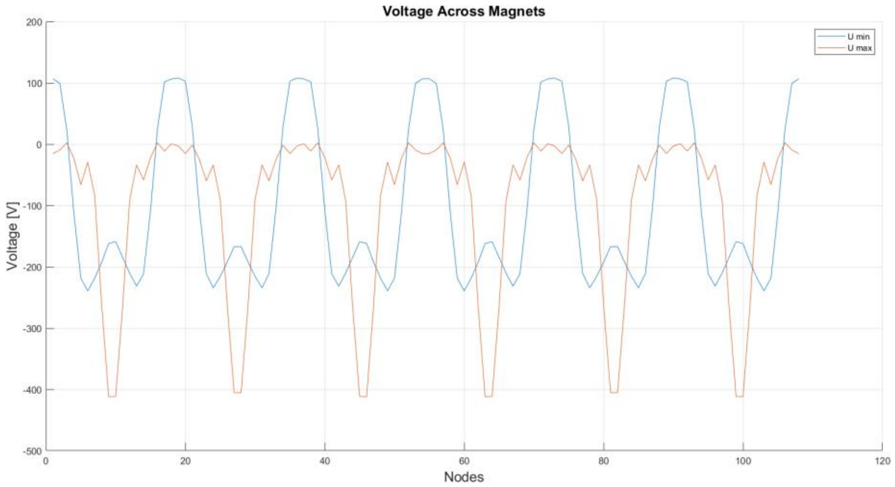
$C_{mag} = 10\ nF$



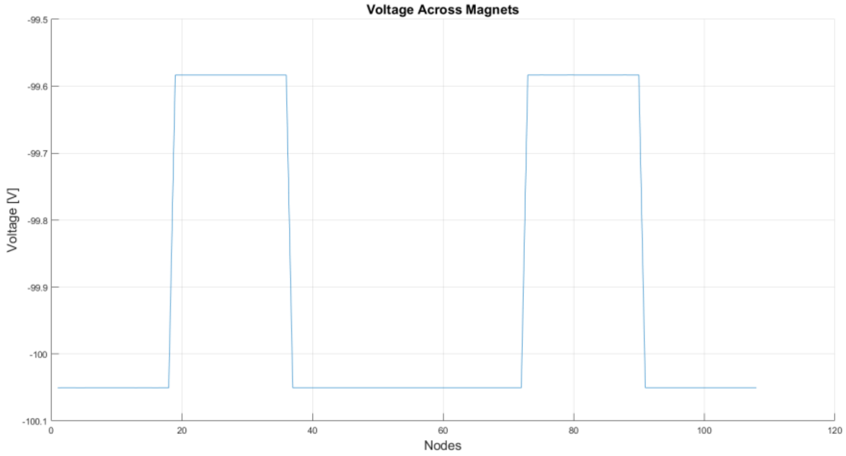
$C_{mag} = 0\ nF$

-> oscillation due to the capacitance of the circuit

4. Simulation Results



$C_{mag} = 10\,nF$



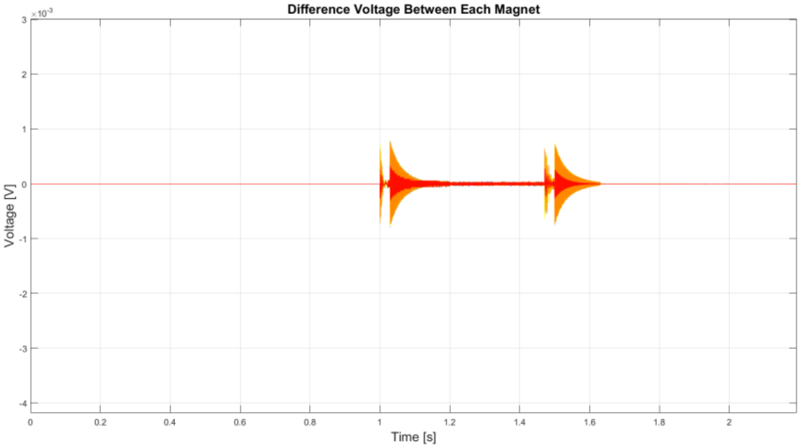
$C_{mag} = 0\,nF$

-> Oscillating with different frequencies

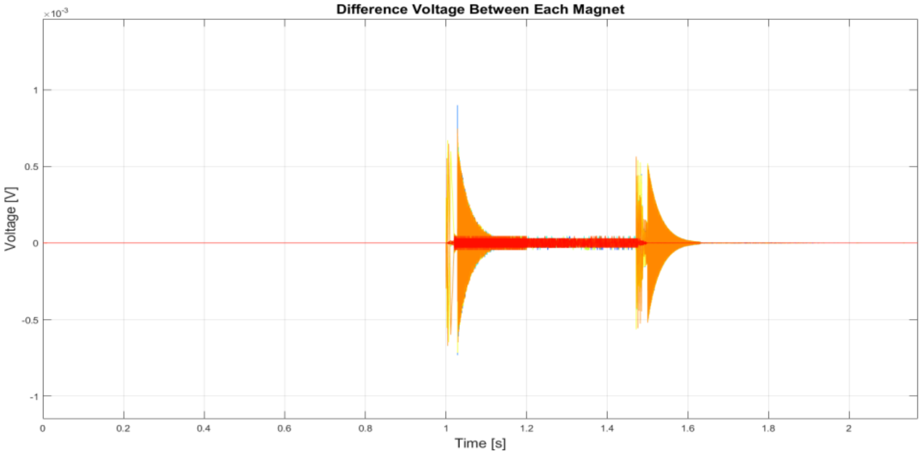
-> 18 magnets oscillating with the same frequencies

4. Simulation Results

Voltage Difference between each magnet



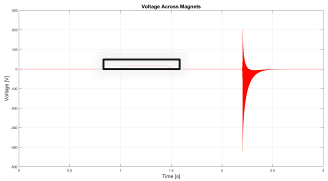
$C_{mag} = 10\ nF$

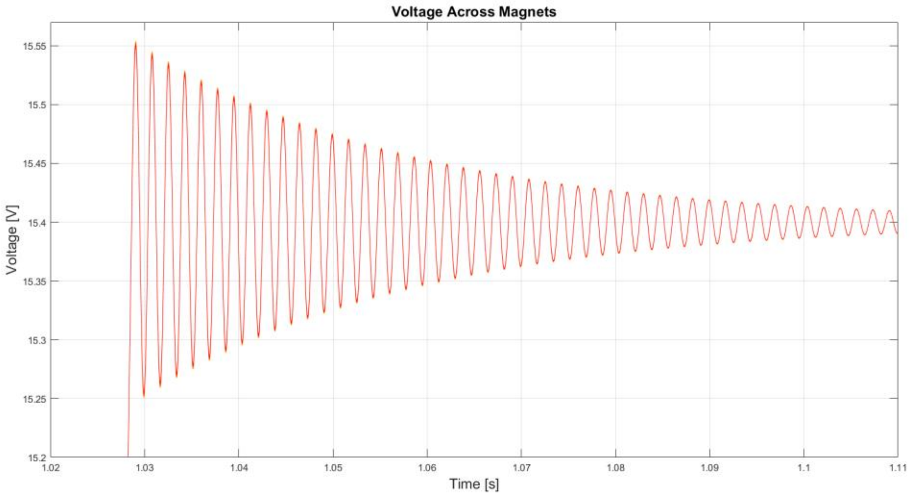


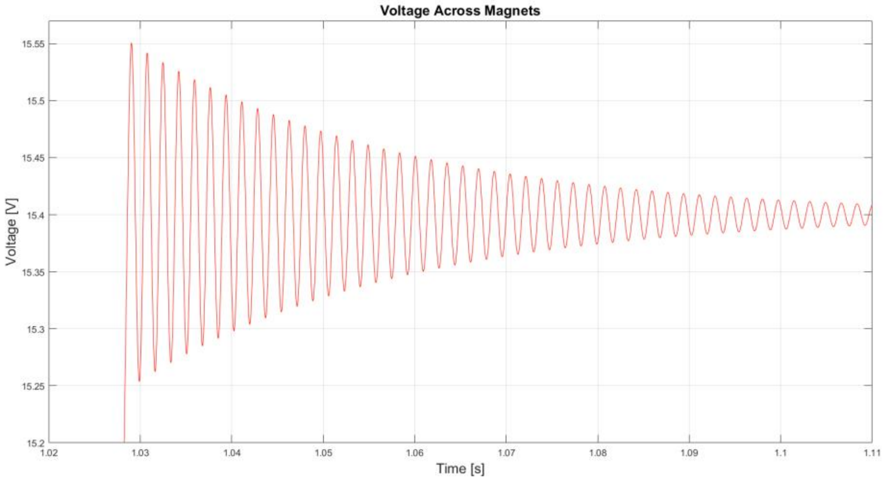
$C_{mag} = 0\ nF$

-> both below 1 mV

4. Simulation Results



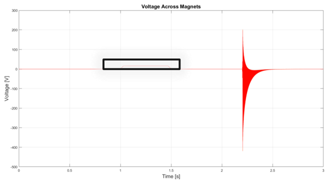


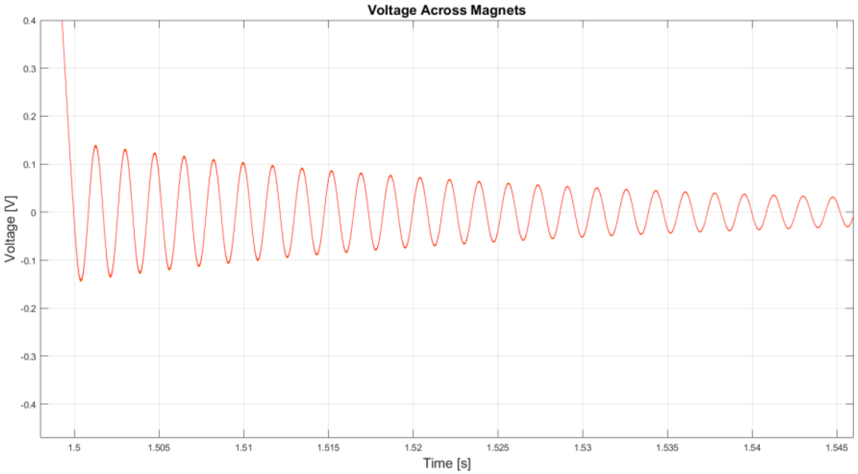


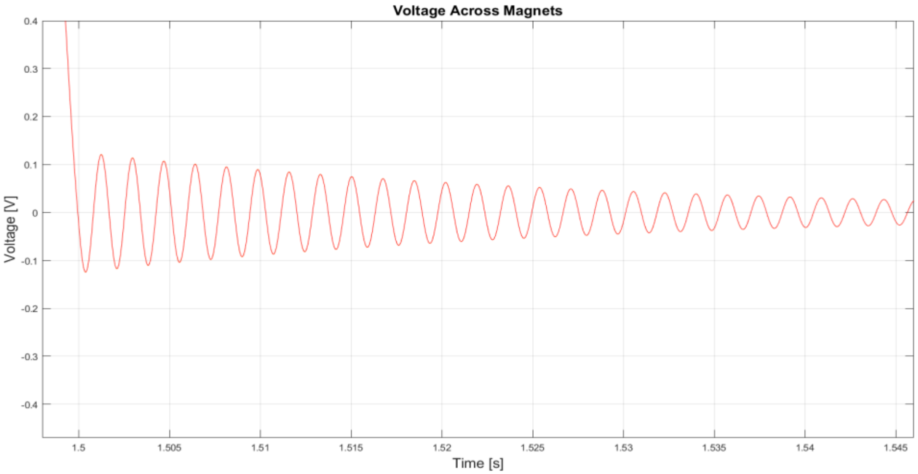
$C_{mag} = 10\,nF$ $\quad f \approx 588{,}23\,Hz$

$C_{mag} = 0\,nF$ $\quad f \approx 571\,Hz$

4. Simulation Results



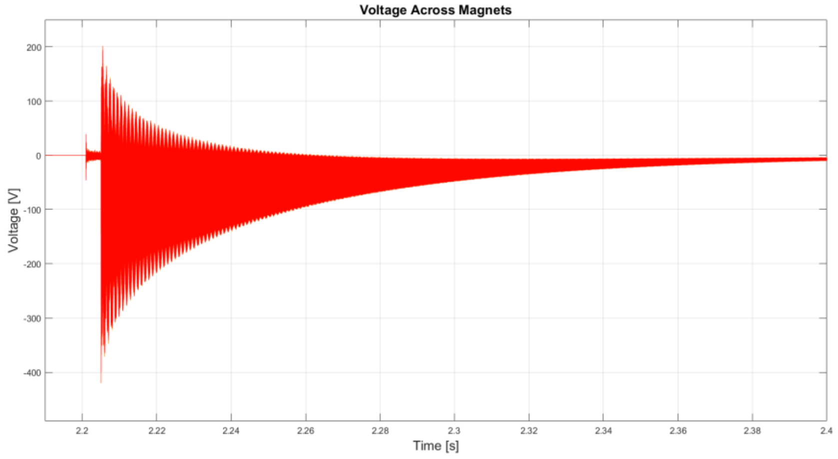


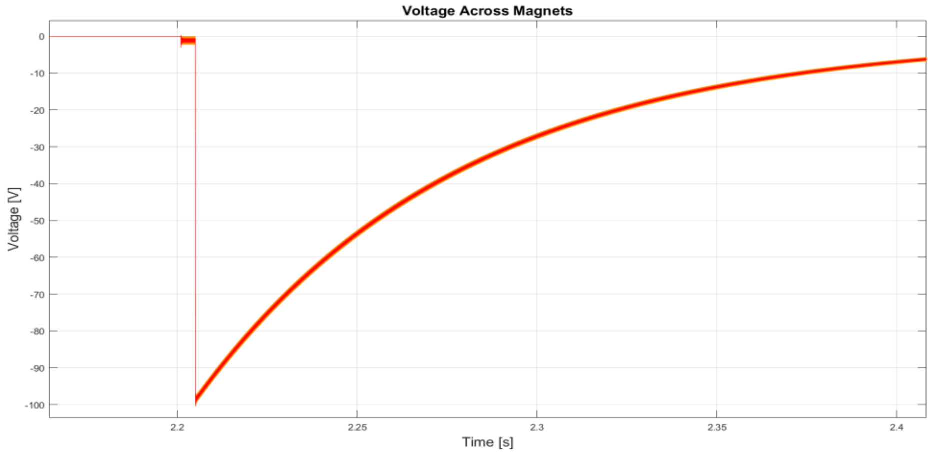


$C_{mag} = 10\ nF$ $f \approx 588{,}23\ Hz$

$C_{mag} = 0\ nF$ $f = 571\ Hz$

4. Simulation Results



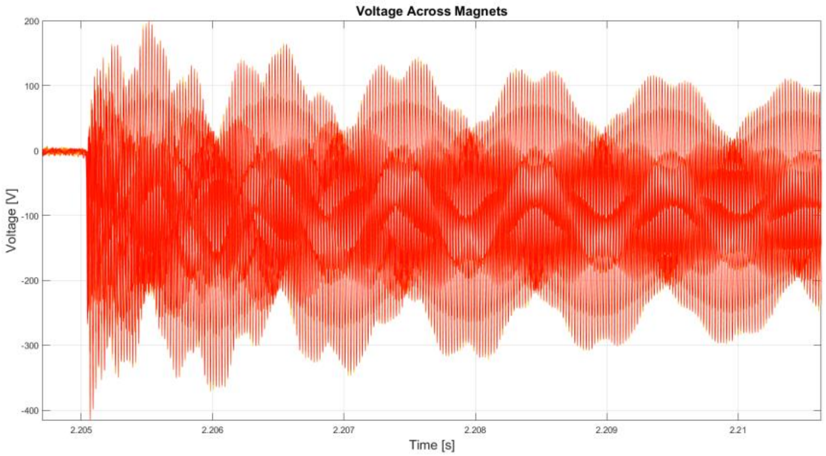


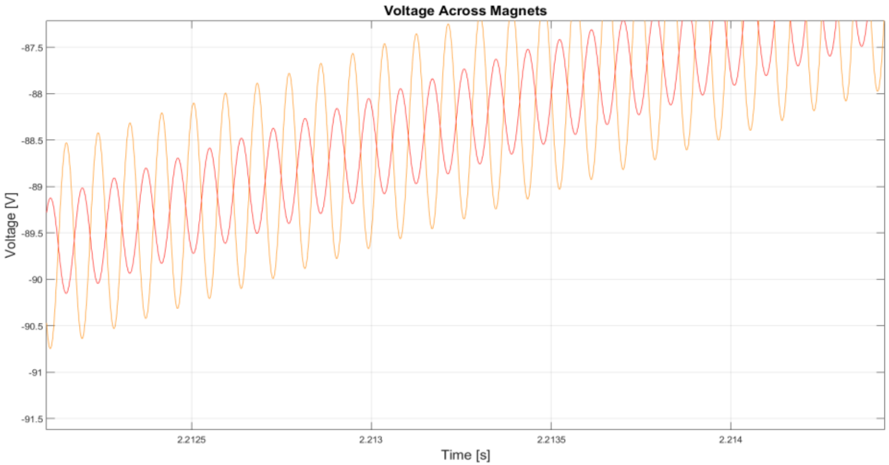
$C_{mag} = 10\ nF$

$C_{mag} = 0\ nF$

-> Frequency analysis is needed

4. Simulation Results



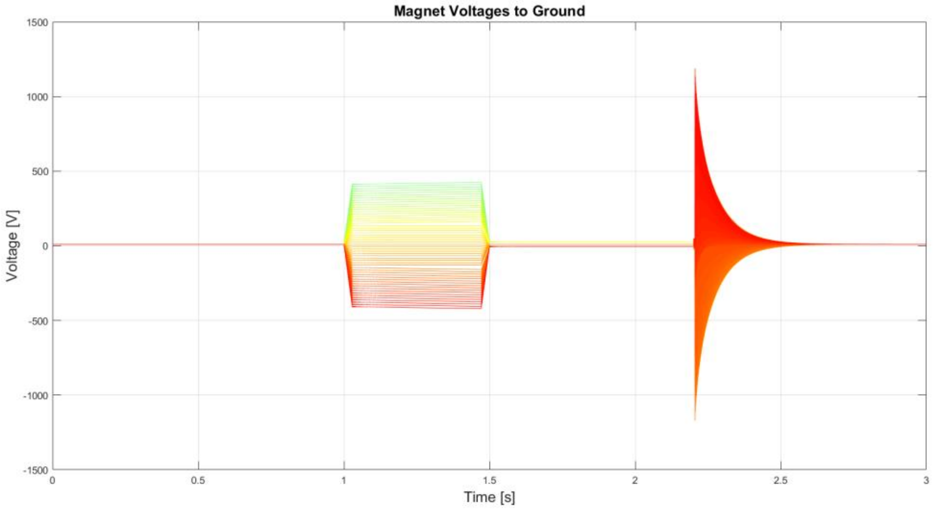


$C_{mag} = 10\, nF$ $f \approx 62\, kHz$

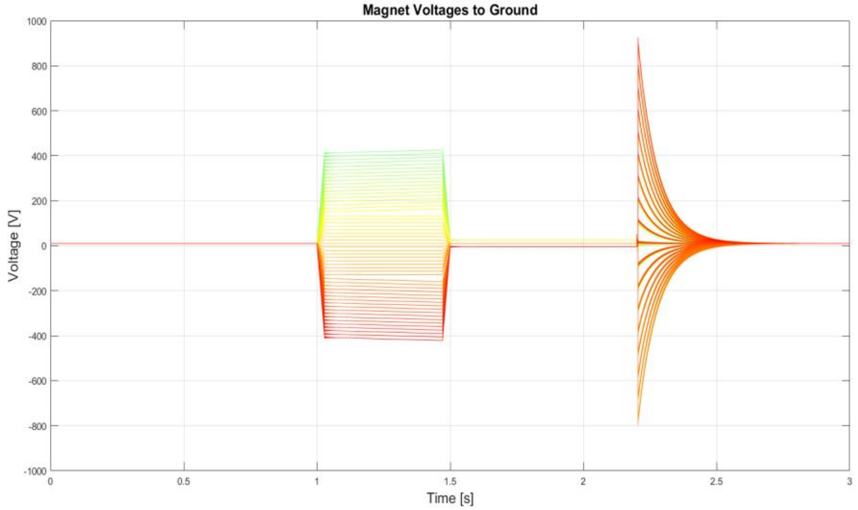
$C_{mag} = 0\, nF$ $f \approx 11.280\, kHz$

4. Simulation Results

Voltage to Ground



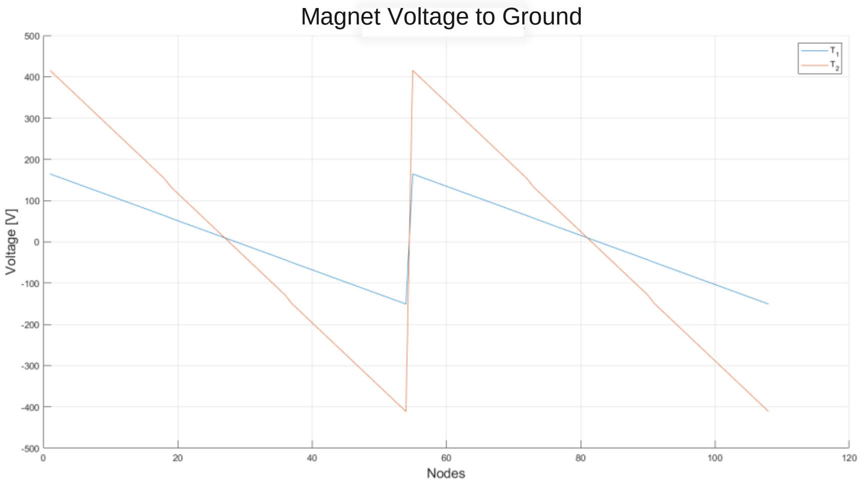
$C_{mag} = 10\ nF$

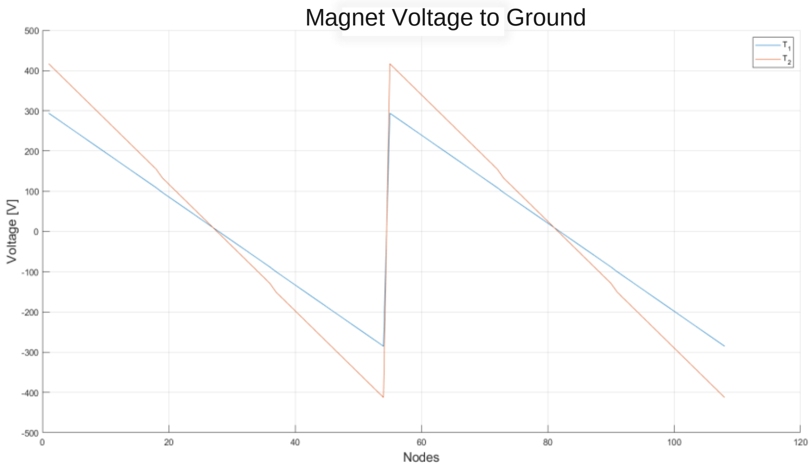


$C_{mag} = 0\ nF$

-> Frequency analysis is needed

4. Simulation Results





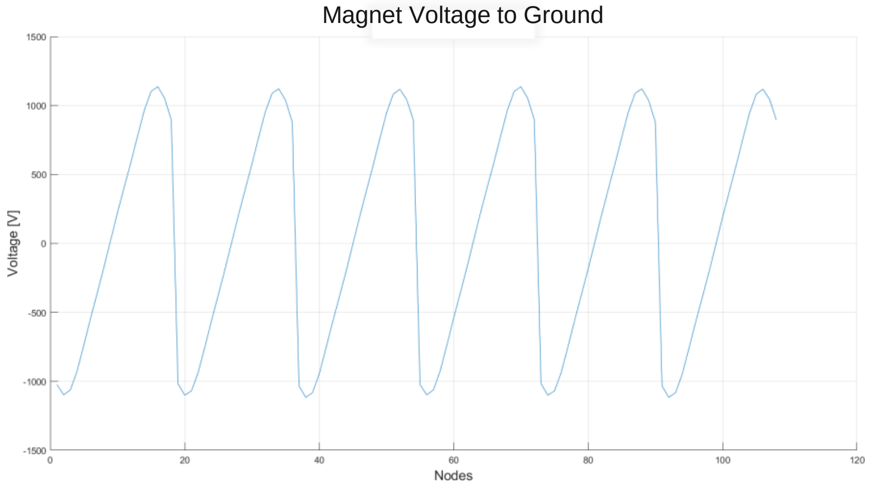
$C_{mag} = 10\ nF$

$C_{mag} = 0\ nF$

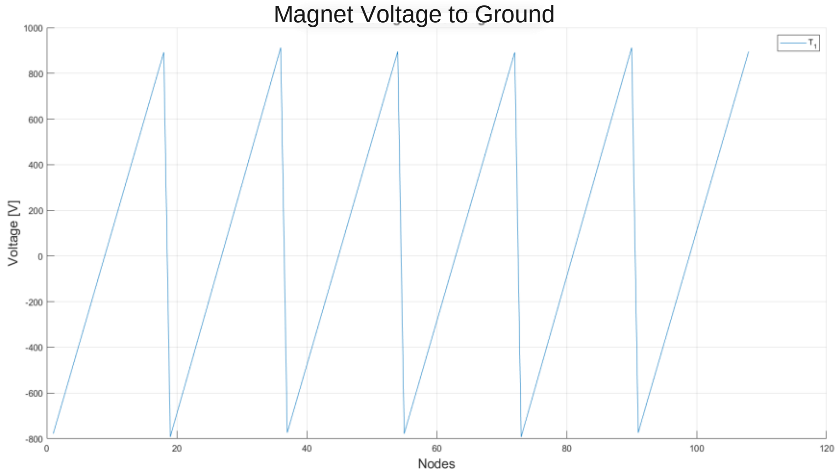
$T_1 = 1{,}1\ s$

$T_2 = 1{,}35\ s$

4. Simulation Results



$C_{mag} = 10\ nF$

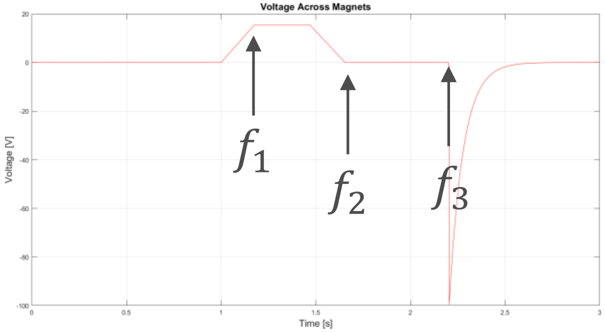


$C_{mag} = 0\ nF$

4. Simulations Results and Parameter Study

Variation of C_mag

f_mag [Hz]	f_filter [Hz]	C_mag [nF]	C_GROUND [uF]	L_mag [mH]	C_WCC_1 [nF]	C_WCC_2 [nF]	f_1 [Hz]	f_2 [Hz]	f_3 [Hz]
67863,90	413,01	10	5	0,55	42,5	30	588,23	588,23	23256
95974,04	413,01	5	5	0,55	42,5	30	585,65	585,65	32659
135727,79	413,01	2,5	5	0,55	42,5	30	584,5	584,5	45400
--	413,01	0	5	0,55	42,5	30	571	571	11280



$$f = \frac{1}{2\pi\sqrt{LC}}$$

$$f_{filter} = \frac{1}{2\pi\sqrt{L_{mag} \cdot C_{GROUND} \cdot 108}}$$

$$f_{mag} = \frac{1}{2\pi\sqrt{L_{mag} \cdot C\_mag}}$$

1. Introduction to the Project
2. SIS 100 Circuit
3. Controller in PSpice for Power Supply
4. Simulation Results
5. Conclusion and Further Work

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Conclusions

1. The capacitance of the magnets influence only the oscillation frequency after the fast power abort

2. The capacitance of the water cooled cable also influence only the oscillation frequency after the fast power abort

3. The ground capacitors influence the oscillation frequency during the ramp up phase (of the stimulus)

5. Conclusion and Further Work

<u>Furher Work</u>

1. Define and simulate failer cases that can be accured in the SIS100 circuit
2. Frequency domain simulation
3. FEM simulation of the busbars

Thank you for your attention