RCS Dipole supply using 3 different solutions

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Introduction

- Brookhaven National Laboratory is the host site for the future Electron-Ion Collider (EIC)
- This is a unique high-energy, high-luminosity polarized collider that will be one of the most challenging and exciting accelerator complexes ever built.
- The EIC will be a discovery machine, providing answers to long-elusive mysteries of matter related to our understanding the origin of mass, structure, and binding of atomic nuclei that make up the entire visible universe.
- Part of EIC is the Rapid Cycling Synchrotron (RCS).
- In this presentation we will examine 3 different power supply topologies for the main dipole supply

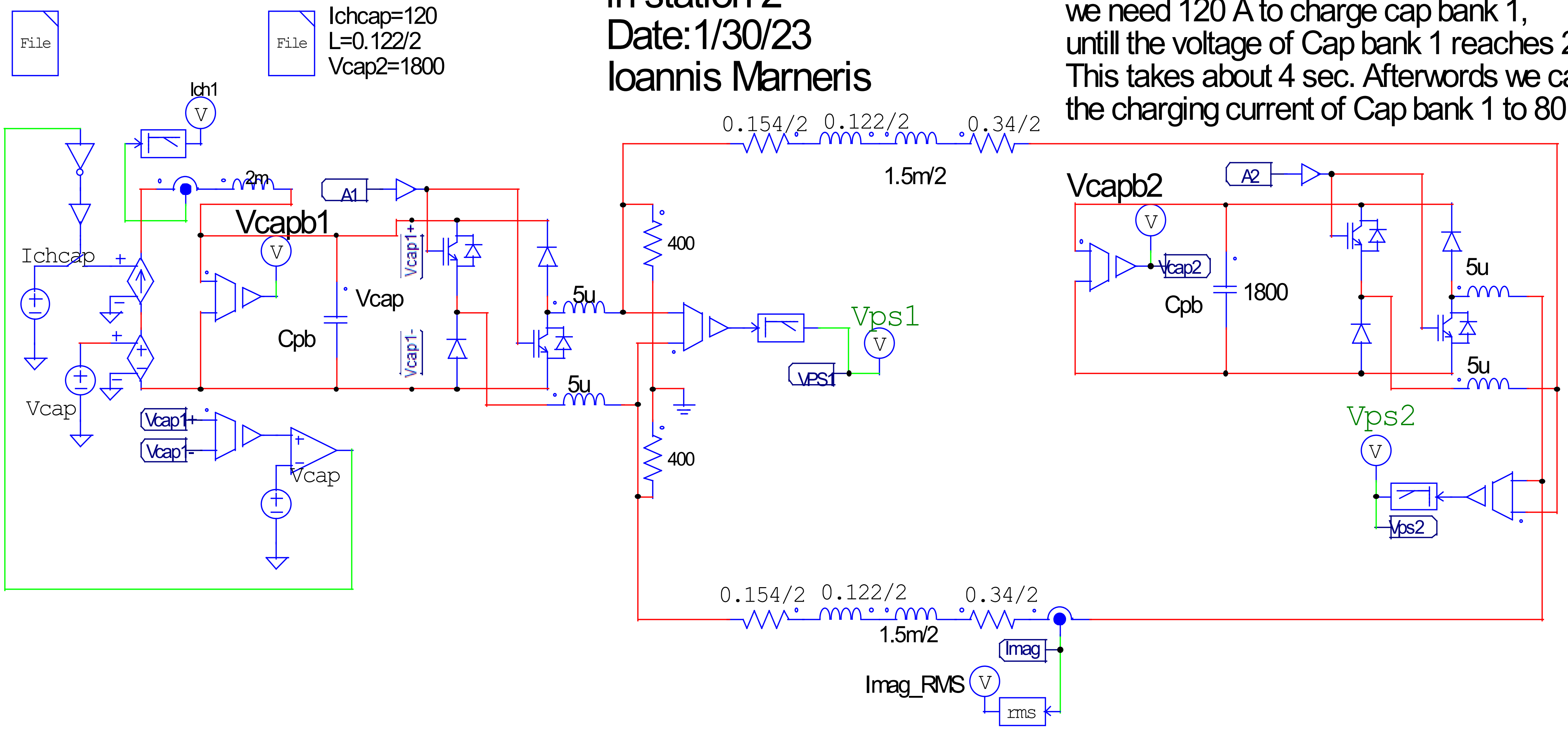
Scope

- Design the new RCS dipole supply.
- Three different topologies for the main RCS dipole supply will be presented.
  - The first topology is based on the ***CERN, POPS-B DC/DC Converter .***
  - The second topology is based on **J-PARC new power supply for the bending magnets.**
  - The third topology is using **electrolytic capacitors** based on **a BNL design of the new power supply for Lawrence Livermore national lab.**
- Advantages and disadvantages of the 3 designs will be discussed.

Solution 1 using film capacitor and 2 power supplies in series

RCS Dipole supplies
using a flying cap bank
in station 2
Date:1/30/23
Ioannis Marneris

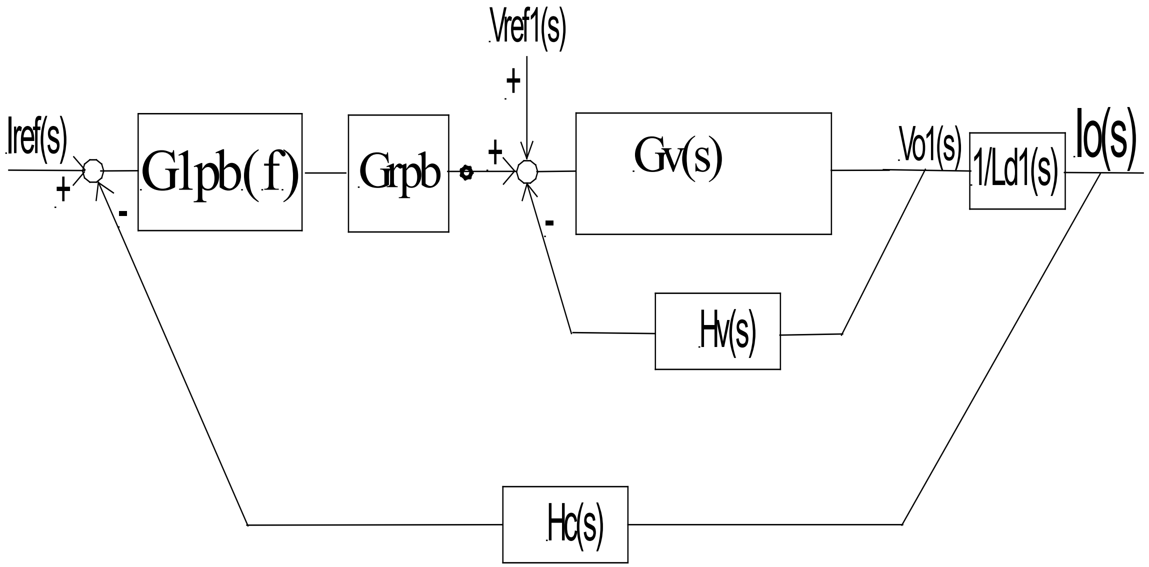
Please note that if Cap bank 2 starts with 0 v,
we need 120 A to charge cap bank 1,
untill the voltage of Cap bank 1 reaches 2800 V.
This takes about 4 sec. Afterwords we can lower
the charging current of Cap bank 1 to 80 A.

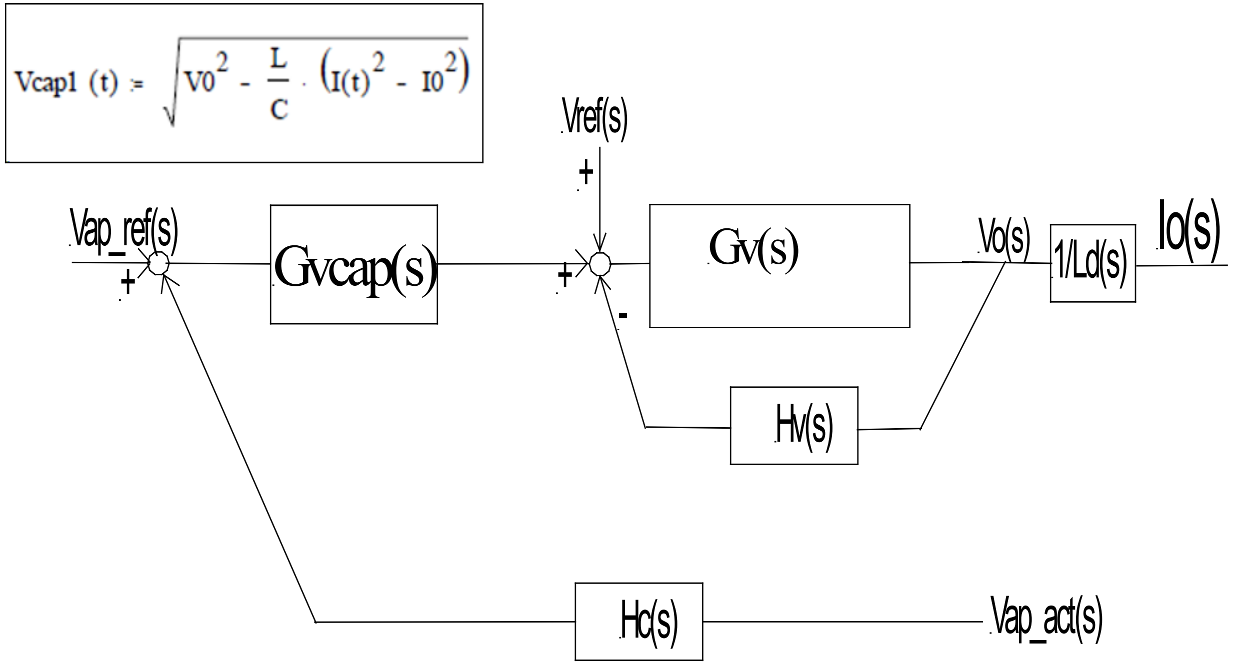


Control Loops of solution 1

One current and a voltage loop of PS's 1

One flying cap bank loop PS 2.

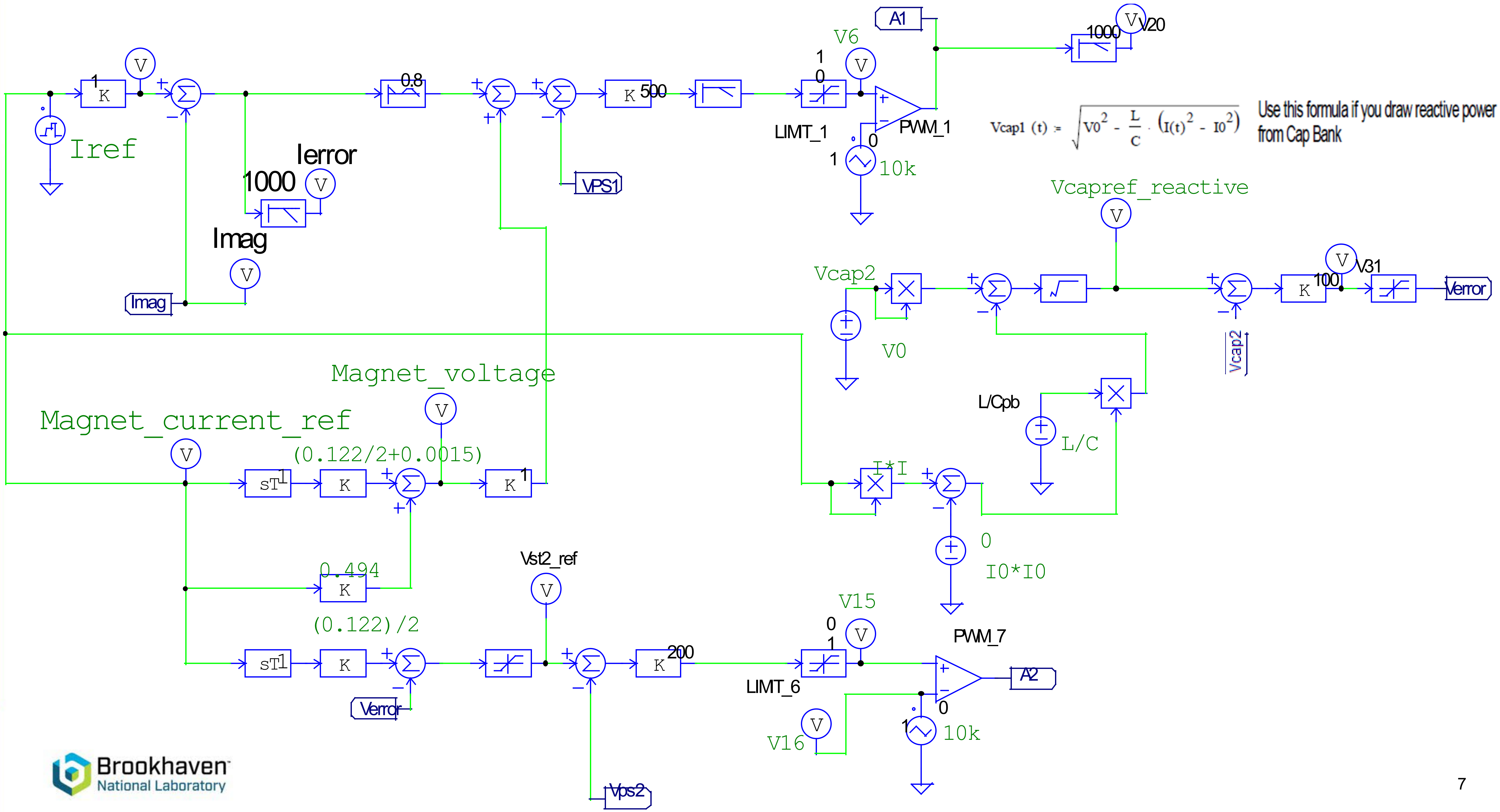




$$Vcap1(t) := \sqrt{V0^2 - \frac{L}{C} \cdot \left(I(t)^2 - I0^2\right)}$$

V0=1800 V, C=0.3 F, L=0.122/2 H

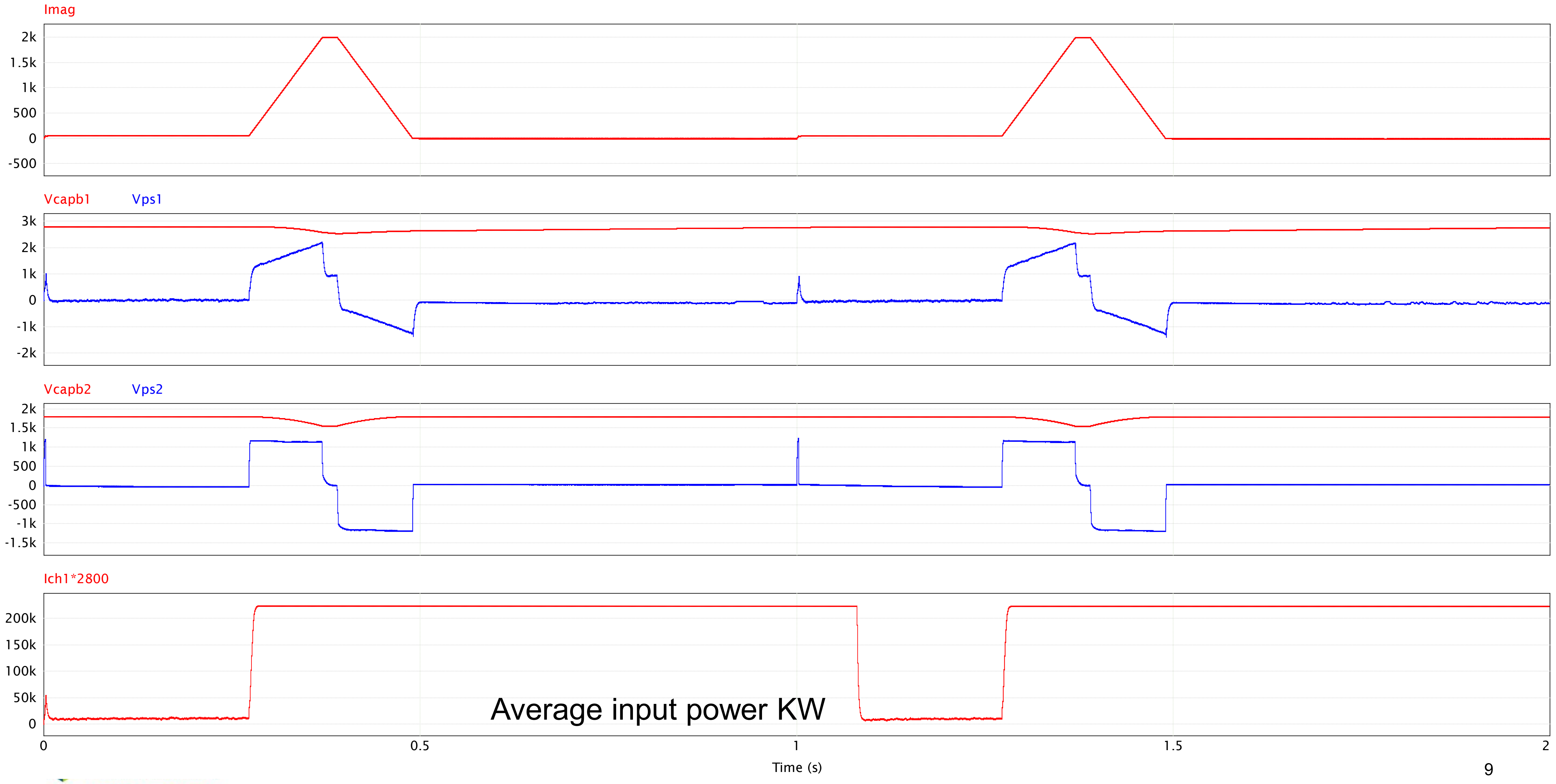
Control system of a flying cap bank on station 2



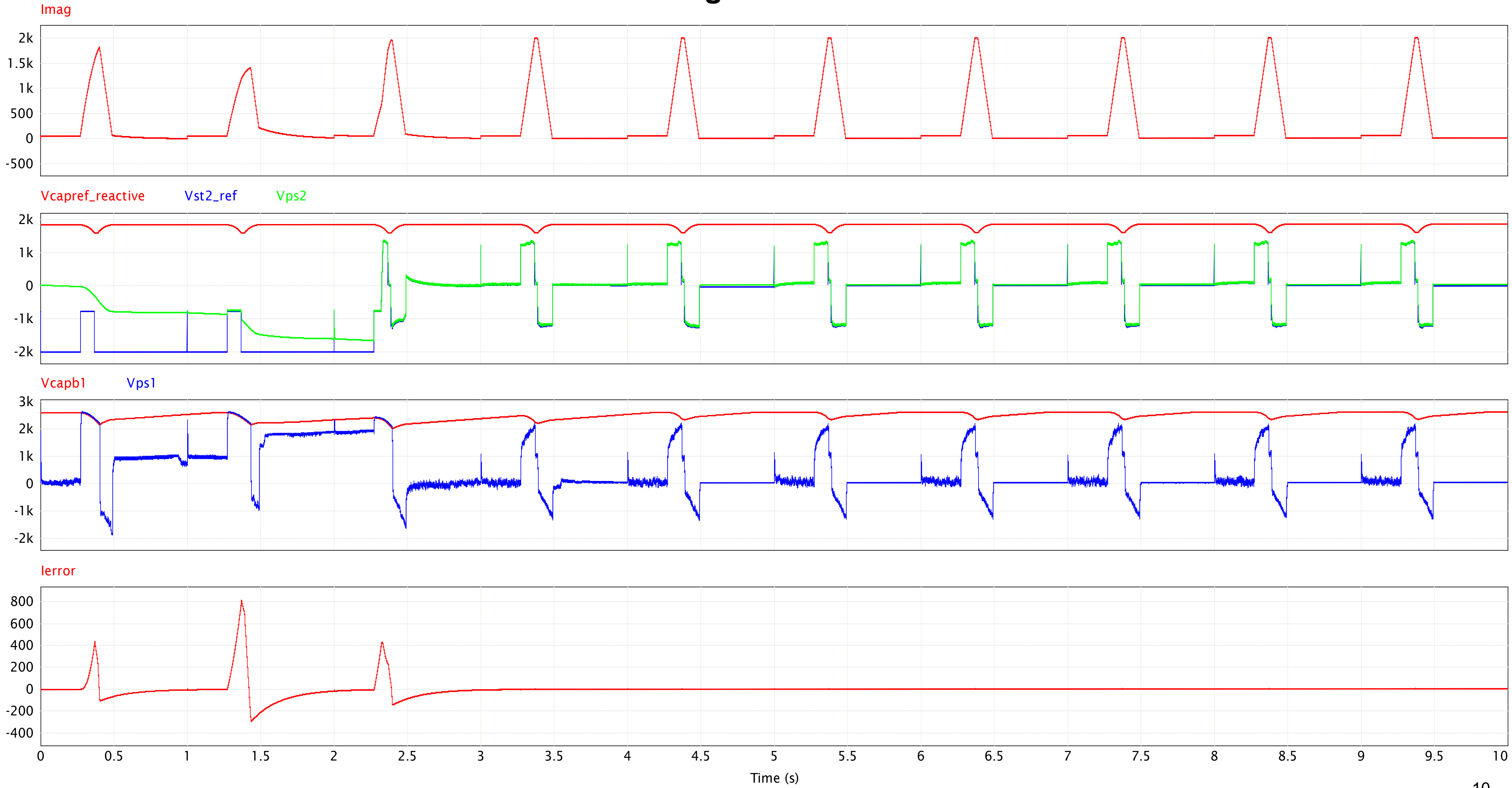
Synopsis of solution 1

- Cap bank station 1 sees 2800 V, Cab bank station 2 sees 1800 V. We use film caps of 0.3 F per station.
- Station 2 has a flying cap bank.
- Two DC/DC converters in series each giving us +/-3600 V.
- Power supply one is grounded in the middle through two 400 Ohm resistors.
- Magnet maximum voltage to ground 1100 V.
- Regulating average input power on station 1 supply.
- Average input power 240 KW.
- Cap banks don’t dip more than 14% of charged voltage.

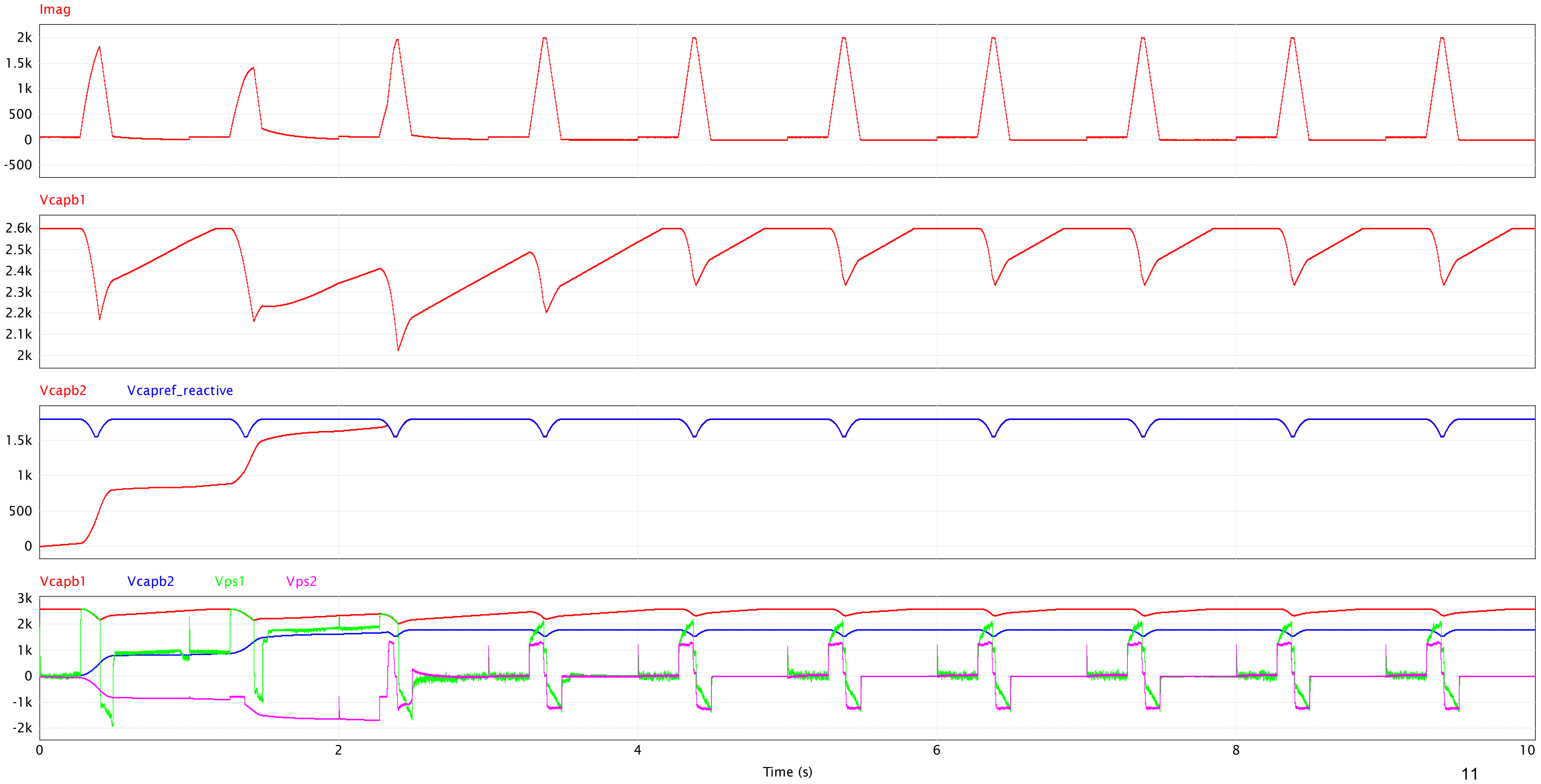
Capacitor bank voltage station 1, capacitor bank reference and voltage station2, magnet current, station 1 and 2 voltages and input power.



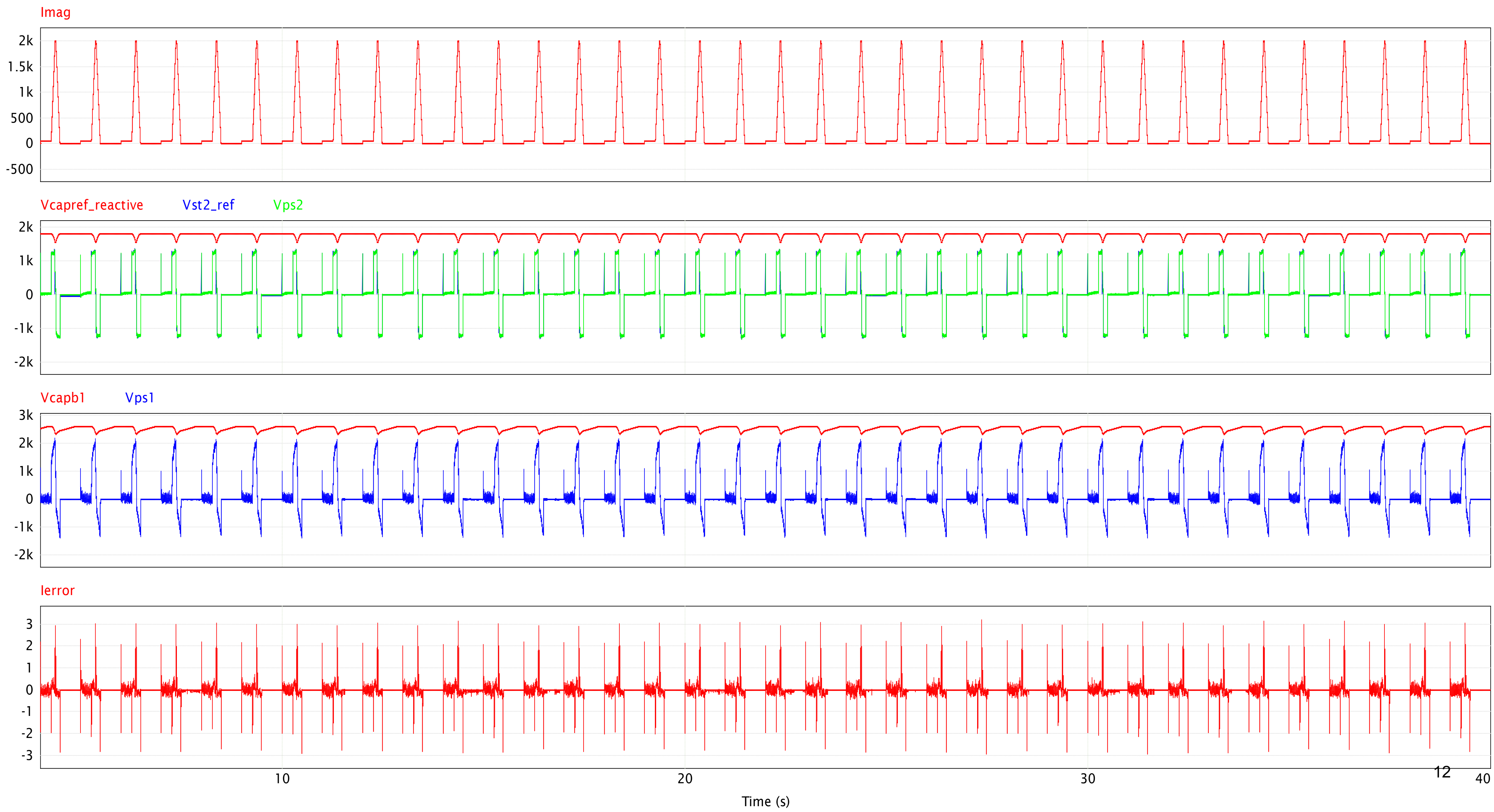
Capacitor bank voltage station 1, capacitor bank reference and voltage station2, magnet current, station 1 and 2 voltages and current error.



Capacitor bank voltage station 1, capacitor bank reference and voltage station2, magnet current, station 1 and 2 voltages
Cap bank 2 was at 0 v. Starting power supply.



Capacitor bank voltage station 1, capacitor bank reference and voltage station2, magnet current, station 1 and 2 voltages Cap bank 2 was at 0 v. Four sec after power supply went on.



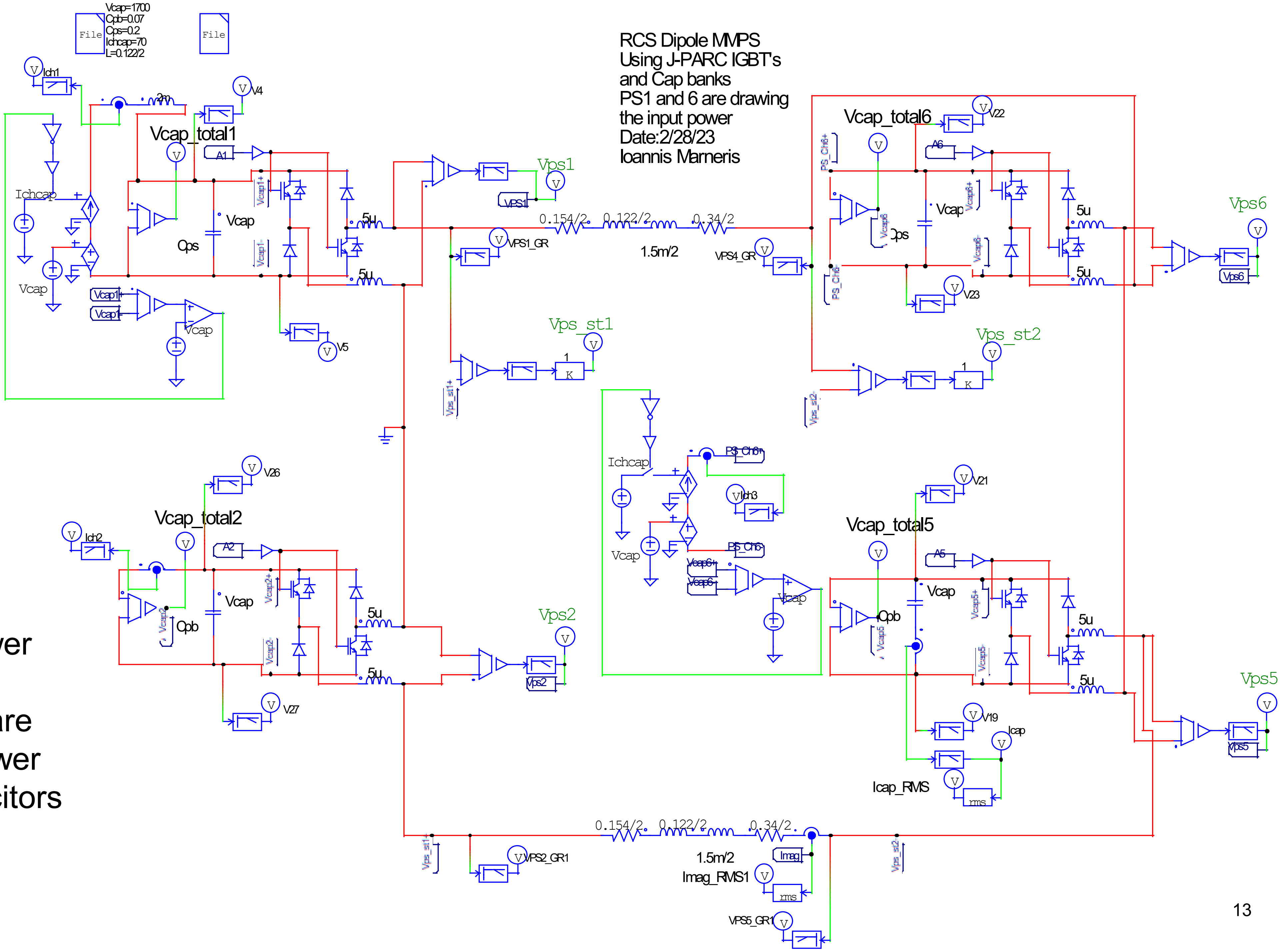
Solution 2, using film capacitors based On the J-PARC design.

4 power supplies in series,

2 supplies with flying capacitors

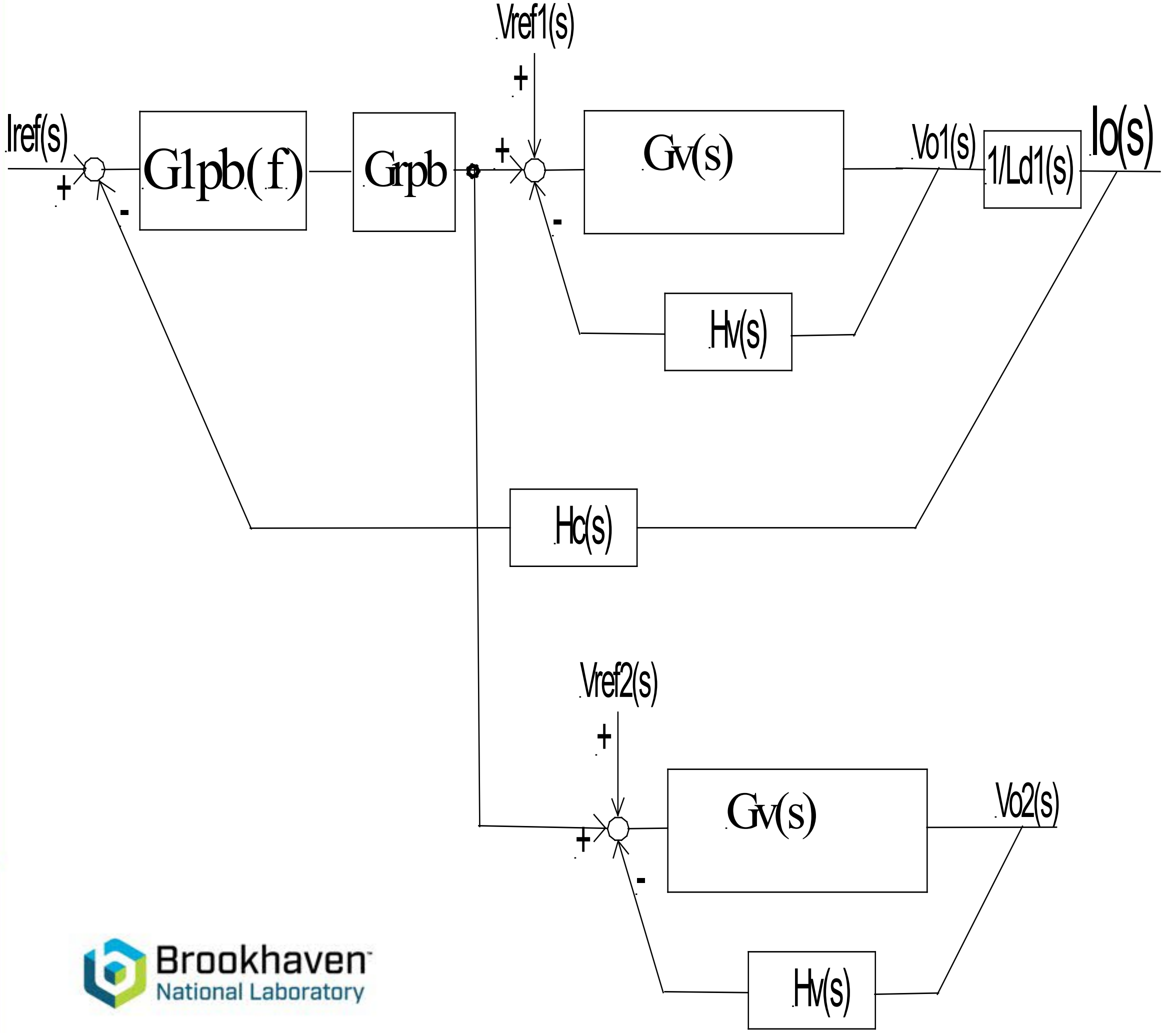
Power supplies 1,6 are drawing real power from the line.

Power supplies 2,5 are Drawing reactive power from the flying capacitors

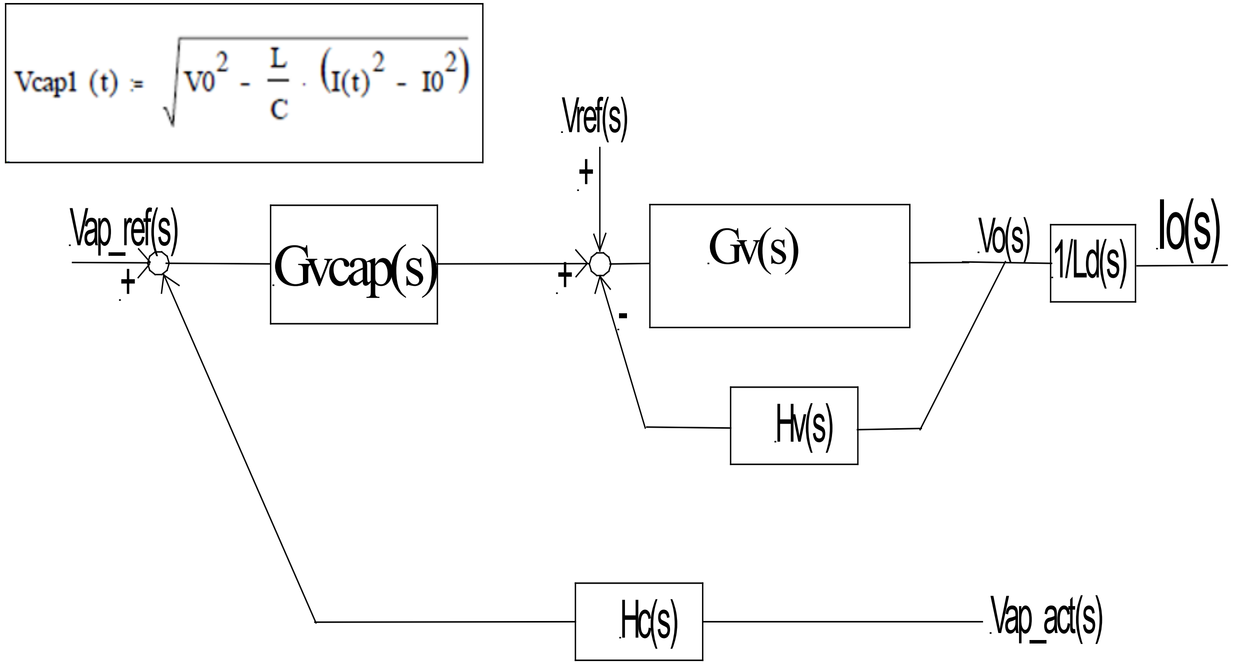


Control Loops of solution 2

One current and two voltage loops of PS's 1 and 6



Two flying cap bank loops, PS's 2,4.



V0=1700 V, C=0.07 F, L=0.122/4 H

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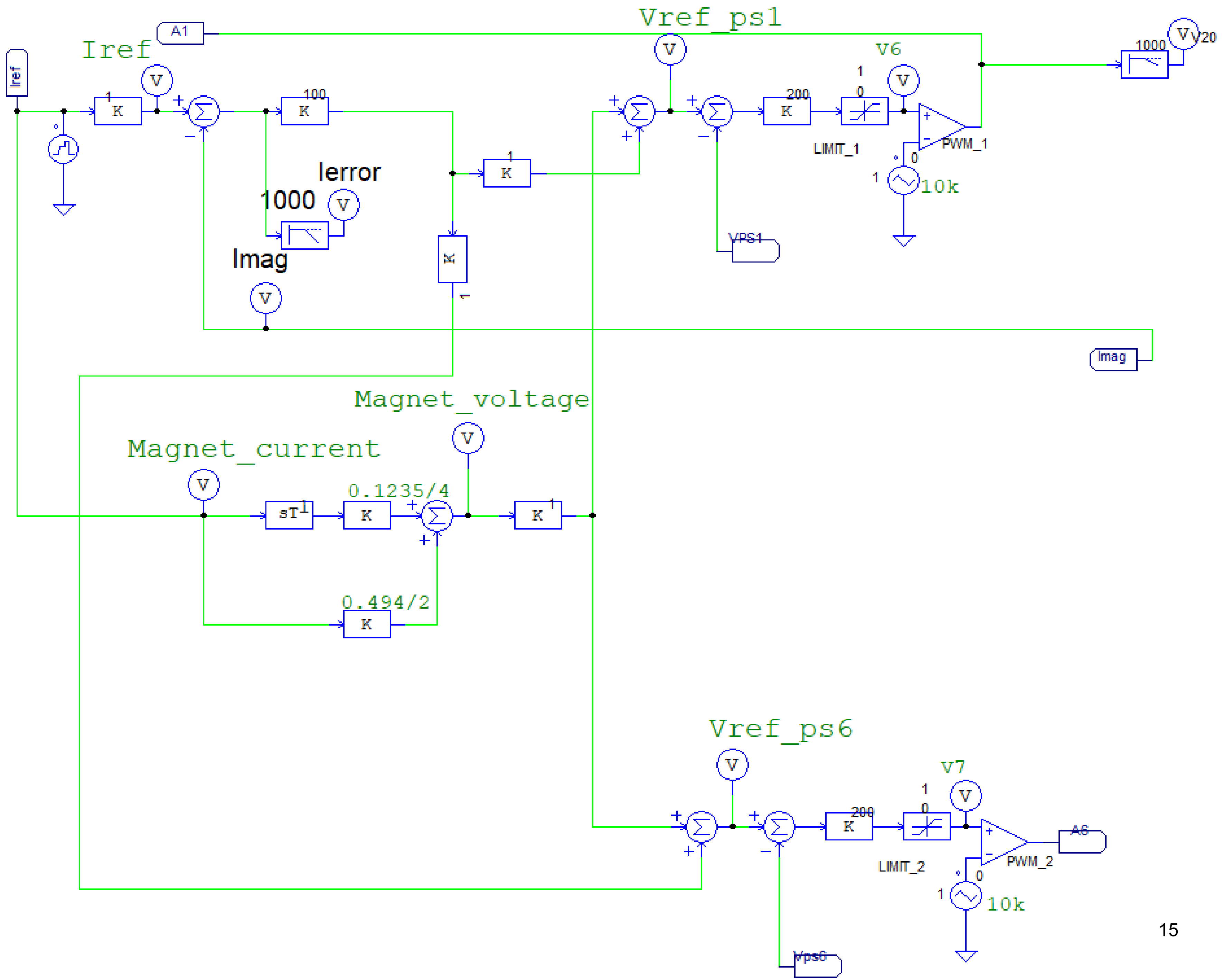
Power supply 1 and 6 voltage and current loops



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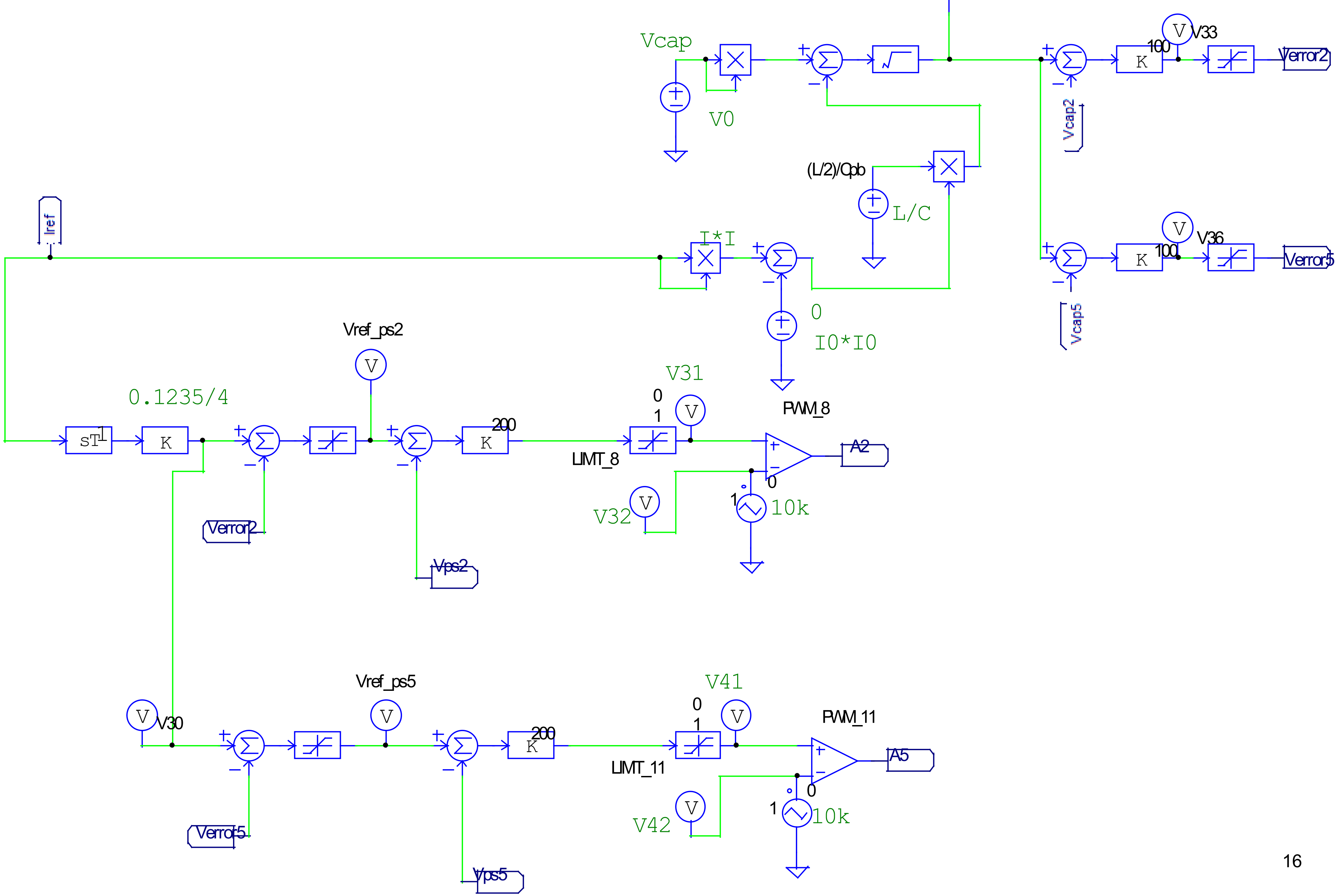
Power supply 2 and 5 voltage loops

$$Vcap1(t) = \sqrt{V0^2 - \frac{L}{C} \cdot \left(I(t)^2 - I0^2\right)}$$

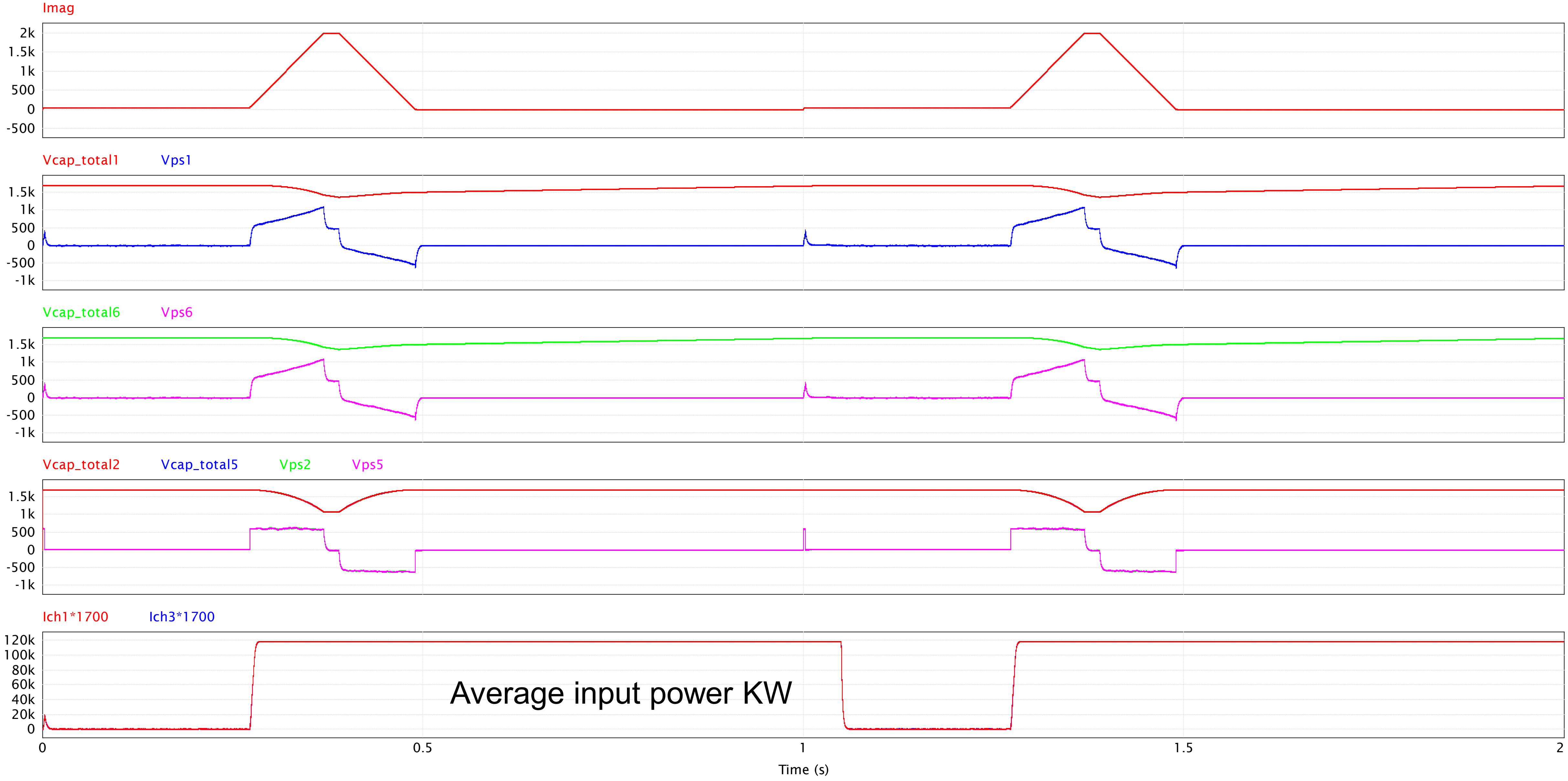
Use this formula if you draw reactive power from Cap Bank



Synopsis of solution 2

- Four H bridges in series each giving us +/-900 V. Two of them are connected to flying cap banks.
- Cap bank of two supplies 0.2 F, 1700 V film caps. Cab bank of the other flying cap supplies, 0.07 F, 1700 V film caps.
- Two Power supplies in series composing station 1, are grounded in the middle.
- Magnet maximum voltage to ground 1100 V.
- Regulating average input power on 2 supplies.
- Average input power 240 KW.
- Cap banks don’t dip more than 37% of charged voltage.

Capacitor bank voltage PS 1,2,5,6 PS voltage 1,2,5.6 magnet current, and input powers ps1, ps6.



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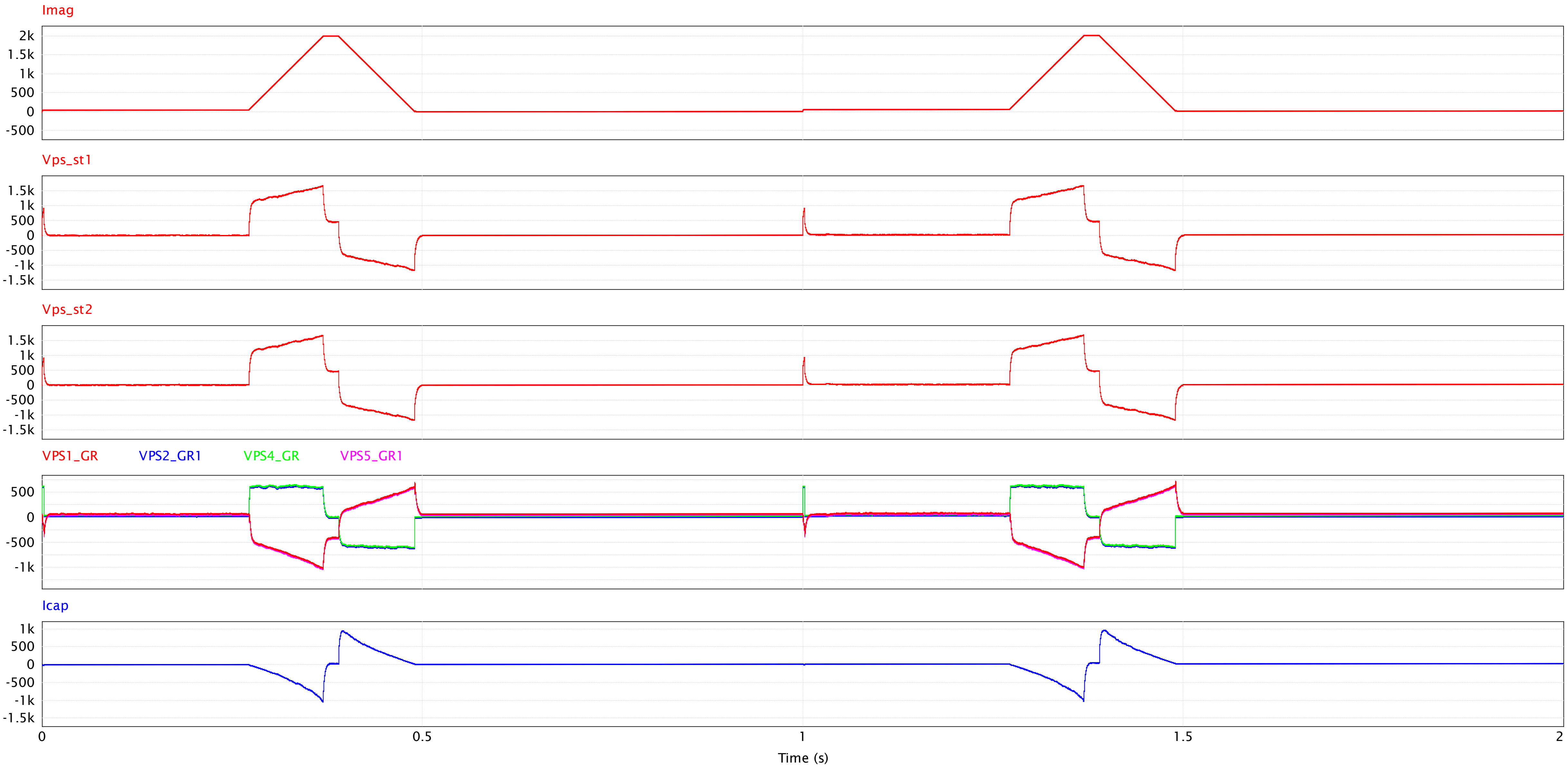
Magnet current station 1 and voltages, magnet voltages to ground and capacitor bank current



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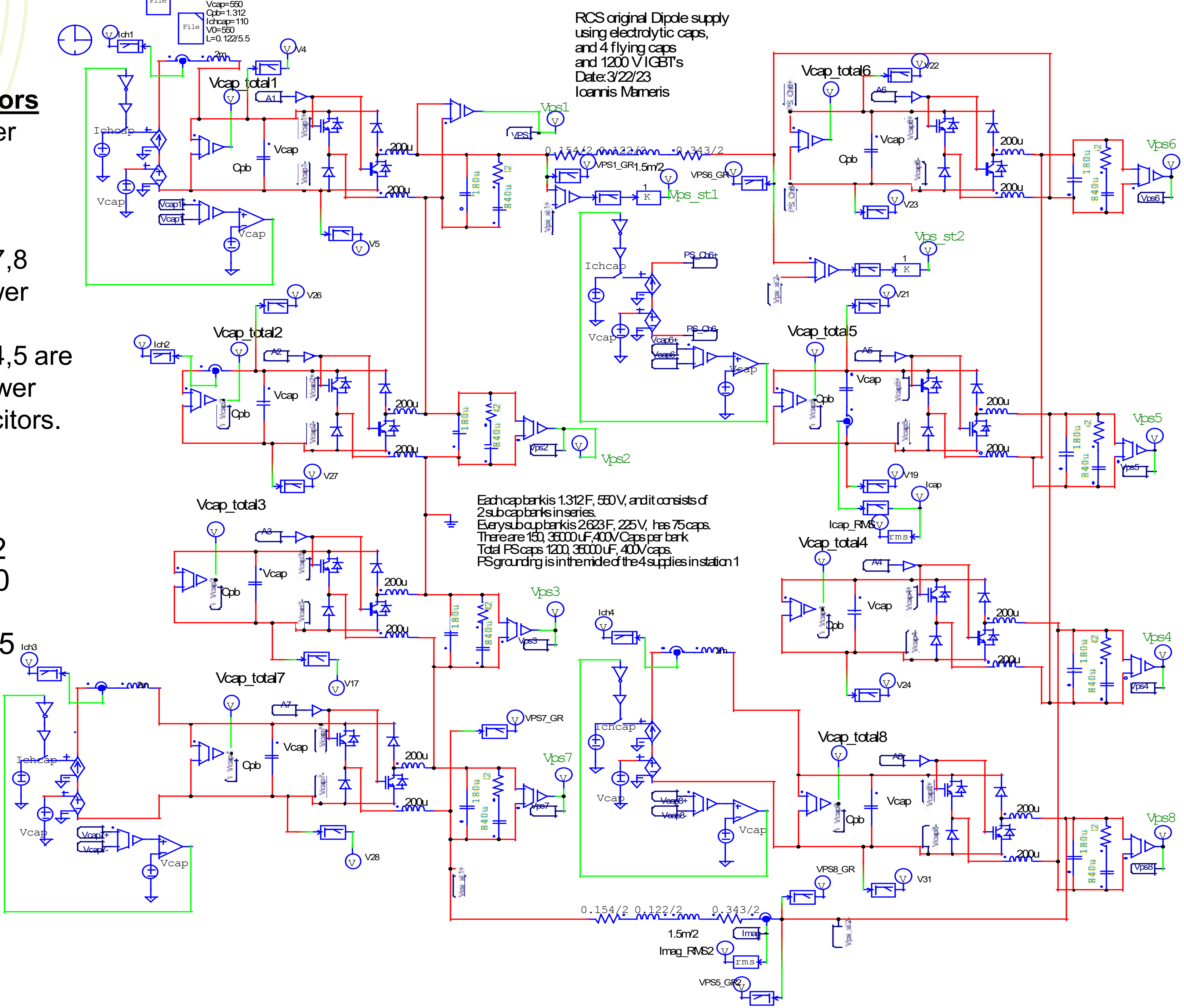
Solution 3, using electrolytic capacitors

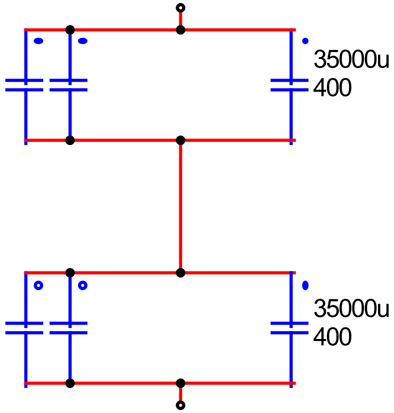
We are using 8 power supplies in series,
4 supplies with flying capacitors.
Power supplies 1,6,7,8 are drawing real power from the line.
Power supplies 2,3,4,5 are Drawing reactive power from the flying capacitors.



File

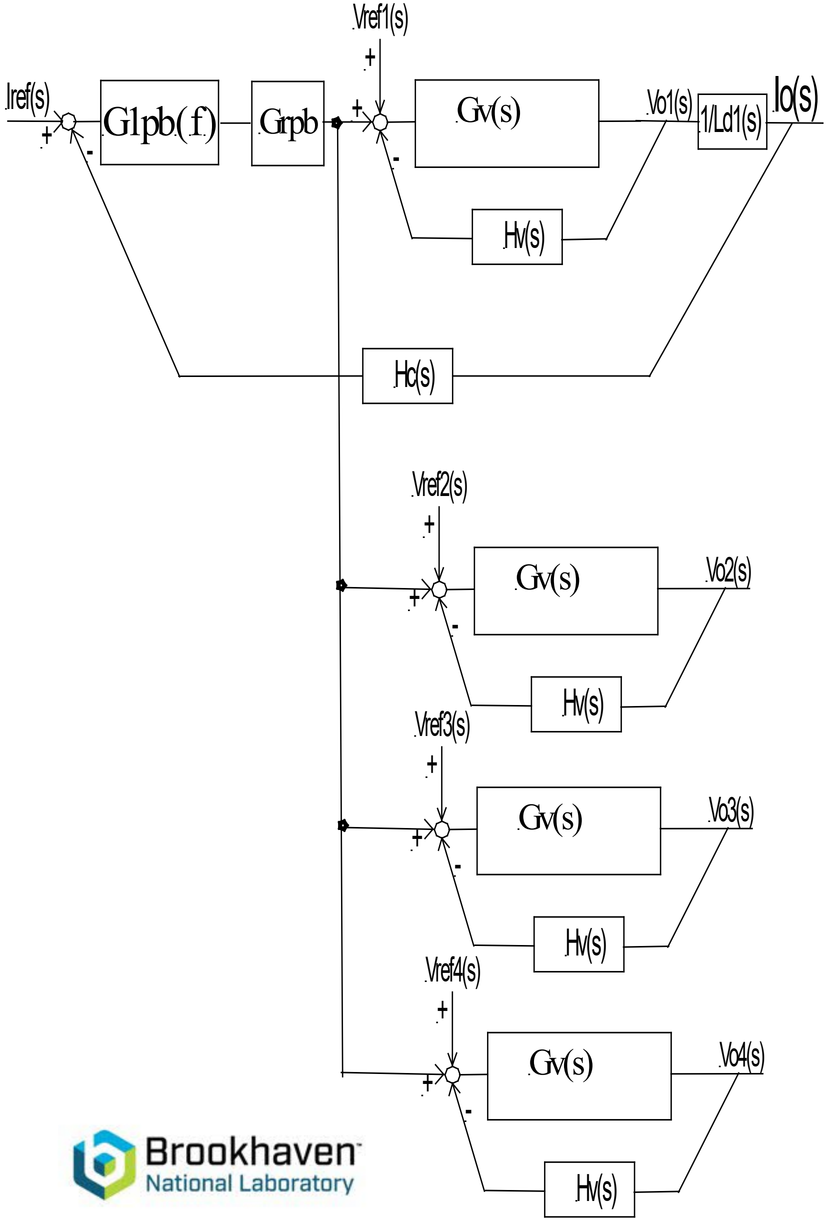
Vcap=550
Cpb=1.312
Ichcap=110
V0=550
L=0.122/5.5

Cap bank 1.315 uF total
Voltage 550 V.
There are 75 caps in parallel.
RMS current per cap 4.32 A
Peak current per cap 22 A



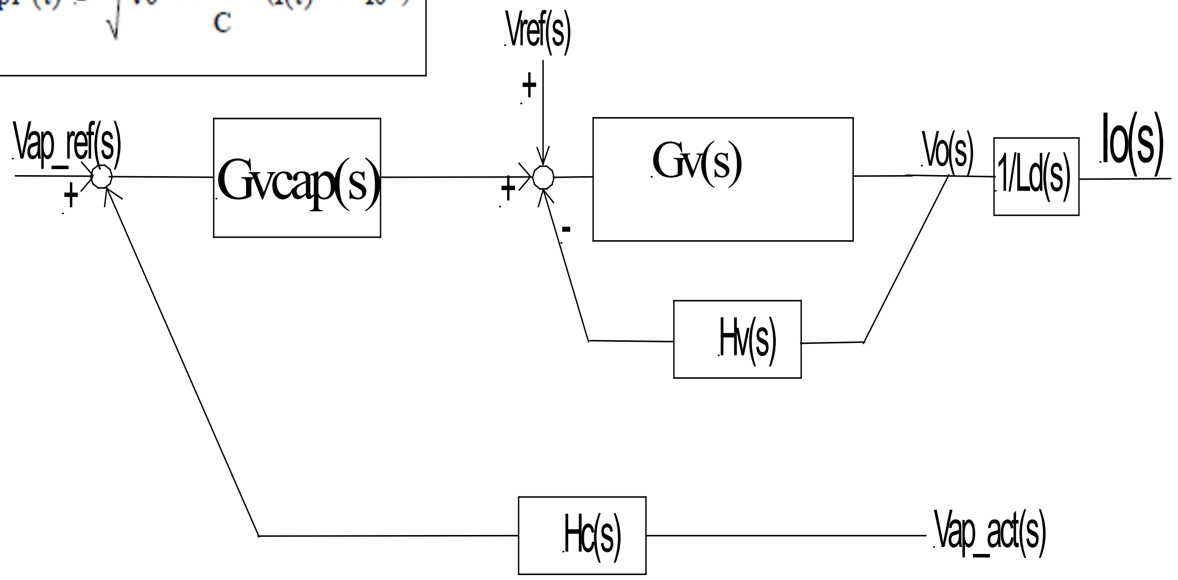
Control Loops of solution 3

One current and four voltage loops, PS's 1,6,7,8



Four flying cap bank loops PS's 2,3,4,5.

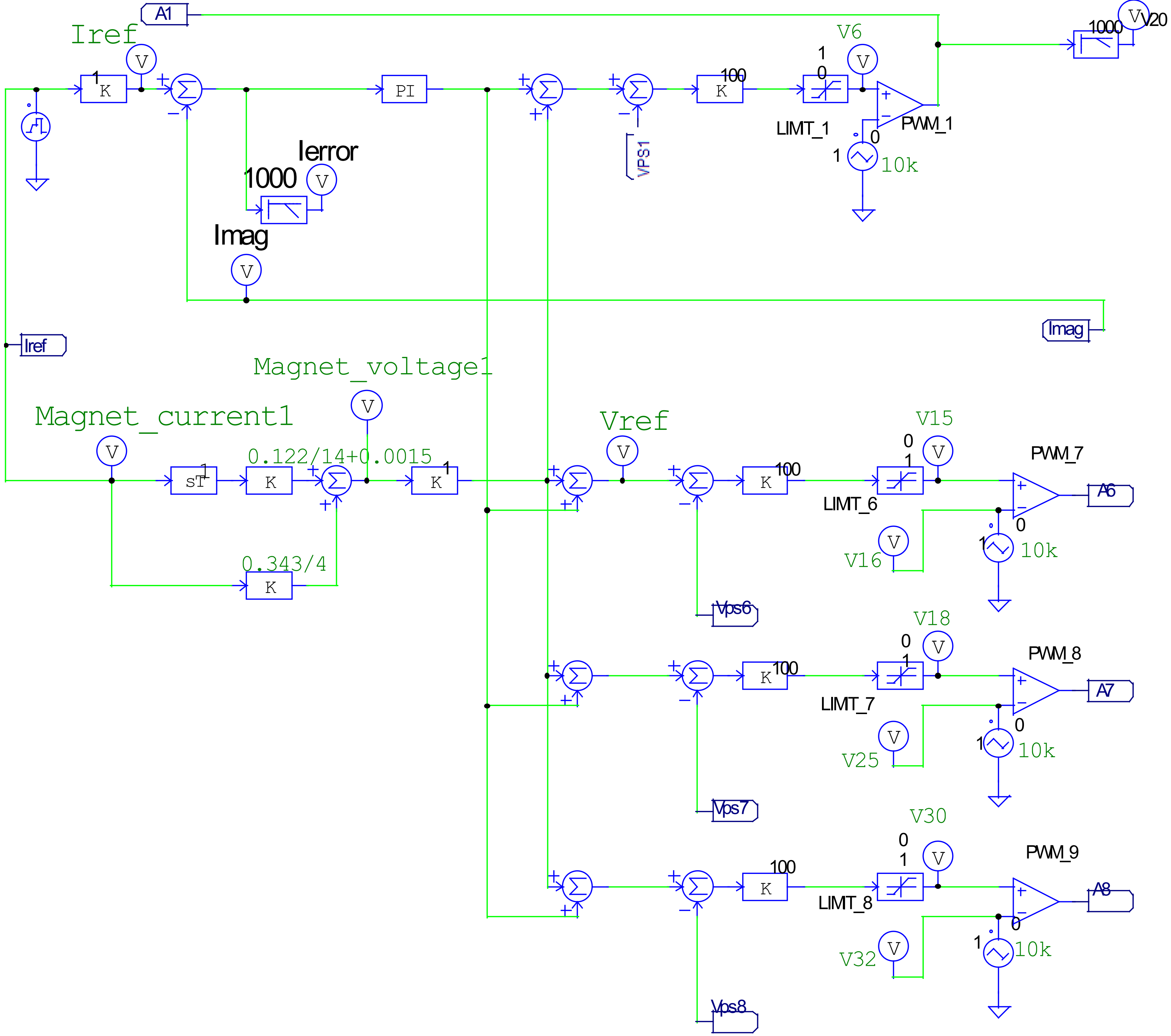
$$\mathrm{Vcap1}\ (t) := \sqrt{\mathrm{V0}^2 - \frac{L}{C} \cdot \left(I(t)^2 - I0^2\right)}$$



V0=550 V, C=1.313 F, L=0.122/5.5 H

Control system. of PS's 1,6,7,8.

Current loop and voltage loops.
Current loop error is fed to PS's 1,6,7,8.
These power supplies have an inner voltage loop.



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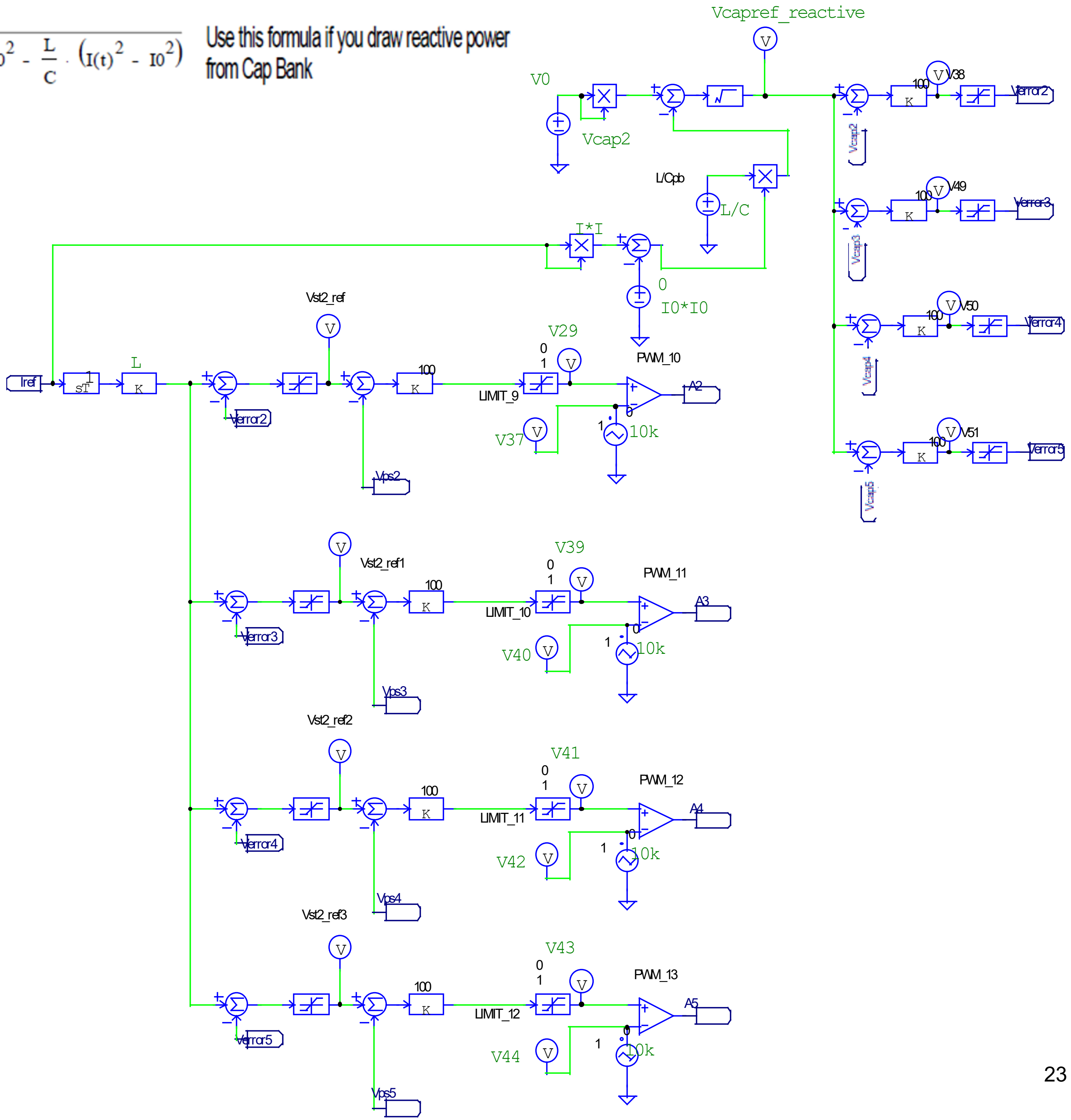
$$Vcap1(t) := \sqrt{V0^2 - \frac{L}{C} \cdot \left(I(t)^2 - I0^2\right)}$$

Use this formula if you draw reactive power from Cap Bank

Control system of ps's 2,3,4,5.

- The voltage reference of these power supplies is calculated as L*dI/dt only and they are the inner loops.
- The outer loops are controling the capacitor bank voltage following the formula below.



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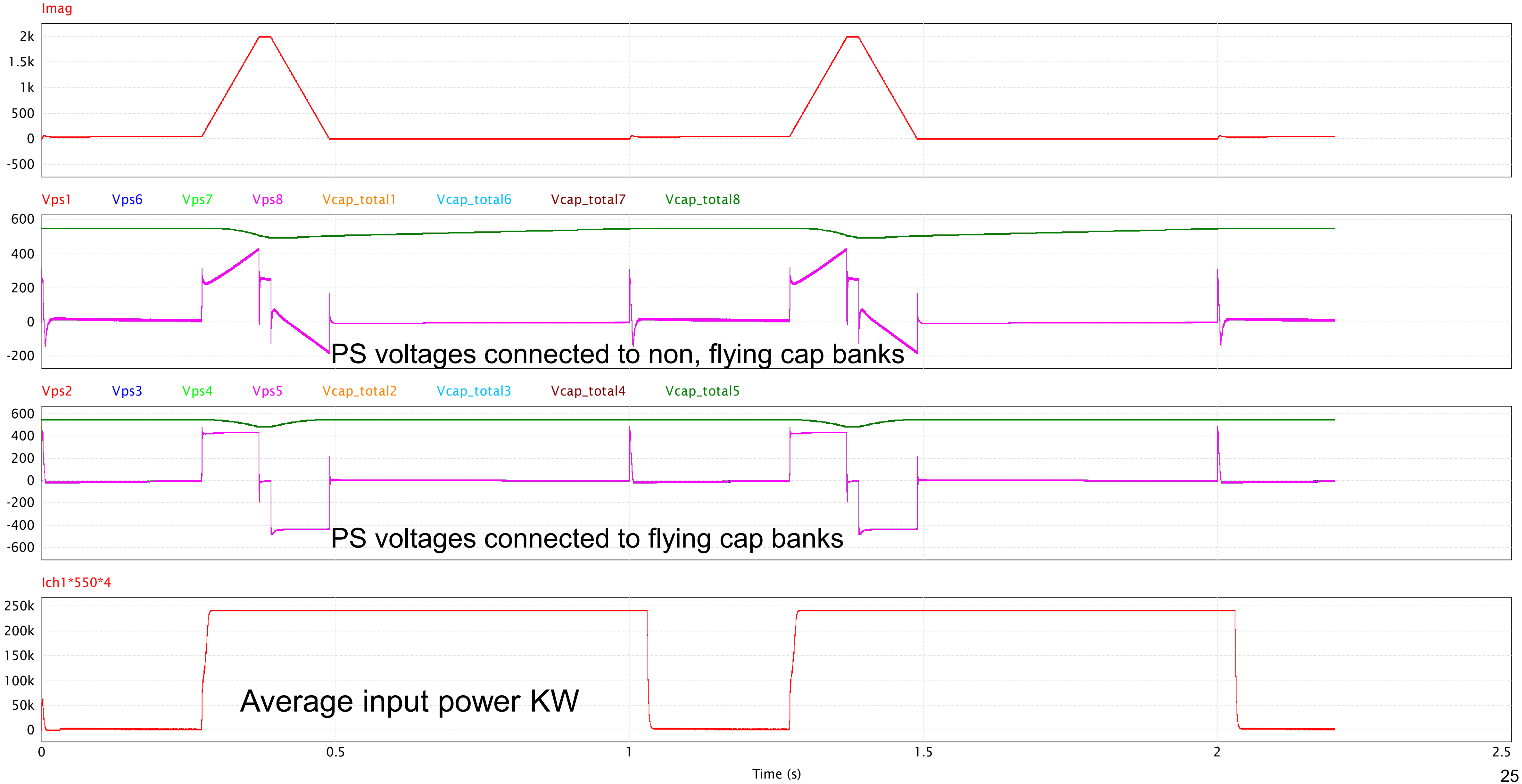
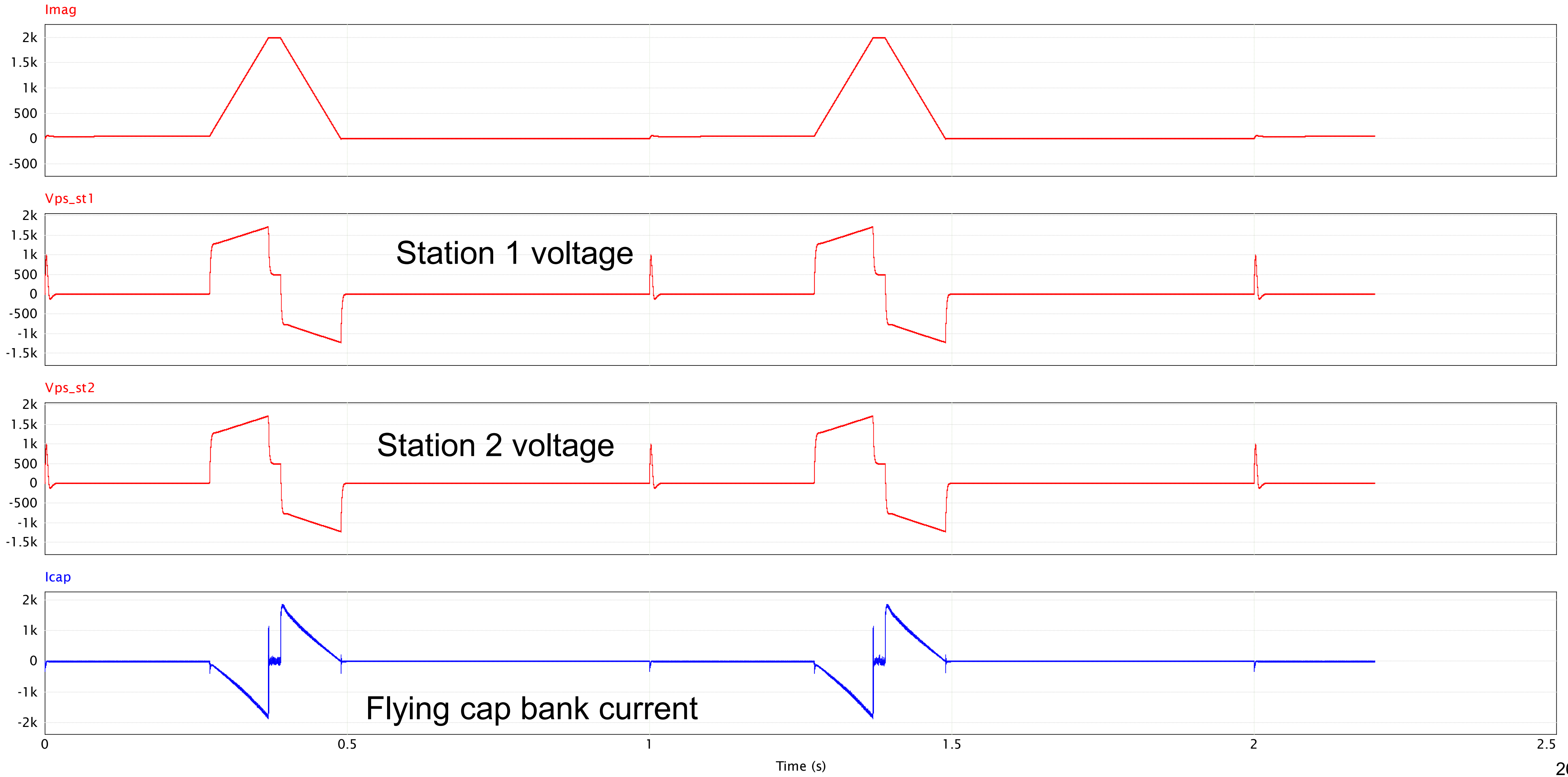
Synopsis of solution 3

- Eight H bridges in series, each giving us +/-450 V. Four of them are connected to flying cap banks.
- Cap bank of each supply 1.312 F, 550 V electrolytic caps.
- Four Power supplies in series composing station 1, are grounded in the middle.
- Magnet maximum voltage to ground 1100 V.
- Regulating average input power on 4 supplies.
- Average input power 240 KW.
- Cap banks don’t dip more than 13% of charged voltage.

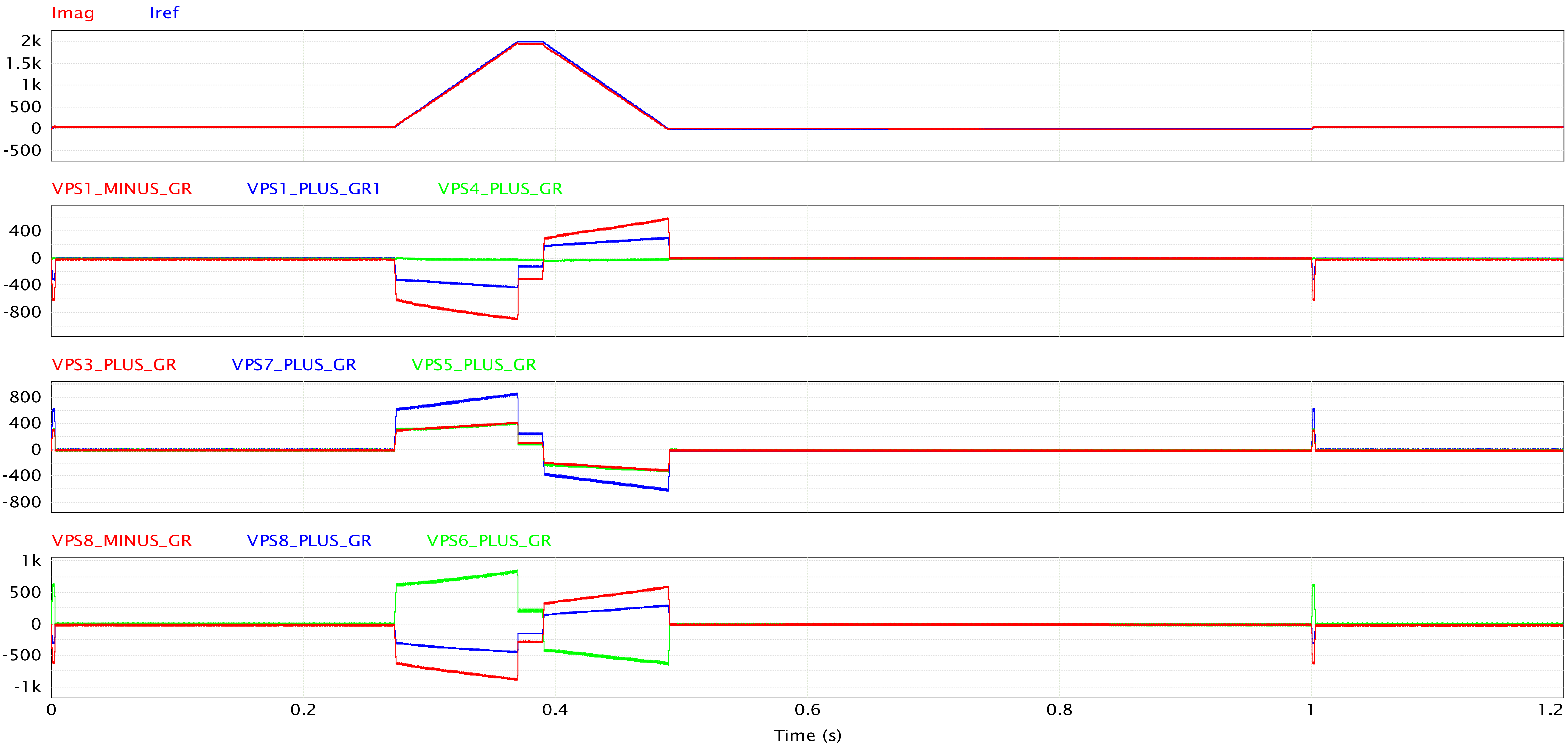
Capacitor bank voltage PS 1,2,3,4,5,6,7,8 PS voltage 1,2,3,4,5,6,7,8 magnet current, and input powers ps1,6,7,8.



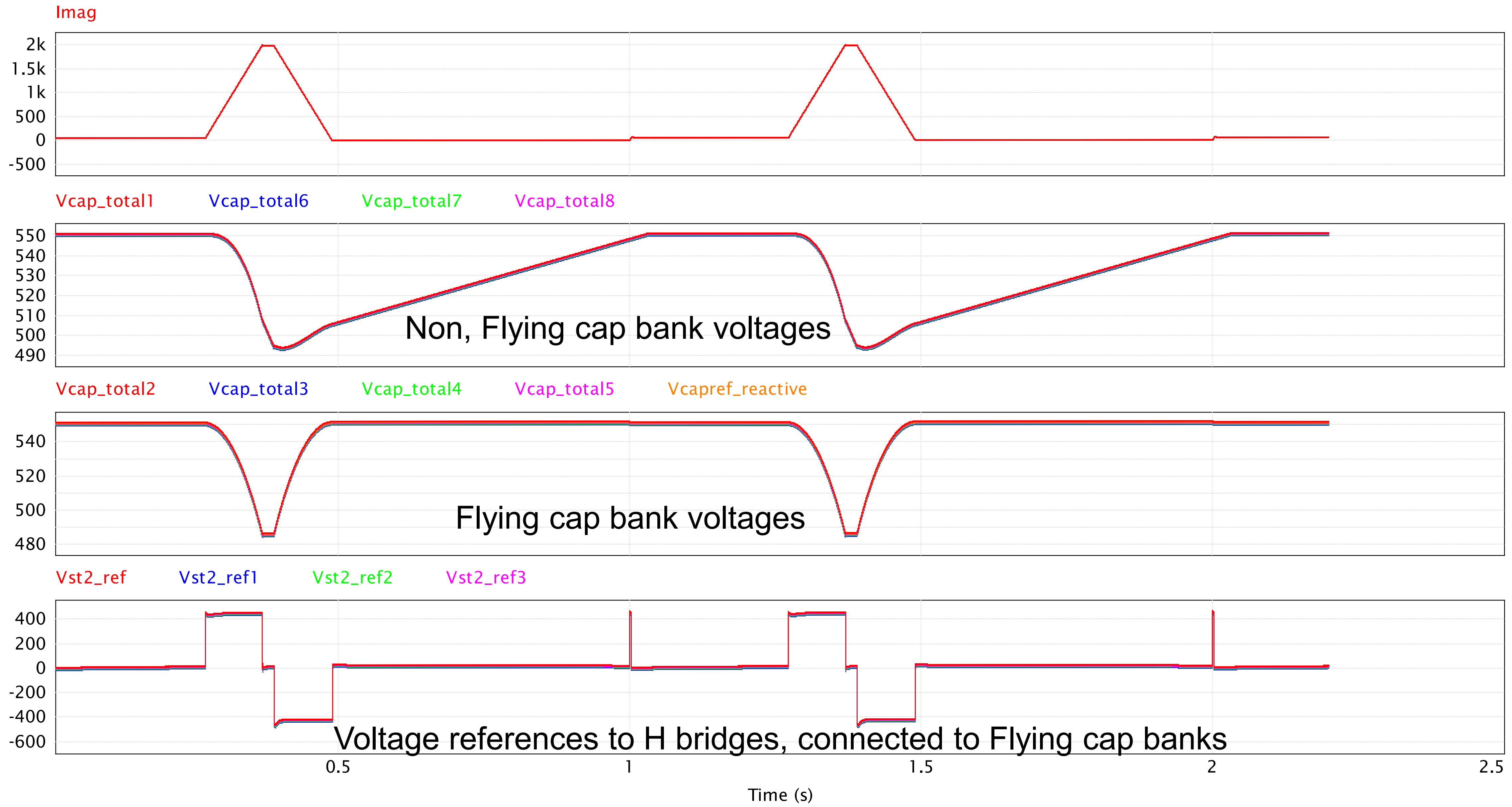
Station 1 and 2 voltages, magnet current, and capacitor bank current of one of the flying capacitors



Power supply voltages to Ground



Capacitor bank voltages, flying capacitor voltage reference and actual voltages, flying capacitor power supply voltage references.



Comparison

All topologies will work, however there may be advantages and disadvantages.

	Advantages?	Disadvantages?
Design based on	Two power supplies in series	Switching frequency 333X6=2KHZ per PS
CERN, POPS-B	Could be 3 level NPC proven designs	High switching losses
	Film capacitors reliability 15 to 20 years?	High voltage of cap banks 2800 V
	Amount of electronics is lower	LC Filter at lower frequency
		More space for cap banks
		Price of film capacitors is more than Electrolytic capacitors
Design based on	Four power supplies	Switching frequency 1 kHz, 2 kHz (output frequency per PS)
J-PARC new supply	Film capacitors reliability 15 to 20 years?	High switching losses
	Lower voltage of cap banks 1700 V	LC Filter at lower frequency
	Amount of electronics is lower	More space for cap banks
		Price of film capacitors is more than Electrolytic capacitors
Design based on	Switching frequency 15 KHZ per PS	Eight power supplies in series
Lawrence Livermore supply	Low switching loses	Life time of electrolytic capacitors?
	LC Filter at higher frequency	Amount of electronics is high
	IGBT design of H bridges is a proven design	
	Less space for capacitor banks	
	Much Lower voltage of cap banks 550 V	
	Price of Electrolytic capacitors is less than film capacitors	

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Summary

- We are in the process of determining answers to the following questions.
  - Which power supply topology is the most reliable?
  - Which topology is the least expensive?
  - Which topology is the simplest to maintain and operate?
  - Which topology occupies the least space?
  - Are there any concerns with flying capacitors?
  - List of manufacturers.
- Your comments are welcome.
- Thank you…

References/ Acknowledgments

- POPS: the 60MW power converter for the PS accelerator: Control strategy and performances
  - Fulvio Boattini; Jean-Paul Burnet; Gregory Skawinski, CERN, Geneva, Switzerland,
- Capacitor bank of power supply for J-PARC MR main magnets
  - Yuichi Morita a,b,*, Yoshinori Kurimoto a,b , Kazuki Miura a , Daichi Naito a,b , Ryu Sagawa c , Tetsushi Shimogawa a,b , Tatsuya Yoshino d
  - a High Energy Accelerator Research Organization, Accelerator Laboratory, Tokai, Ibaraki 319-1106, Japan
  - b The Graduate University for Advanced Studies (SOKENDAI), Tokai, Ibaraki 319-1106, Japan
  - c Universal Engineering, Mito, Ibaraki 310-0851, Japan
  - d Nichicon (Kusatsu) Corporation, Kusatsu, Shiga 525-0053, Japan.

- PSIM simulations by Ioannis Marneris