NEW BOOSTER MMPS

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Outline

- Scope
- Existing Booster MMPS
- Present two solutions for a new supply storing energy in cap banks
- References/Acknowledgments
- Summary
- Backup slides

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Scope

- Pick the right topology for a new Booster Main Magnet Power Supply (MMPS) storing energy in capacitor banks.
- Two different topologies for the Booster MMPS 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.**
- Discursion of the two topologies and questions.

Existing Booster MMPS

- The Booster Main Magnet Power Supply (MMPS) is a 24 pulse, thyristor control supply, rated at 5500 Amps, +/-2000 Volts, or 3000 Amps, +/-6000 Volts.
- The power supply is fed directly from the power utility and the peak magnet power is 18 MWatts.
- The Booster MMPS consists of six pairs of thyristor controlled, power supplies, connected in series and implemented in two stations.
- Each pair, is a 24 pulse, controlled rectifier, rated at +/- 1000 volts DC.
- IAB and IIAB power supplies are rated for 5500 Amps DC, while the rest of the units are rated for 2800 Amps DC.
- PS 1AB has a current loop and an inner voltage loop, PS's 2AB,1CD,2CD,1EF and 2EF the have voltage loops.
- Magnet Resistance (R) 0.107 Ohms
- Magnet Inductance (L) 0.145 H
- Magnet RMS current 3000 A.

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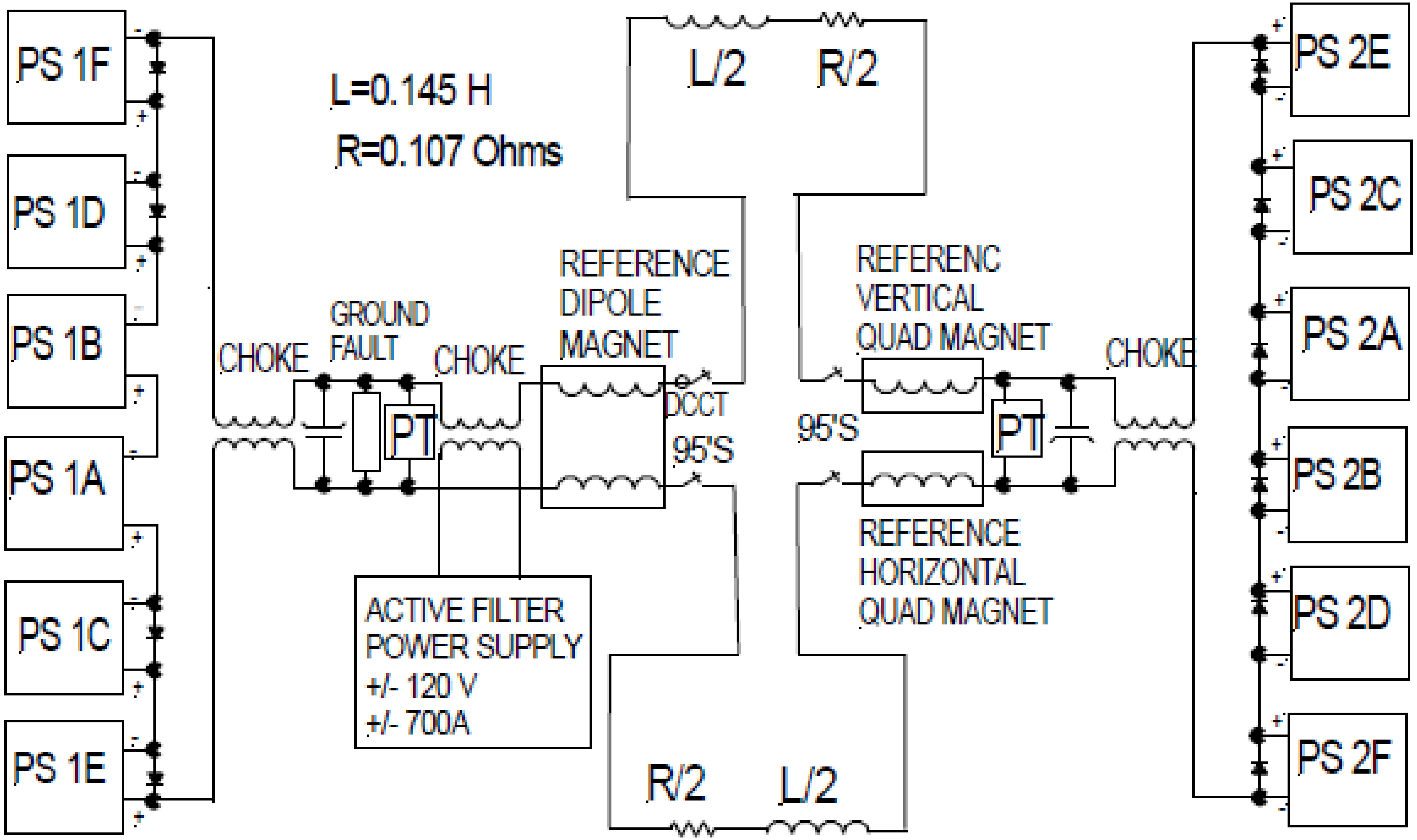
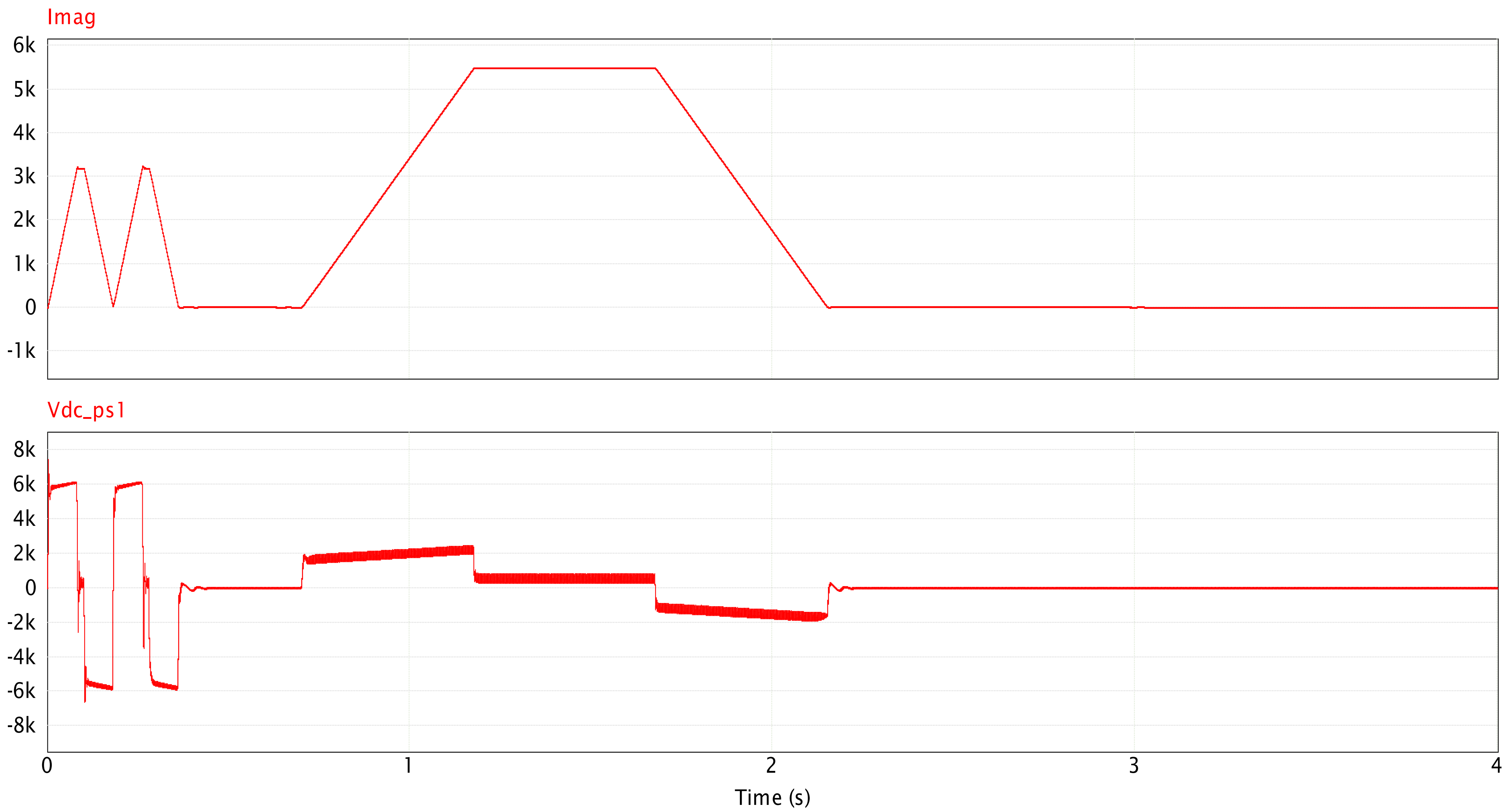
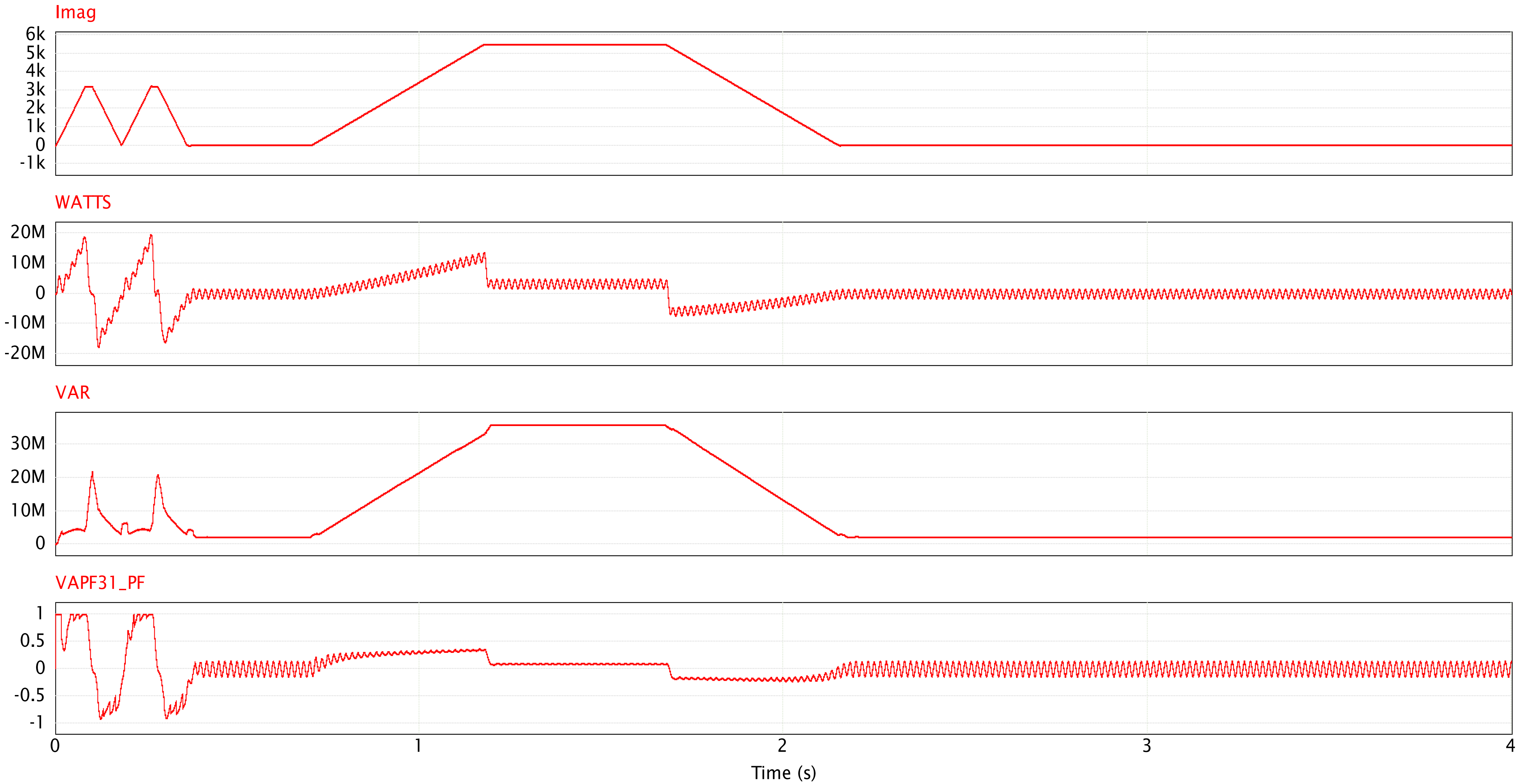
Existing Block Diagram of BMMPS



Simulation results of Existing BMMPS. Magnet current, magnet voltage



Simulation results of Existing BMMPS. Input power, VAR, power factor.



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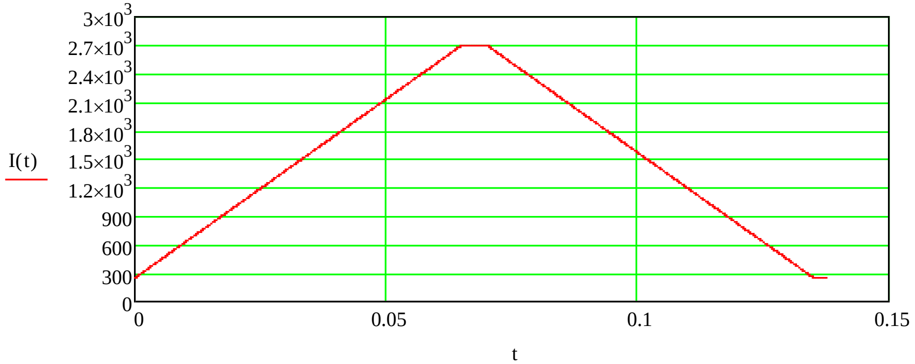
Calculations of Existing BMMPS. Magnet current, magnet voltage and %Flicker

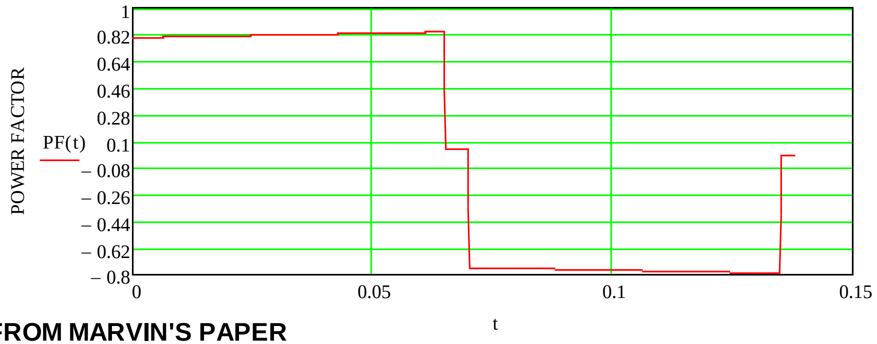
$Vtrans := 210$ $\quad Edo1A := Vtrans \cdot 1.35$ $\quad Edo1A = 283.5$

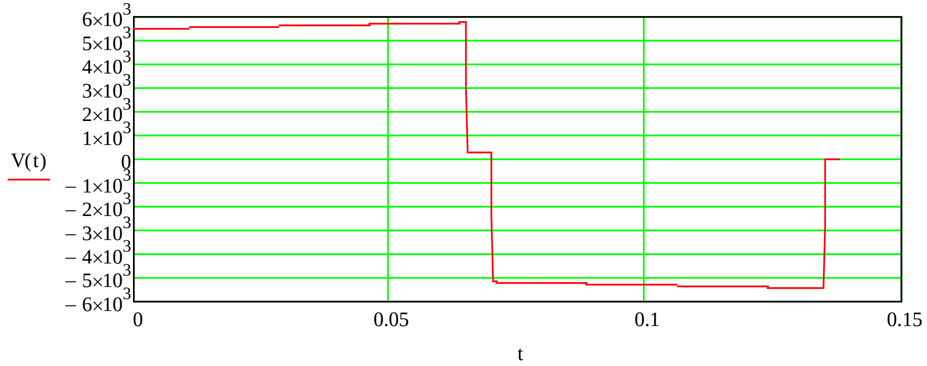
for 12 pulse rectifier q=12

$q := 12$

$$PF(t) := \frac{\frac{V(t)}{24}}{Edo1A} \cdot \frac{q}{\pi} \cdot \sin\left(\frac{\pi}{q}\right)$$





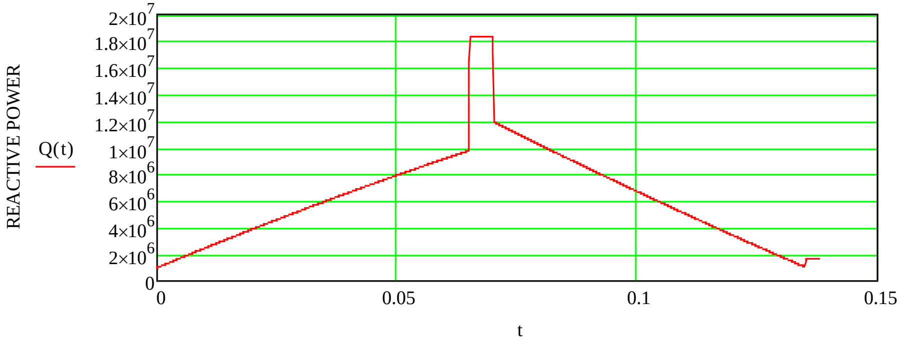


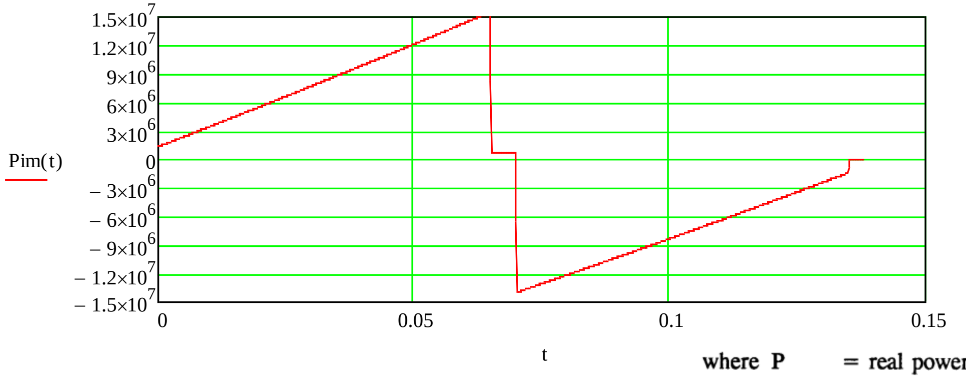
FROM MARVIN'S PAPER

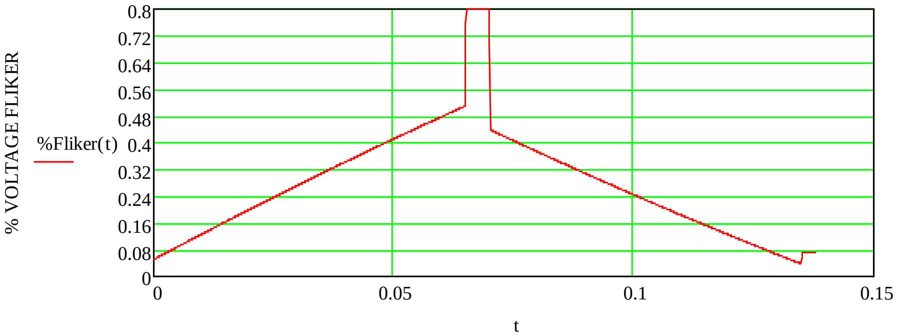
$R := 0.265$ $\quad X := 2.063$ $\quad SCC := 2308 \cdot 10^6$

$$Q(t) := \tan\left(\text{acos}\left(\frac{\frac{V(t)}{24}}{Edo1A}\right)\right) \cdot Pim(t)$$

$$\%Fliker(t) := \frac{Q(t) + Pim(t) \cdot \left(\frac{R}{X}\right)}{SCC} \cdot 100$$







where P = real power
Q = reactive power
SCC = short circuit capacity of the port
$\left(\frac{r}{x}\right)$ = ratio of resistance to reactance at the port

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CERN, POPS-B DC/DC Converter block diagram. Three **18 MW, 6000 A / 3000 V.**

The DC/DC converter shall consist of two identical power modules, each of them acting as a pole of an H bridge.

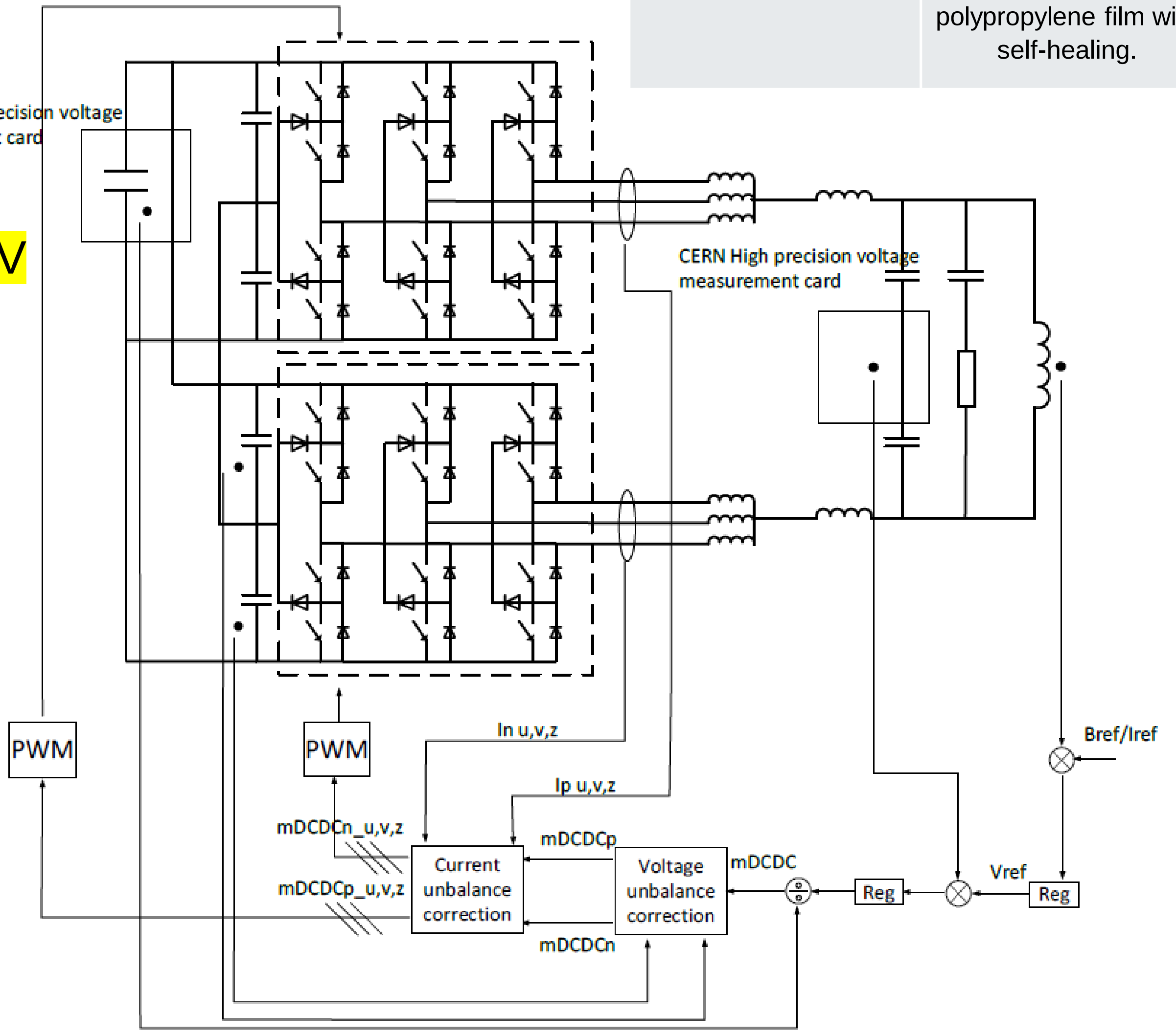
A 3-level neutral point clamped (NPC)

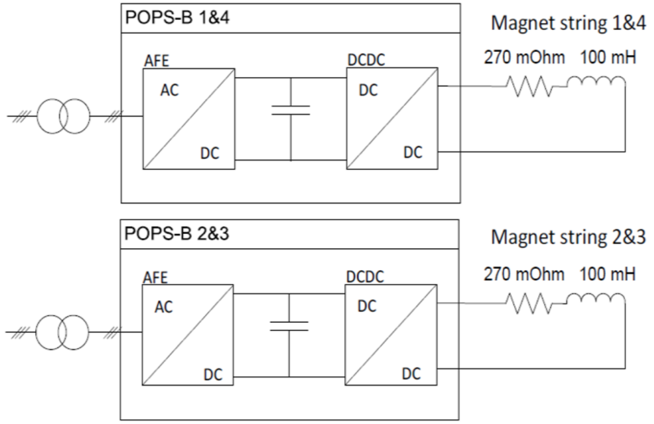
The PWM operation of all 3L-NPC legs shall be interleaved as shown to reduce the output voltage and current ripple and move the lowest frequency up by a factor of six with respect to the switching frequency. Given a switching frequency of 333 Hz, the equivalent lowest output voltage PWM frequency shall then be 2000 Hz. The switches shall be IEGT or IGCT and use press-pack technology.

Capacitor type	Metalized polypropylene film with self-healing.

0.3 F

5000 V





Fulvio Boattini, Cern.

Figure 21: DC/DC control functional diagram

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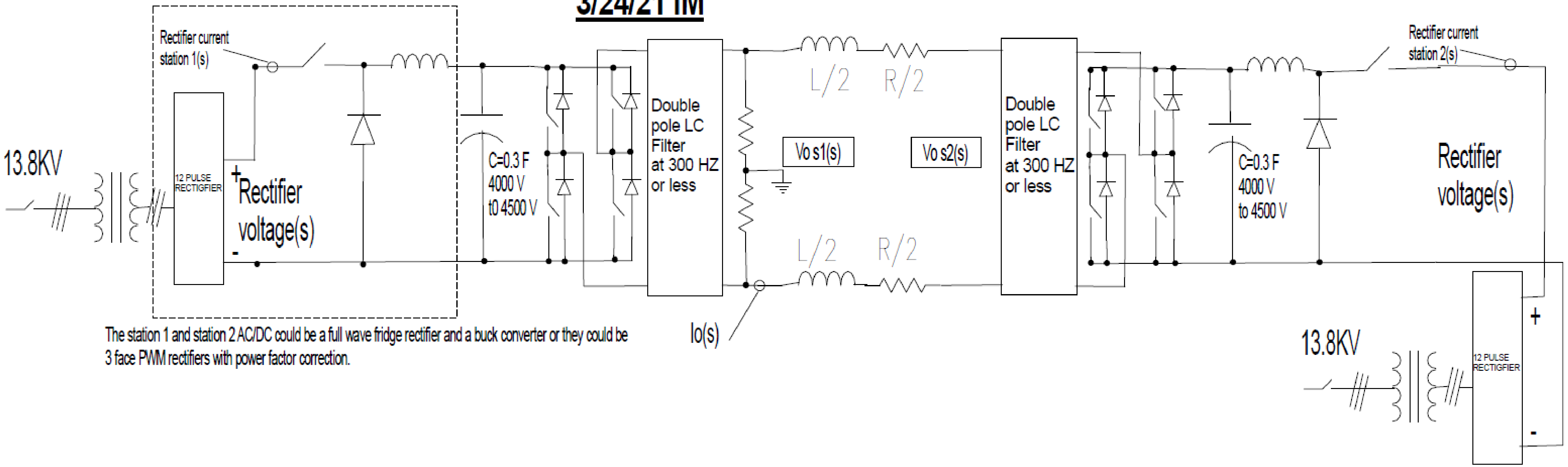
New Booster MMPS POWER and control system
3/24/21 IM



The station 1 and station 2 AC/DC could be a full wave fridge rectifier and a buck converter or they could be 3 face PWM rectifiers with power factor correction.

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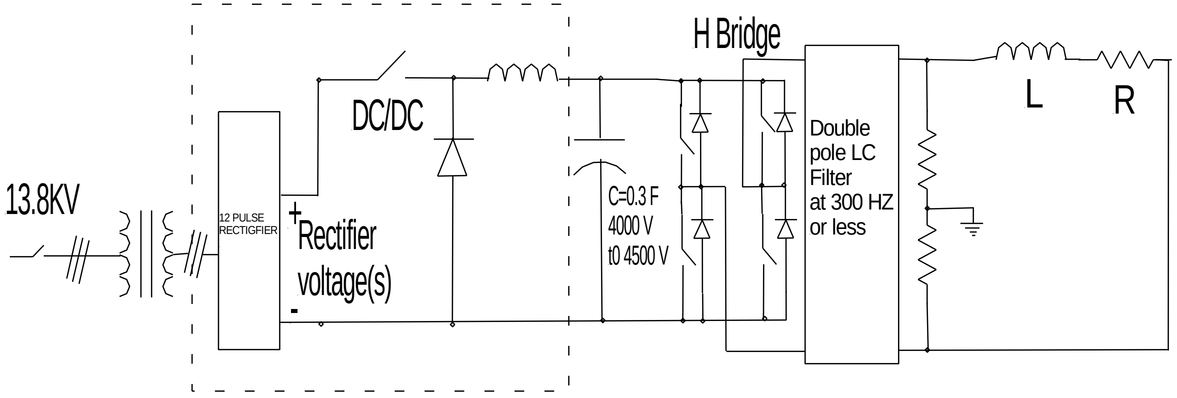
Regulation schemes of Solutions 1A, 1B

1. Regulation of 4 quadrant dc/dc converters, or 3 level NPC.
   - Station I PS has a current loop and a voltage loop within the current loop. I ref and Verf of loops provided by BNL
   - Station II only a voltage loop Vref of loop provided by BNL.
2. power regulation loops of buck converters.
   - A . Regulate station I and II average powers over a super cycle using a power reference of the anticipated average power over the super cycle provided by BNL. Use one for station I and one for station II.
   - B. Use a current limit to regulate input power in both modes explained above depending on our choice.
   - C. Regulate station I and II active peak powers over a super cycle using the formula for Vcap1(t) one for station I and one for station II.

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

- V0=5000 V, C=0.166 F, L=0.145/2 H

Mathcad analysis to calculate the cab bank wave forms for drawing average power or real peak power from the in coming line



$C := 0.3$

$P := Pam$

$Pam := \frac{Pam}{2}$

$P = 7.181 \times 10^{5}$

$V0 := 4000$

$R := \frac{R}{2}$

$L := \frac{L}{2}$

$$Vct(t) := \frac{\sqrt{C \cdot \left(L \cdot I0^{2} + C \cdot V0^{2} - L \cdot I(t)^{2} - 2 \cdot R \cdot \int_{0}^{t} I(t)^{2}\, dt + 2 \cdot Pam \cdot t \right)}}{C}$$

REAL PLUS REACTIVE

$I0 := Ifp$

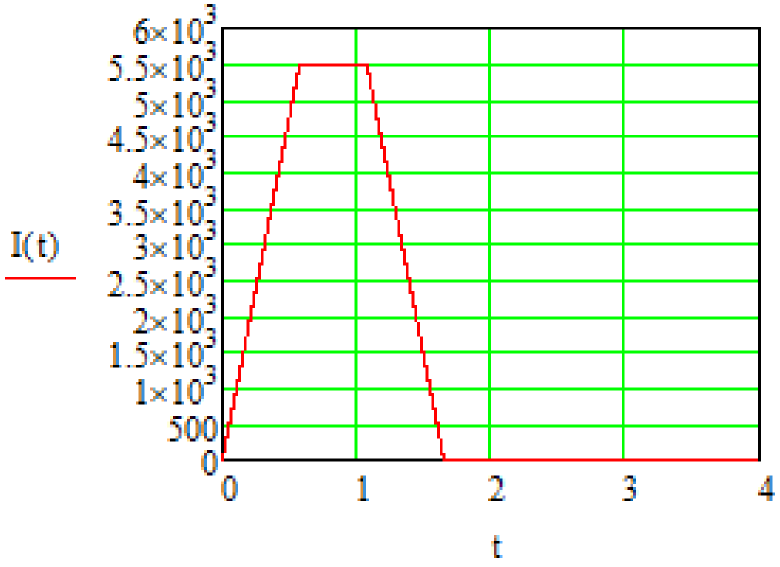
$I0 = 0.35$

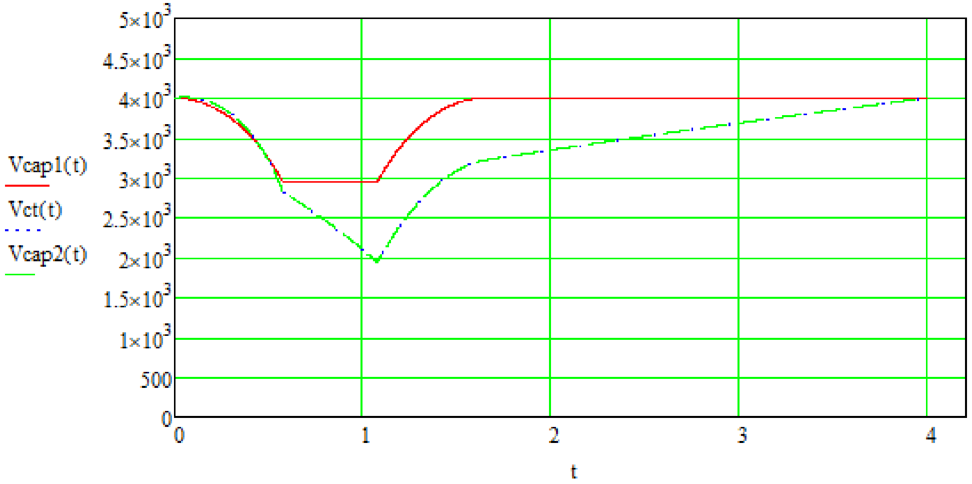
$$Vcap1(t) := \sqrt{V0^{2} - \frac{L}{C} \cdot \left(I(t)^{2} - I0^{2} \right)}$$

REACTIVE

$$Vcap2(t) := \sqrt{Vcap1(t)^{2} + \frac{2}{C} \cdot \left(Pam \cdot t - R \cdot \int_{0}^{t} I(t)^{2}\, dt \right)}$$

REAL PLUS REACTIVE





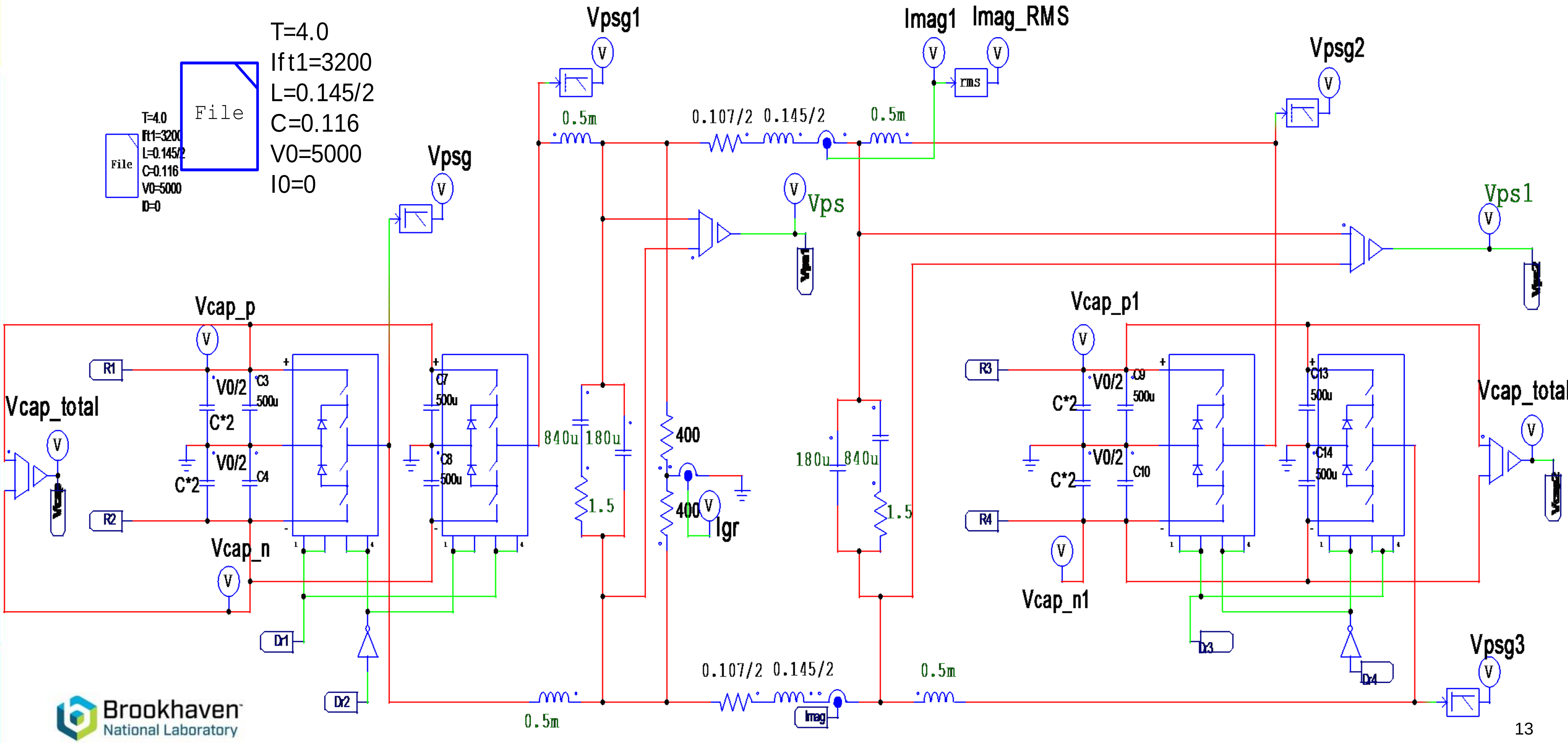
$R = 0.054$

$L = 0.073$

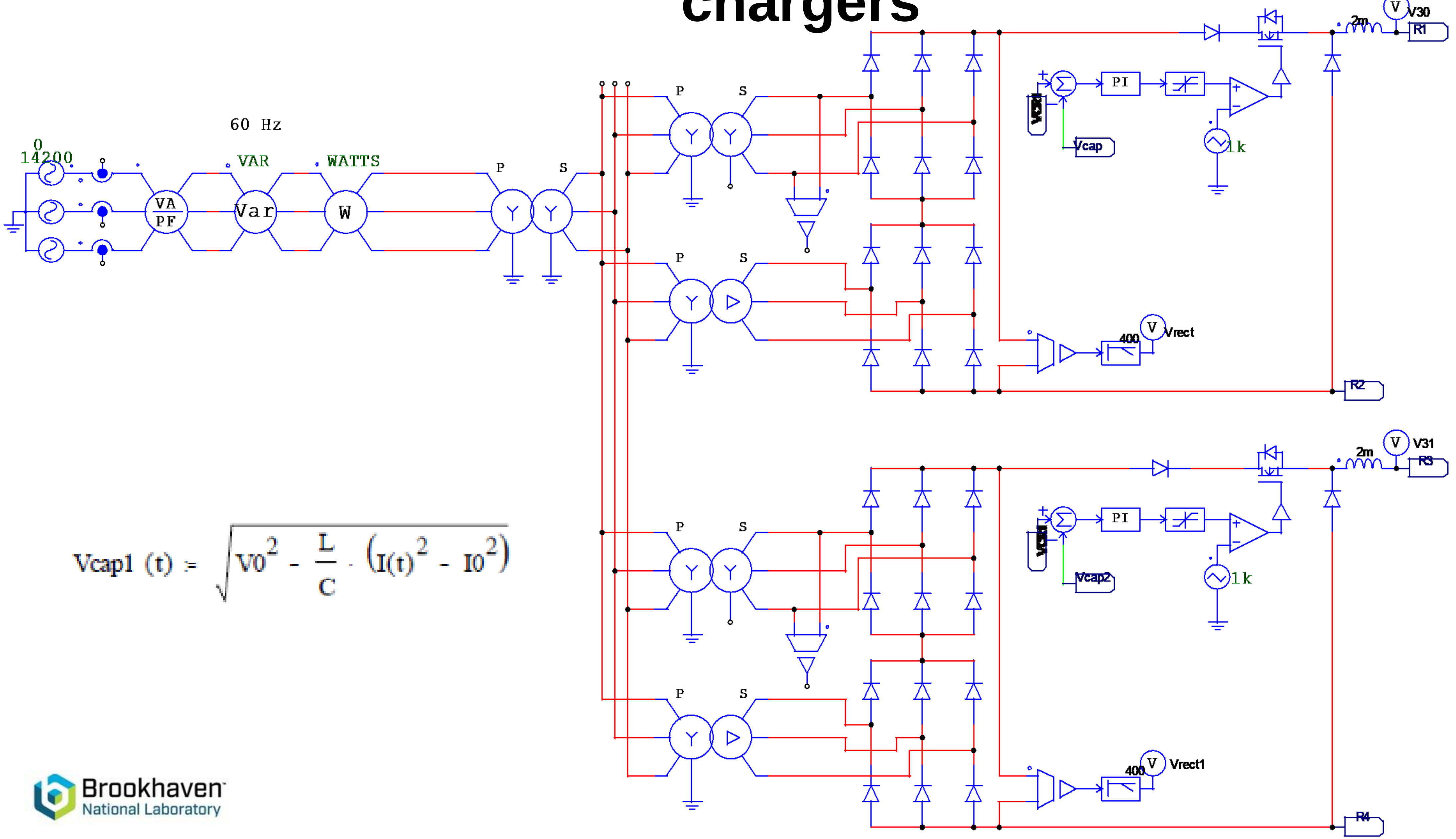
$Pam = 3.591 \times 10^{5}$

Booster MMPS simulation using 3 level NPC, drawing active peak power from the line

Solution 1A using film capacitor and 2 power supplies in series



Front end, with station 1 and 2 capacitor bank chargers



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

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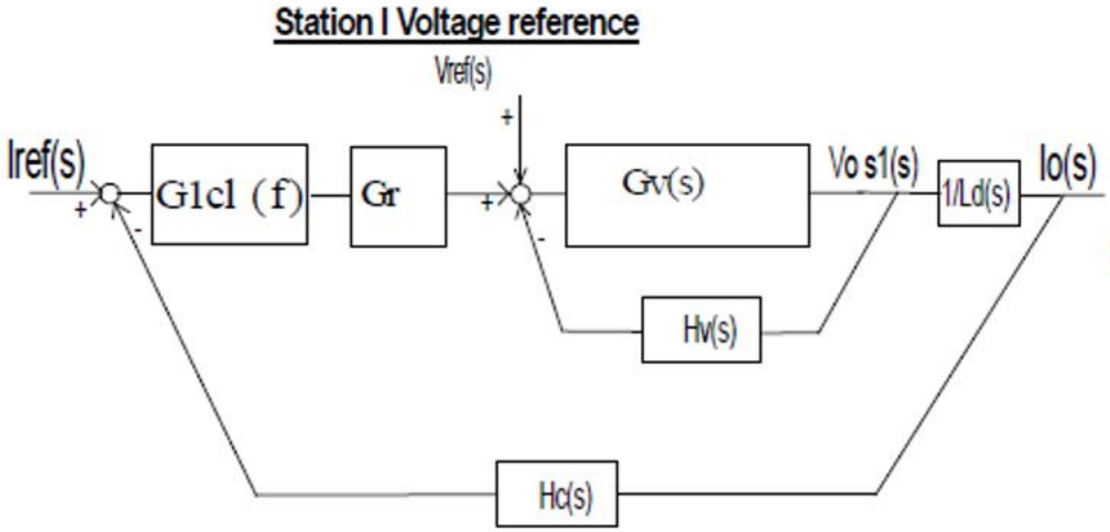
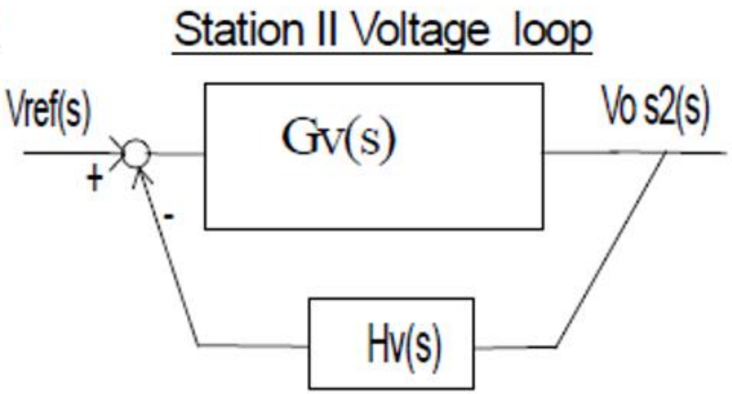
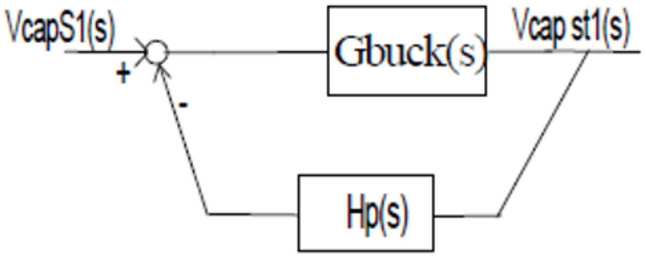
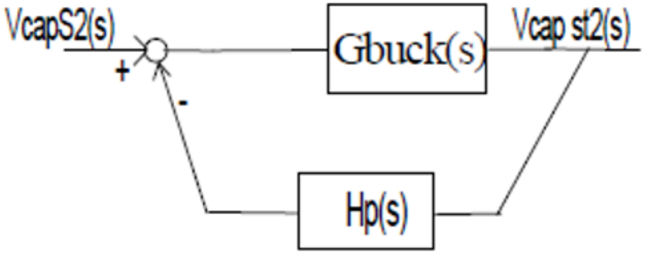
New Booster MMPS Control system, of solution 1A.









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

V0=5000 V, C=0.166 F, L=0.145/2 H

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Synopsis of solution 1A

- We use two, 3 level NPC in series, each giving us +/-3000 V.
- Cap bank station 1 or 2, 5000 V film cap composed of 2 in series, with connection point grounded.
- Each cap bank in series is 0.232 F and sees 2500 V. Total cap bank per station is 0.116 F and it sees 5000 V.
- Power supply in station 1 is grounded in the middle through two 400 Ohm resistors.
- Magnet maximum voltage to ground 1500 V.
- Regulating **active peak input power** on both supplies.
- Maximum input power 3.2 MW.
- Cap banks don’t dip more than 50% of charged voltage.
- Flicker went down from 0.8% to 0.066% a factor of 12.

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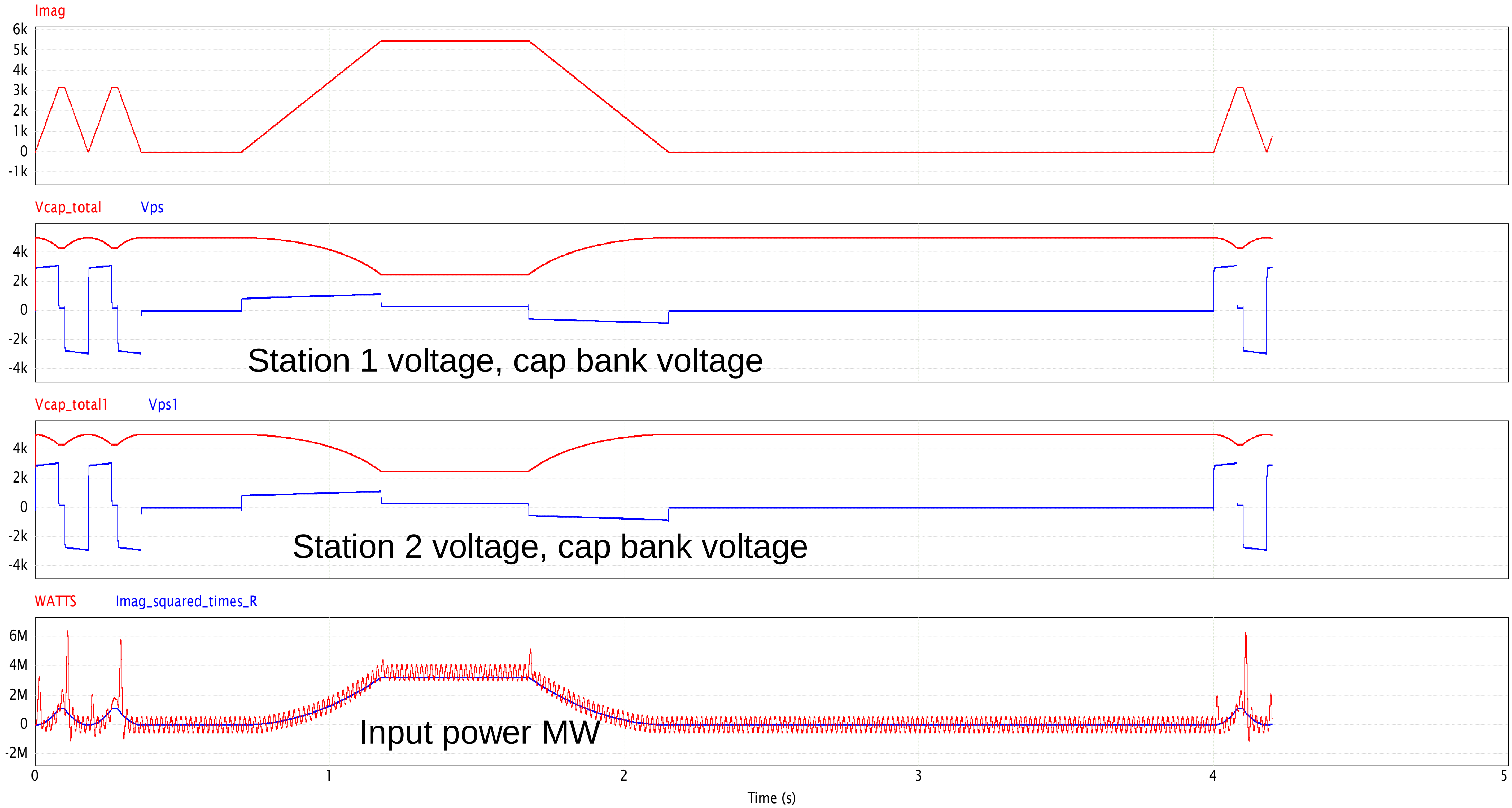
Magnet current, cap bank voltages st1,2 Station 1,2 PS voltages, Input and calculated real power



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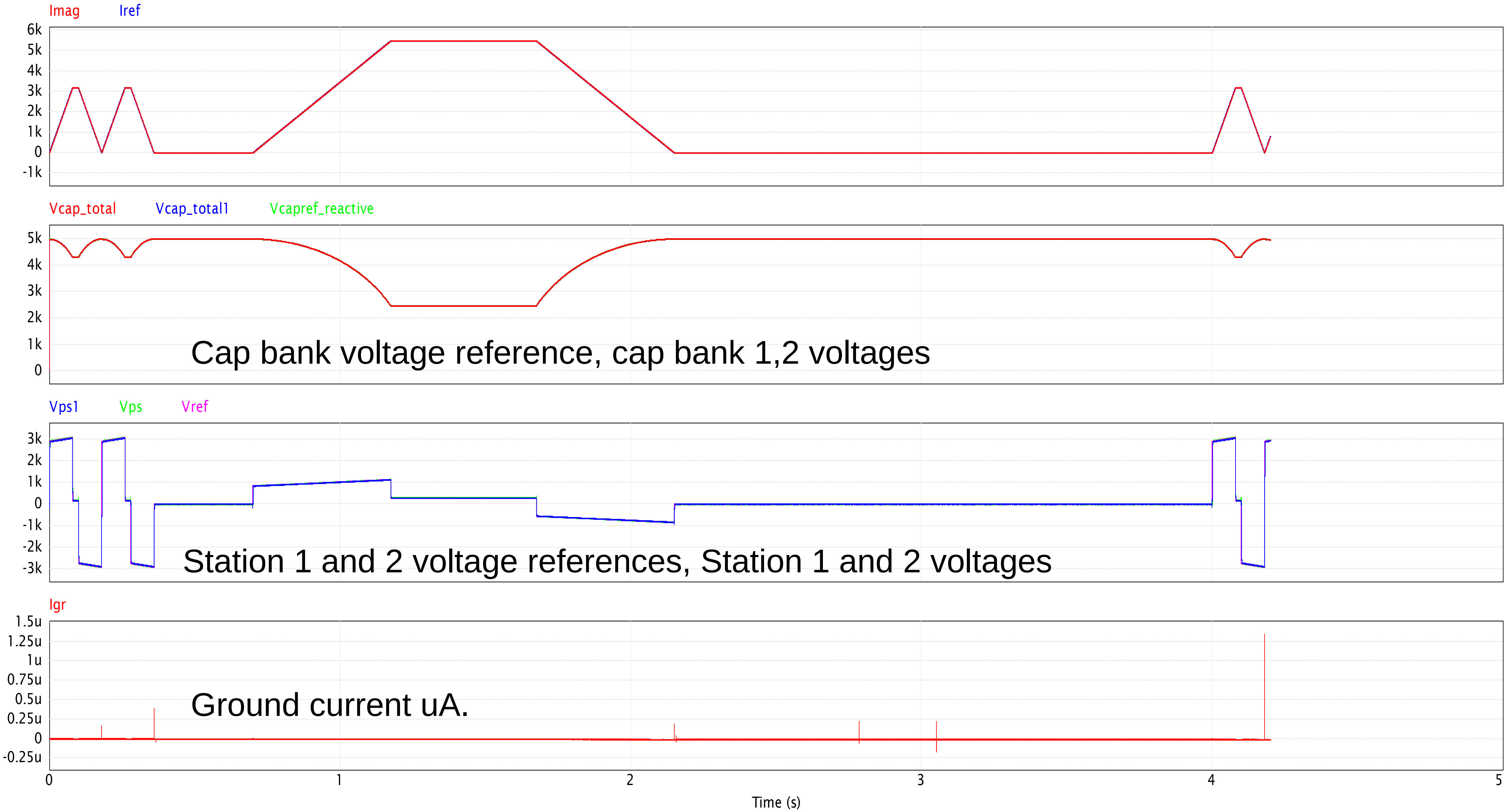
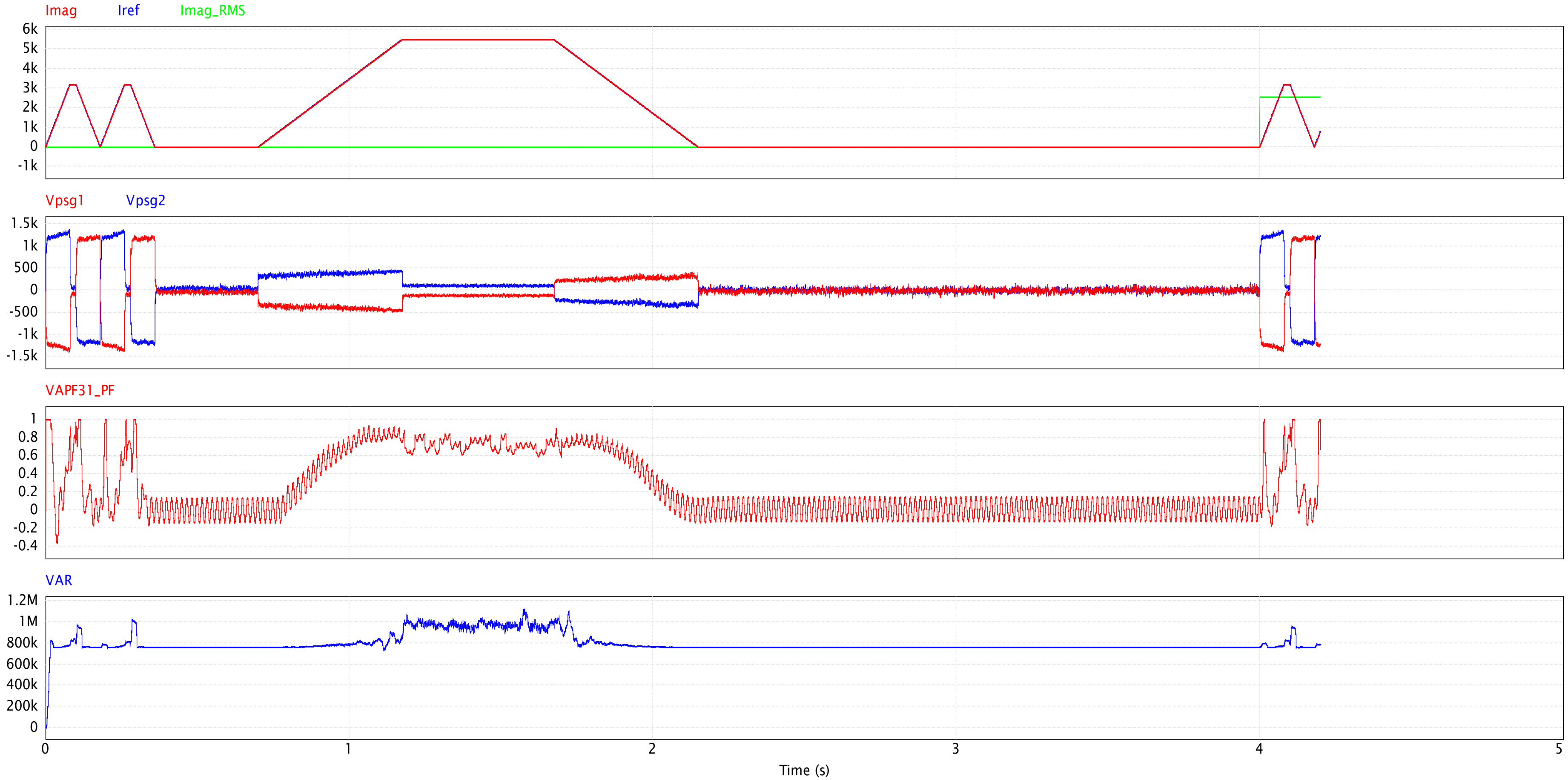
Magnet current and current reference cap bank voltages st1,2, Station 1,2 PS voltages and references, ground current



Magnet instantaneous and RMS currents, supply voltages to ground reactive input power, power factor



FROM MARVIN'S PAPER

$R := 0.265$ $X := 2.063$ $SCC := 2308 \cdot 10^{6}$

$$\%Fliker(t) := \frac{Q(t) + Pim(t) \cdot \left(\frac{R}{X}\right)}{SCC} \cdot 100$$

$$\%Fliker(t) := \frac{10^{6} + 4 \cdot 10^{6} \cdot \left(\frac{R}{X}\right)}{SCC} \cdot 100$$

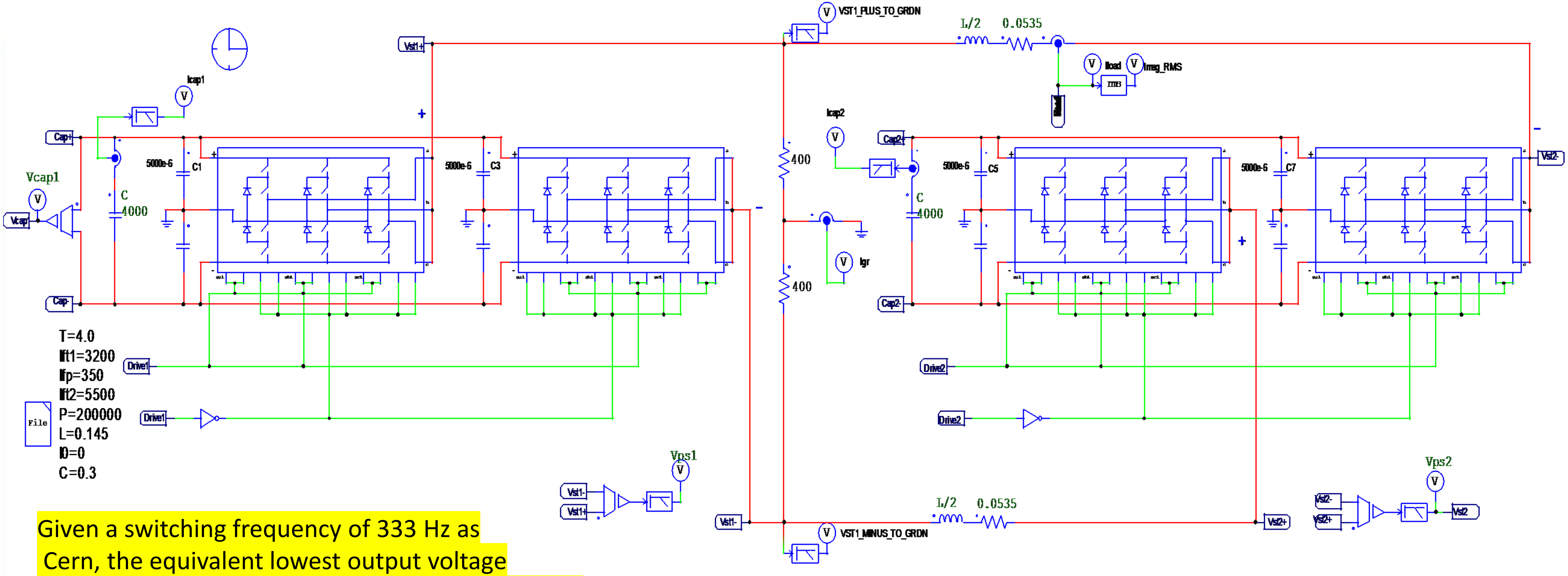
%Flicker is calculated
From above graphs

$\%Fliker(t) = 0.066$

%Flicker is very small currently we have
a %Flicker of 0.8, see above slide number 8

Booster MMPS simulation using 3 level NPC, similar to CERN POPS-B, drawing average active power from the line

Solution 1B using film capacitor and 2 power supplies in series



Given a switching frequency of 333 Hz as Cern, the equivalent lowest output voltage PWM frequency shall then be 2000 Hz per station.

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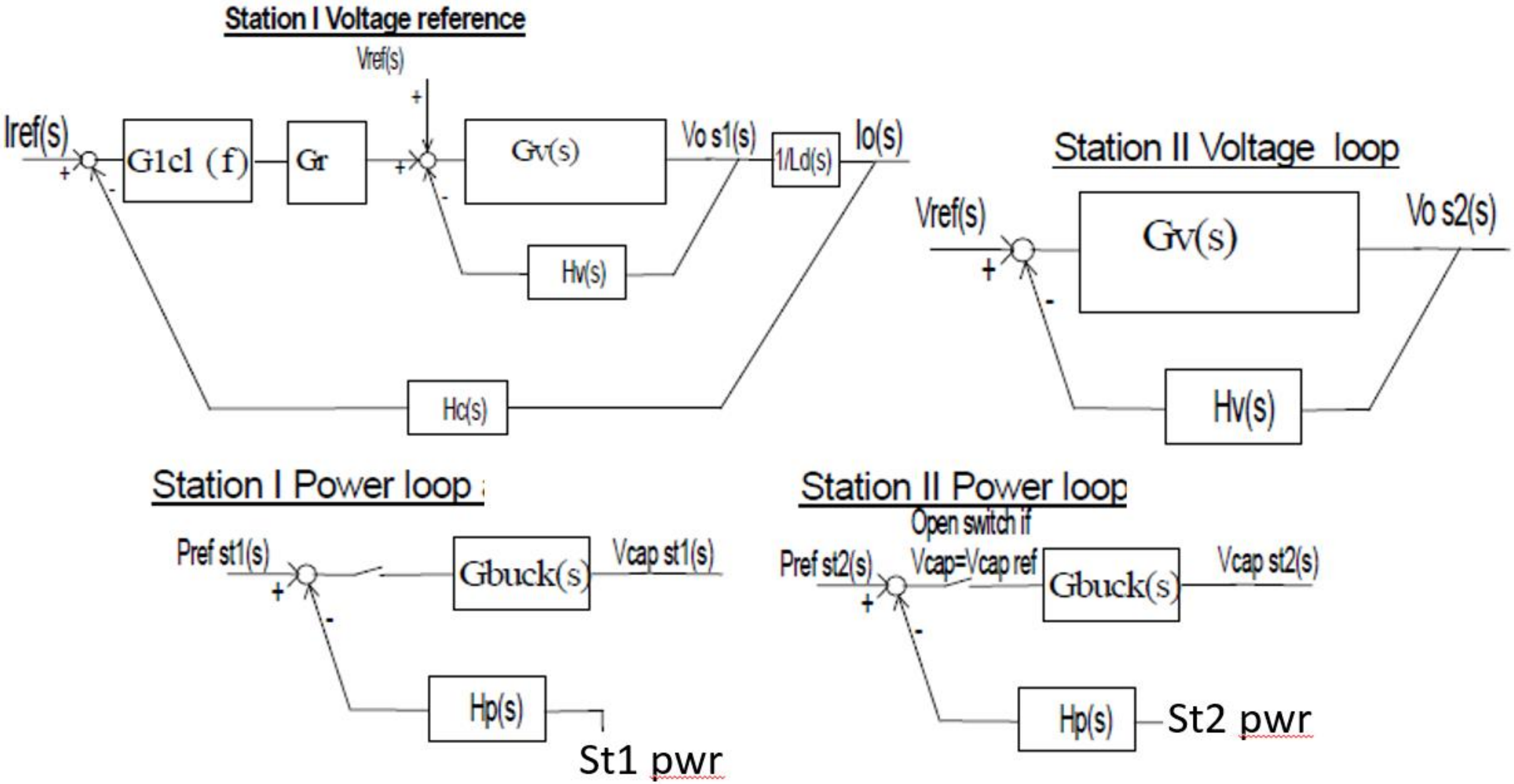
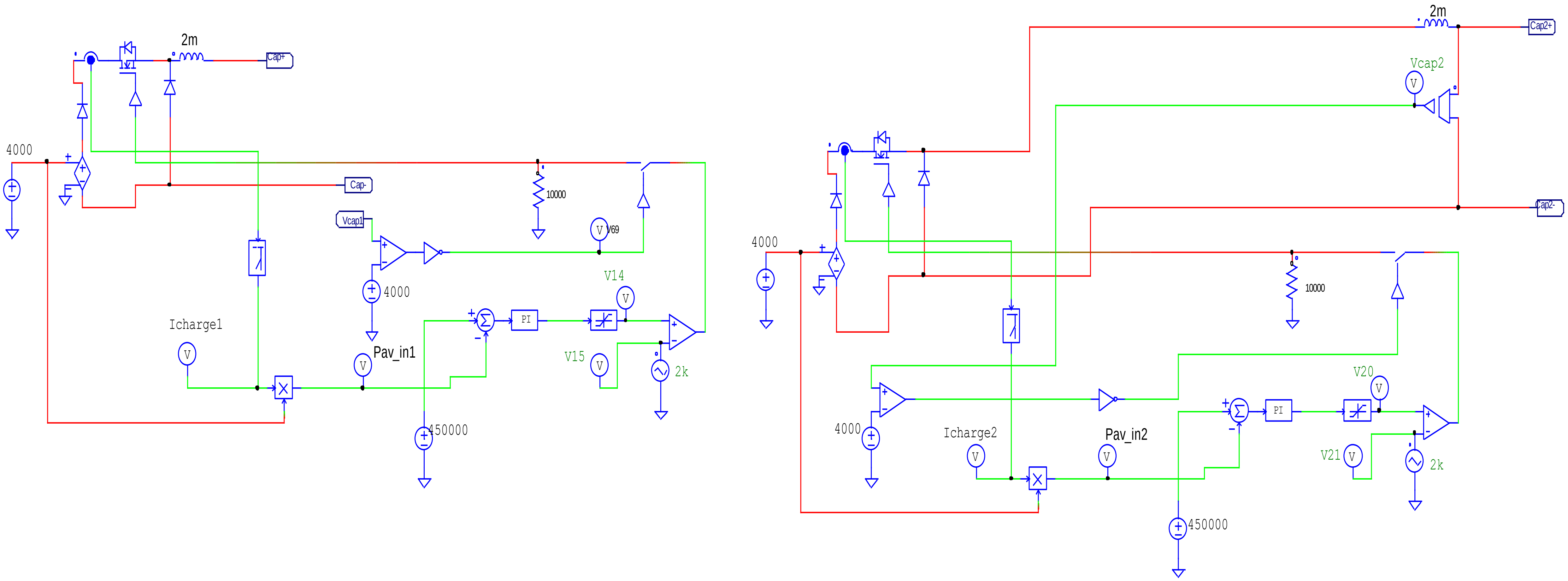
New Booster MMPS Control system, of solution 1B.



Buck converters charging the cap banks using average power regulators



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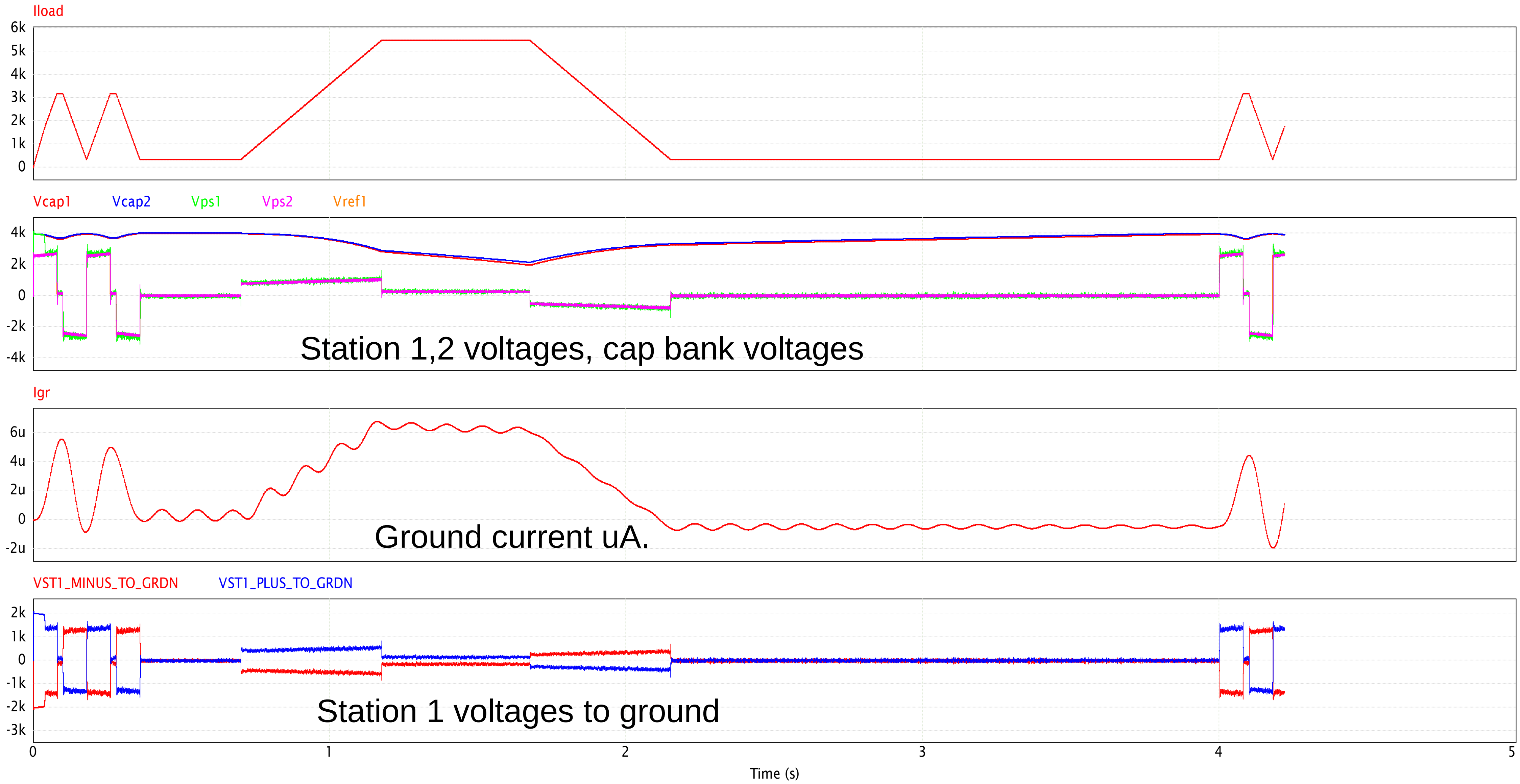
Synopsis of solution 1B

- We use two, 3 level NPC in series each giving us +/-3000 V.
- Cap bank station 1 or 2, sees 4000 V, We use film cap banks of 0.3 F per station.
- Power supply in station 1 is grounded in the middle through two 400 Ohm resistors.
- Magnet maximum voltage to ground 1500 V.
- Regulating **average input power** on both supplies.
- Average input power 900 KW.
- Cap banks don’t dip more than 50% of charged voltage.

Simulation data Super cycle 1



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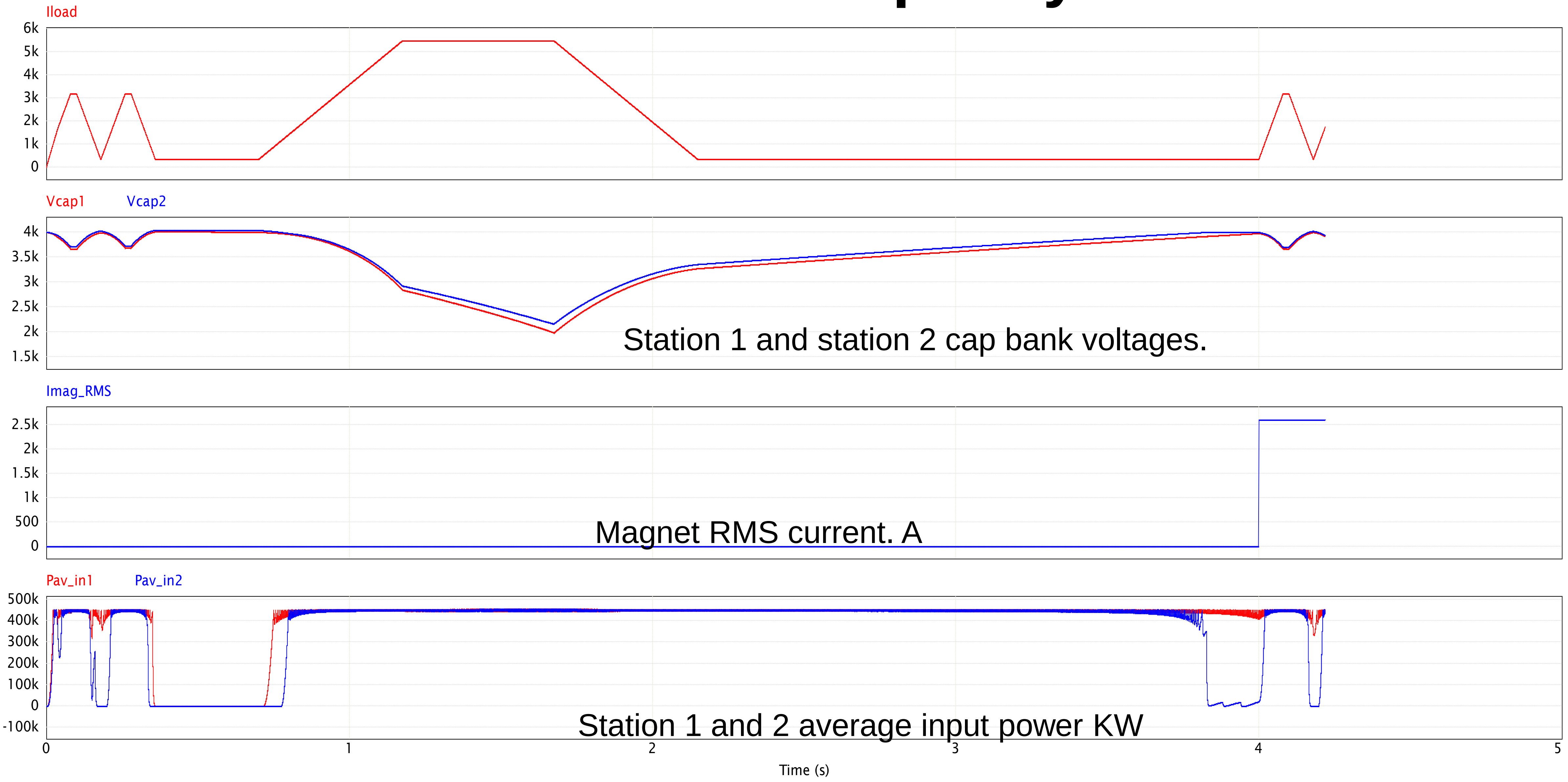
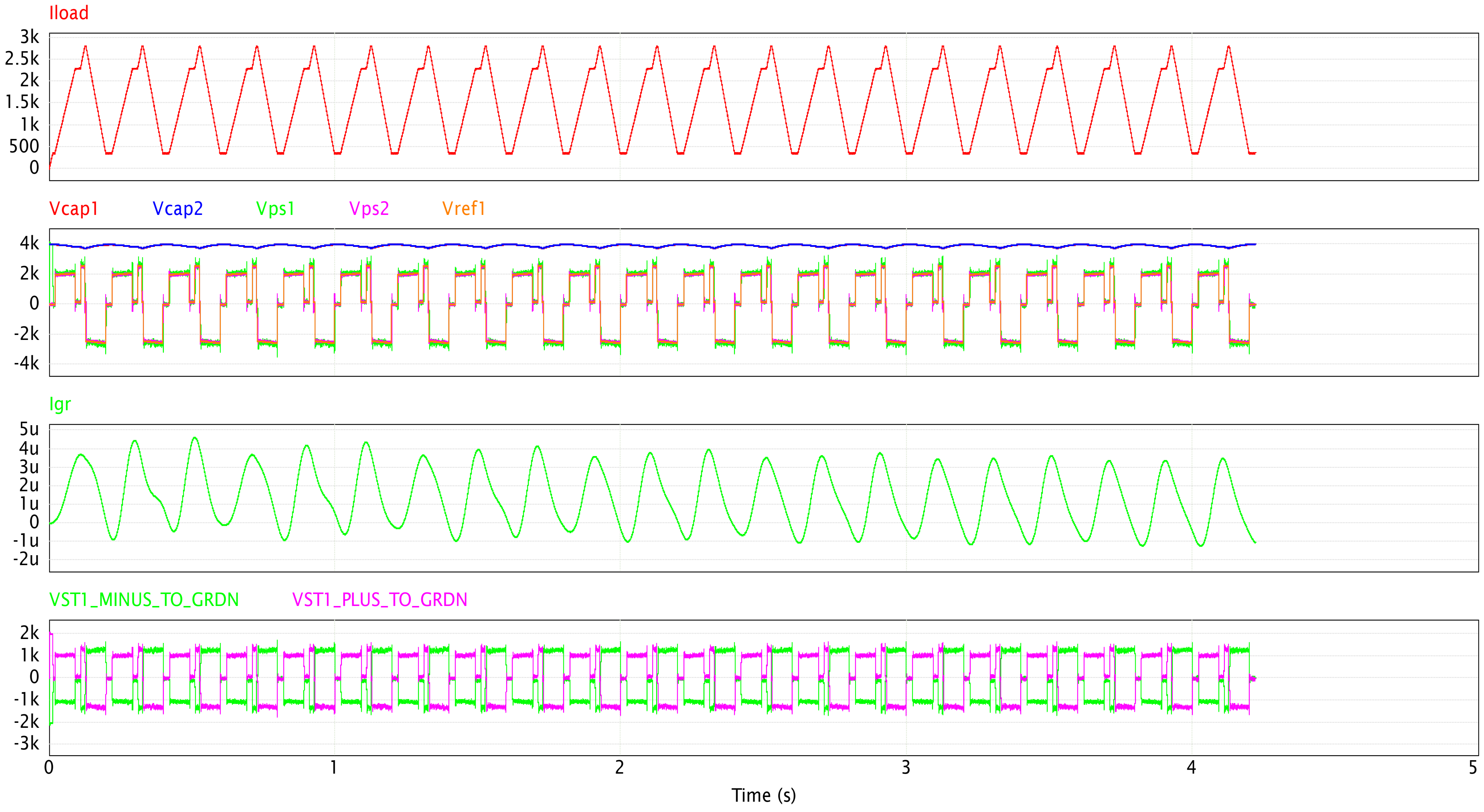
Simulation data Super cycle 1



Simulation data Super cycle 2



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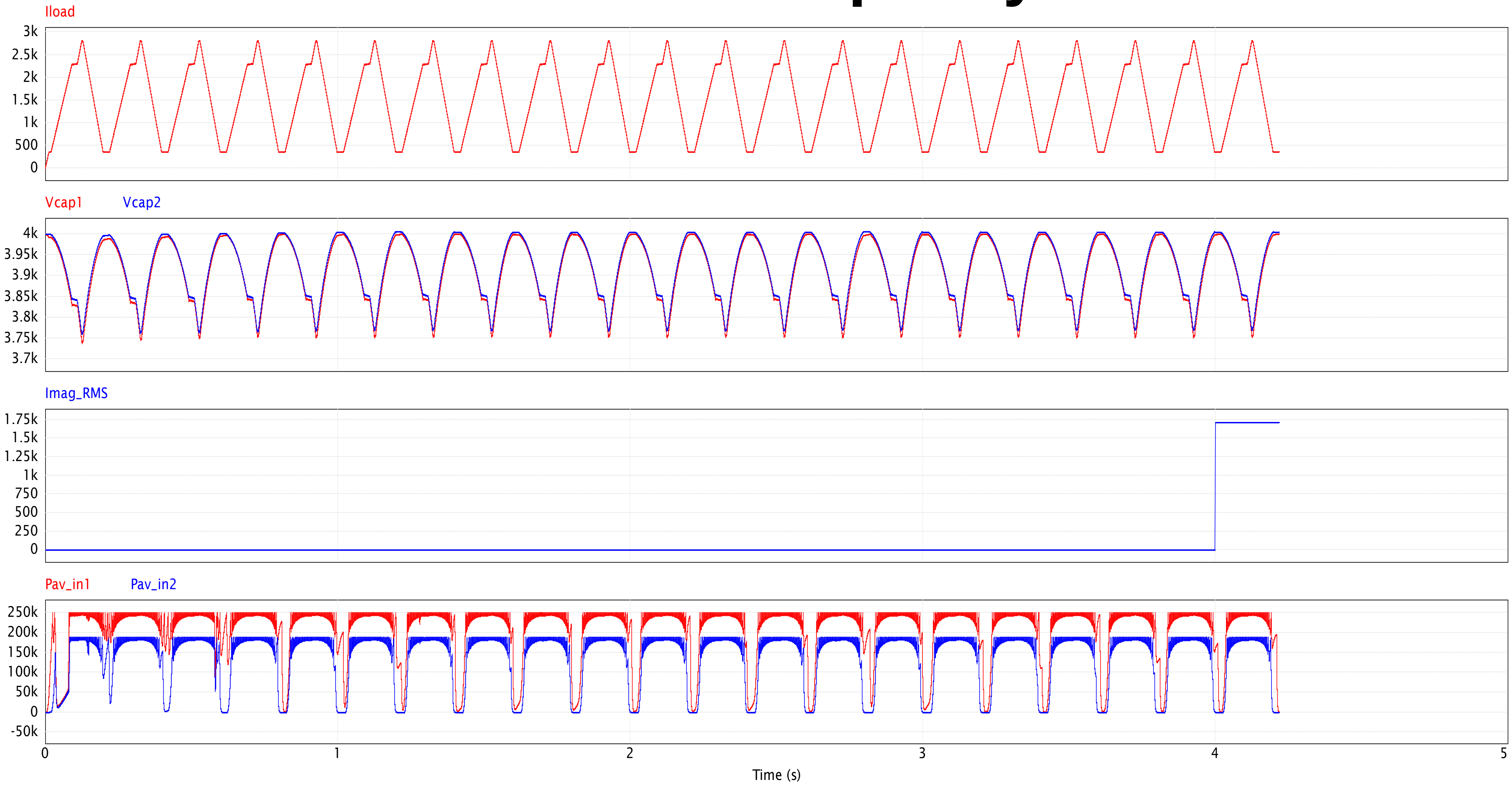
Simulation data Super cycle 2

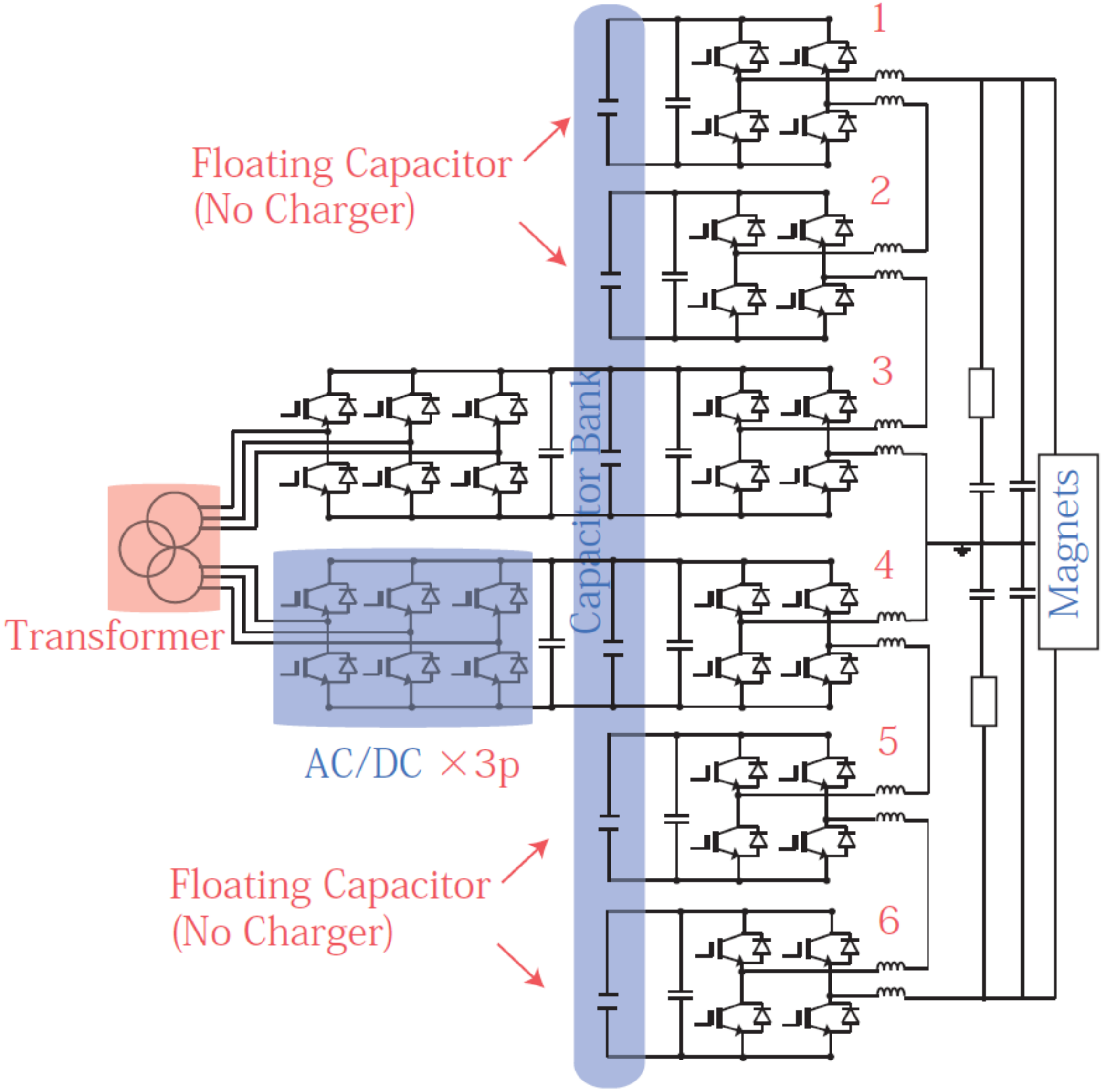


Floating Capacitor Method

The large power converter is designed as six of 1.7 kV IGBT bridges connected in series to regulate 10 kV for the output voltage.

1. They use 3300 V -1200 A IGBT (Mitsubishi CM1200HC-66H).
2. Each unit is a 2-level half bridge using 4 IGBTs.
3. The rating of the unit is 1700 V and 525 A
4. The IGBT rated (1200 x 2p = 2400 A).
5. Capacitors are Dry-type Metalized polypropylene film with self-healing capacitors.
6. Switching frequency 1 kHz (IGBT) 2 kHz (output frequency)
7. They asked a smaller company to make the large power PS.

Large power converters for the bends and some portions of the quadrupoles are required to regulate approximately 6 kV and 1.0-1.5 kA while small power converters for other quadrupoles must regulate 1.5 kV and 1.0 kA.



Yoshinori Kurimoto1, Yuichi Morita1, Tetsushi Shimogawa1, Katsuki Miura1 and Ryu Sagawa2 *J-PARC*

J-PARK Schematic of the new PS for the bending magnets.

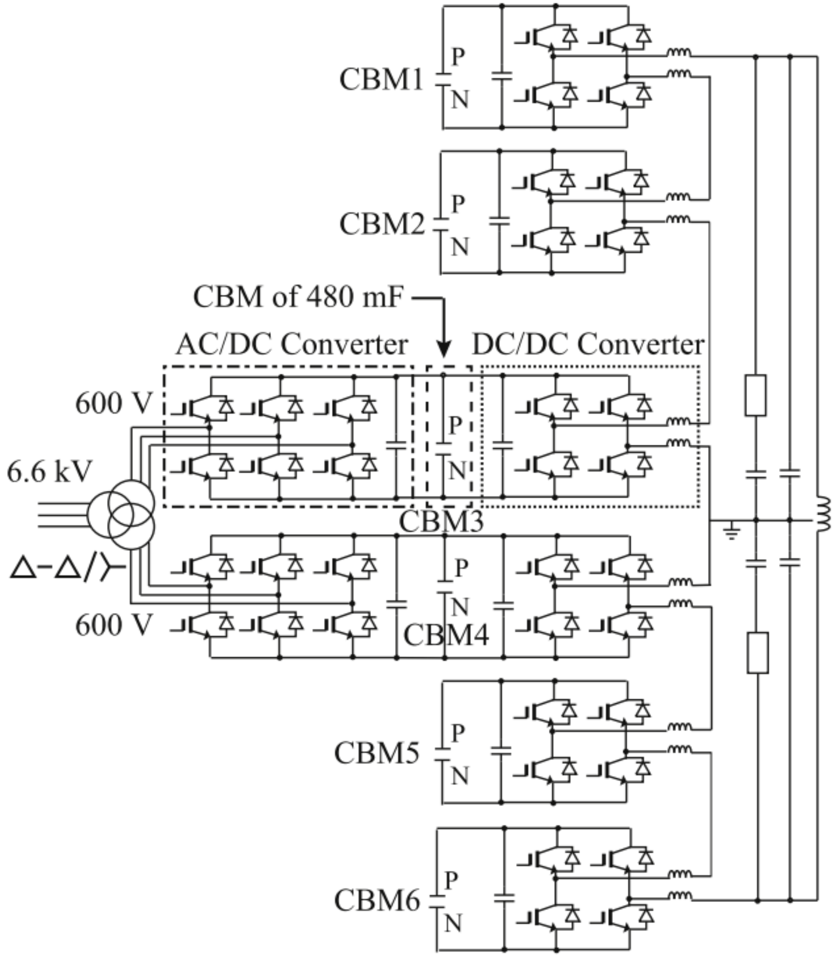


Fig. 3. Schematic of the new PS for the bending magnets in the MR.

Table 2
Typical applications of the CB.

	LMJ	NIF	POPS
E_{total} [MJ]	450	400	18
E_{CBM} [MJ]	0.8	2	3
N_{CBM}	540	192	6
E_{cap} [kJ]	84	84	25
V_{chrg} [kV]	24	24	5

Table 3
Specifications for the new PS with the CBs.

Peak output current [A]	1600
Peak output voltage [V]	6000
Total inductance of load [H]	1.6
E_{total} [MJ]	4.2
E_{CBM} [MJ]	0.7
N_{CBM}	6
E_{cap} [kJ]	7
V_{chrg} [V]	1667

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Solution 2, using film capacitors based On the J-PARK design, Regulating average input power from the line

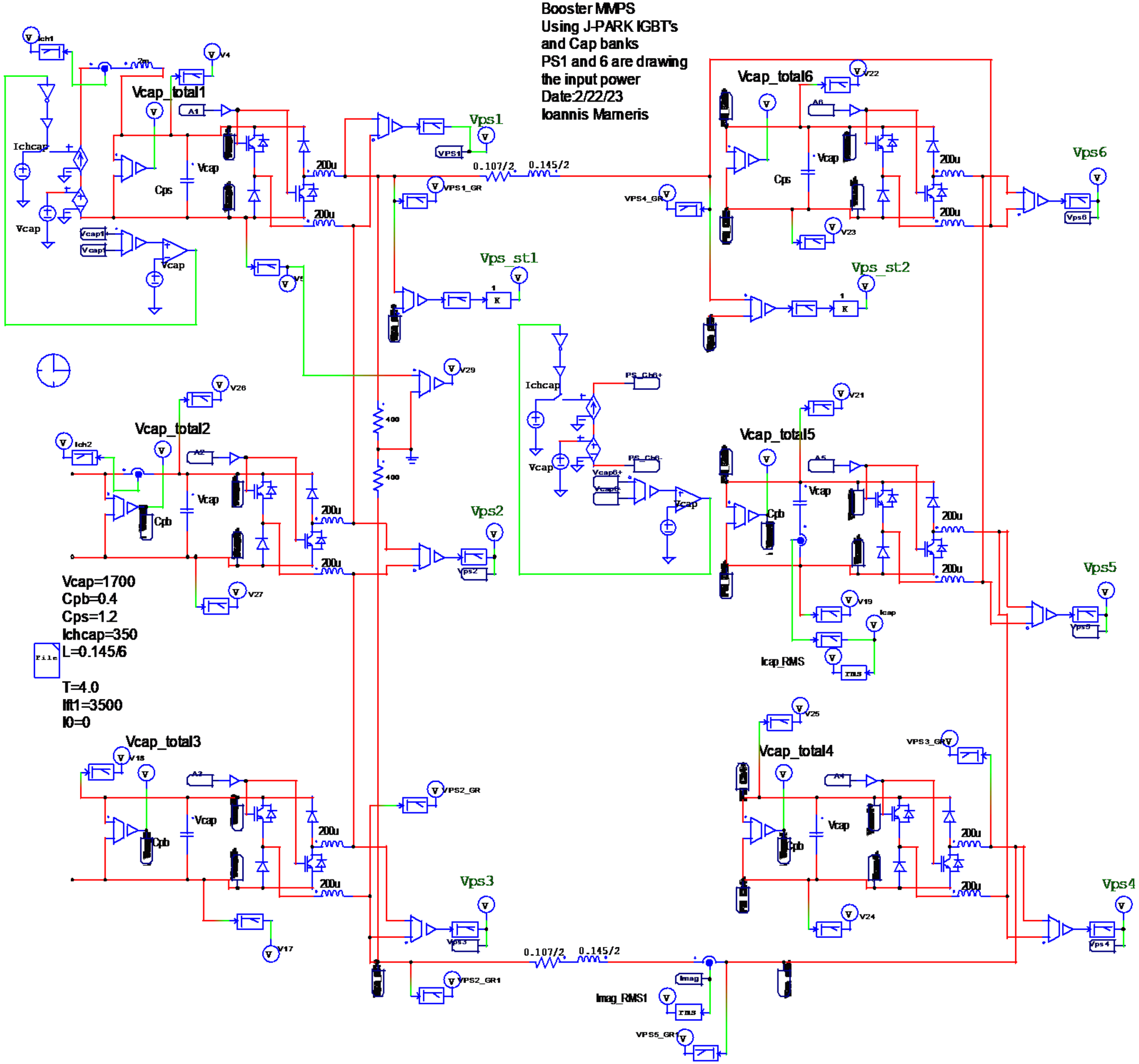
6 power supplies in series,

4 supplies with flying capacitors

File

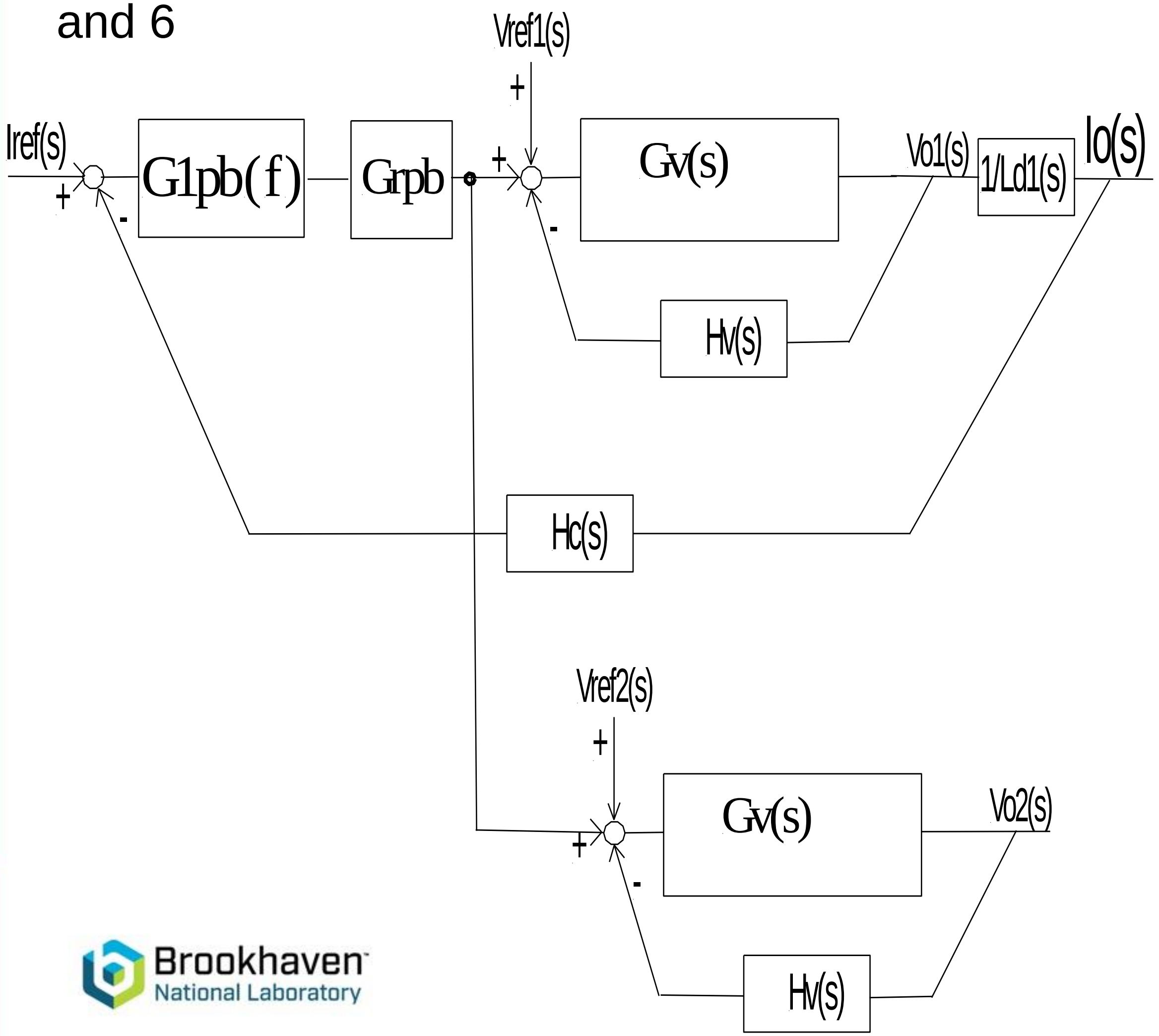
Vcap=1700
Cpb=0.4
Cps=1.2
Ichcap=350
L=0.145/6

T=4.0
Ift1=3500
I0=0



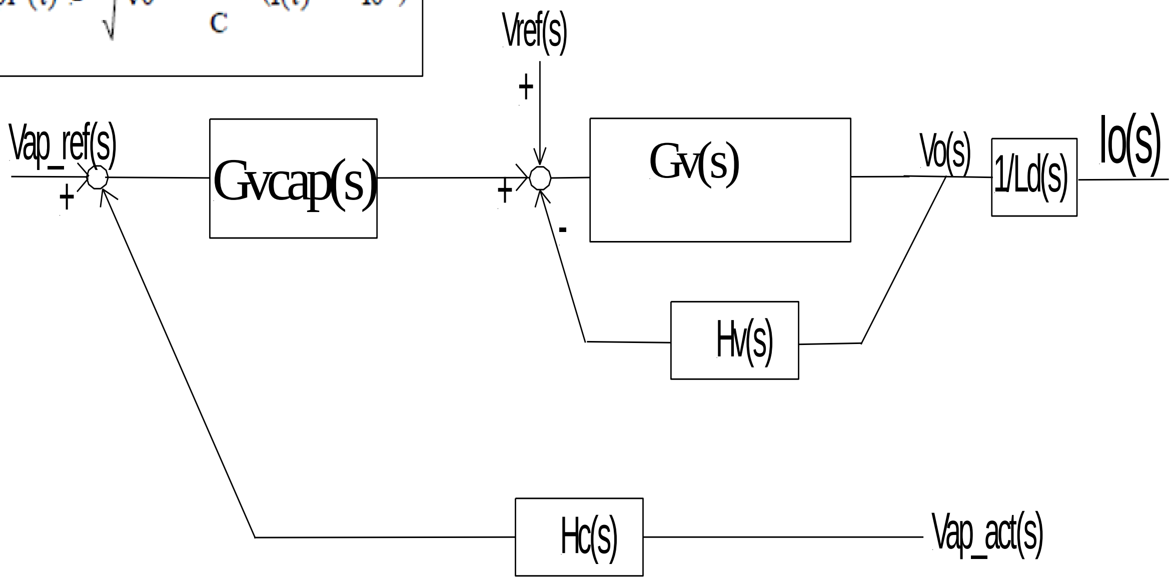
Control Loops of the second topology

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



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

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

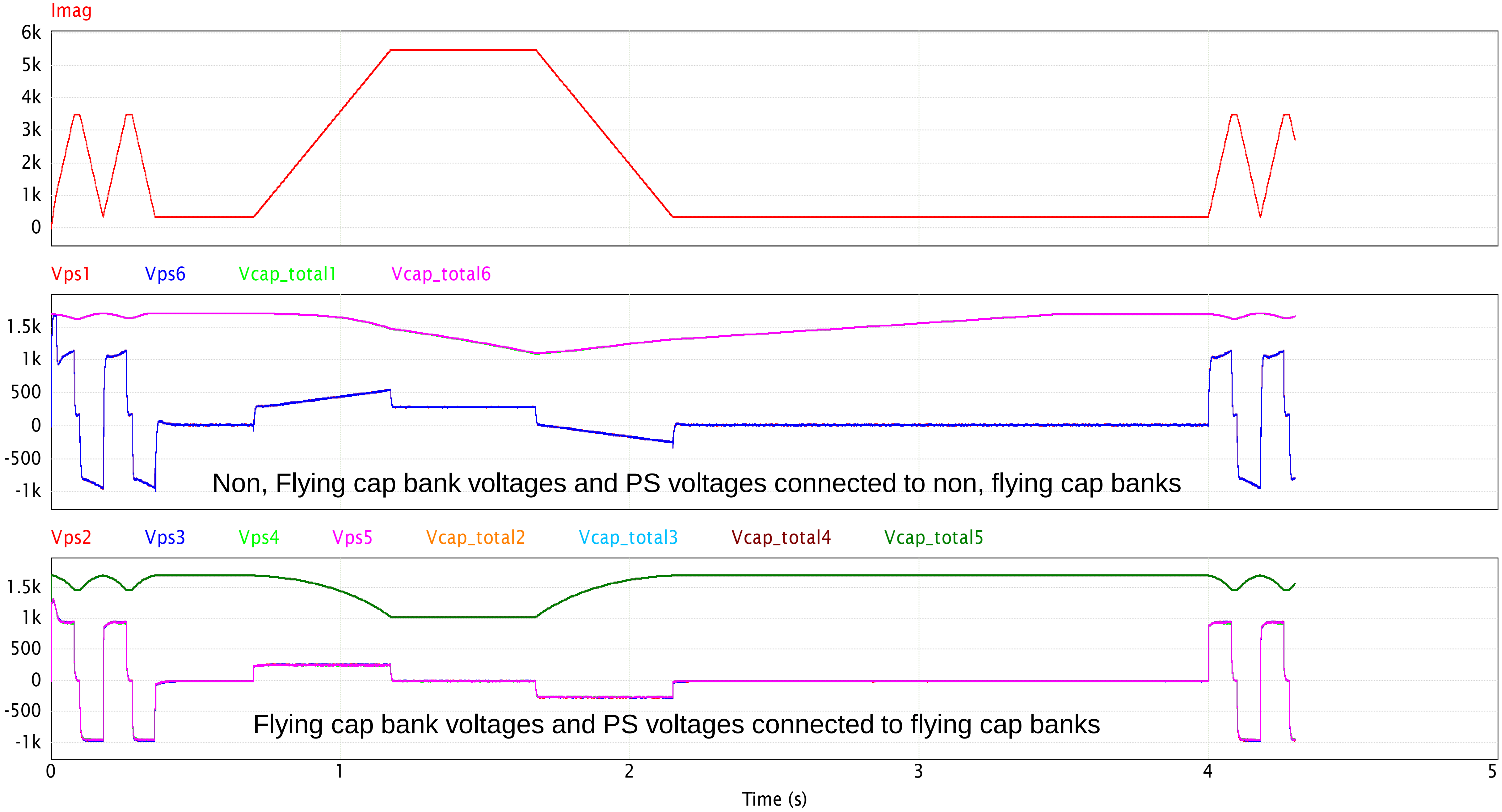


V0=1700 V, C=0.4 F, L=0.145/6 H

Synopsis of solution 2

- We use six H bridges in series, 2 of them giving us +/-1150 V, the other four connected to flying capacitors, giving us +/-925 V.
- Cap bank of two supplies 1.2 F, 1700 V film caps. Cap bank of four flying cap supplies, 0.4 F, 1700 V film caps.
- Three Power supplies in series composing station 1, which is grounded in the middle through two 400 Ohm resistors.
- Magnet maximum voltage to ground 1500 V.
- Regulating **average input power** on two supplies.
- Average input power 900 KW.
- Cap banks don’t dip more than 41% of charged voltage.

Simulation data Super cycle 1



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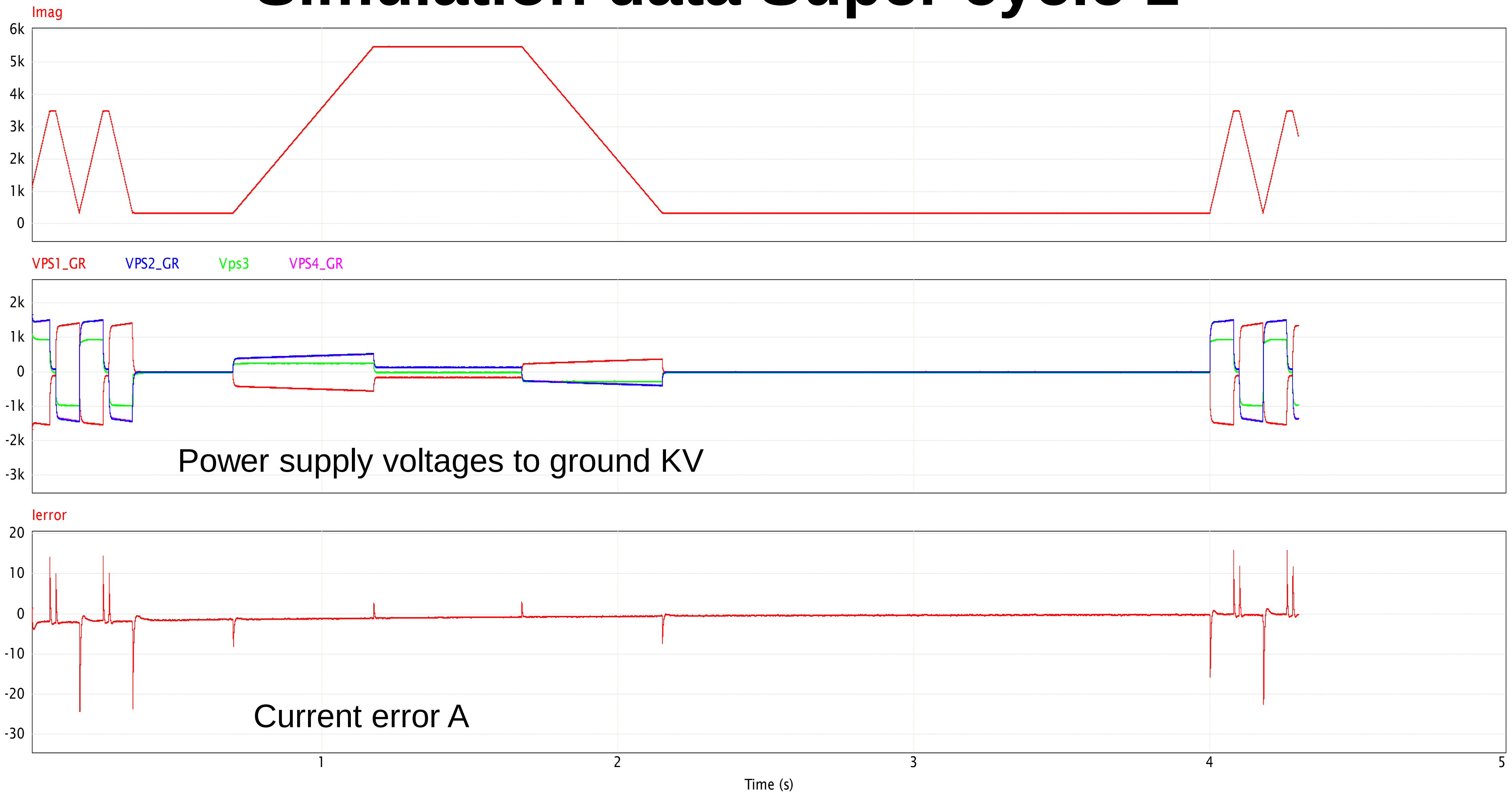
Simulation data Super cycle 1



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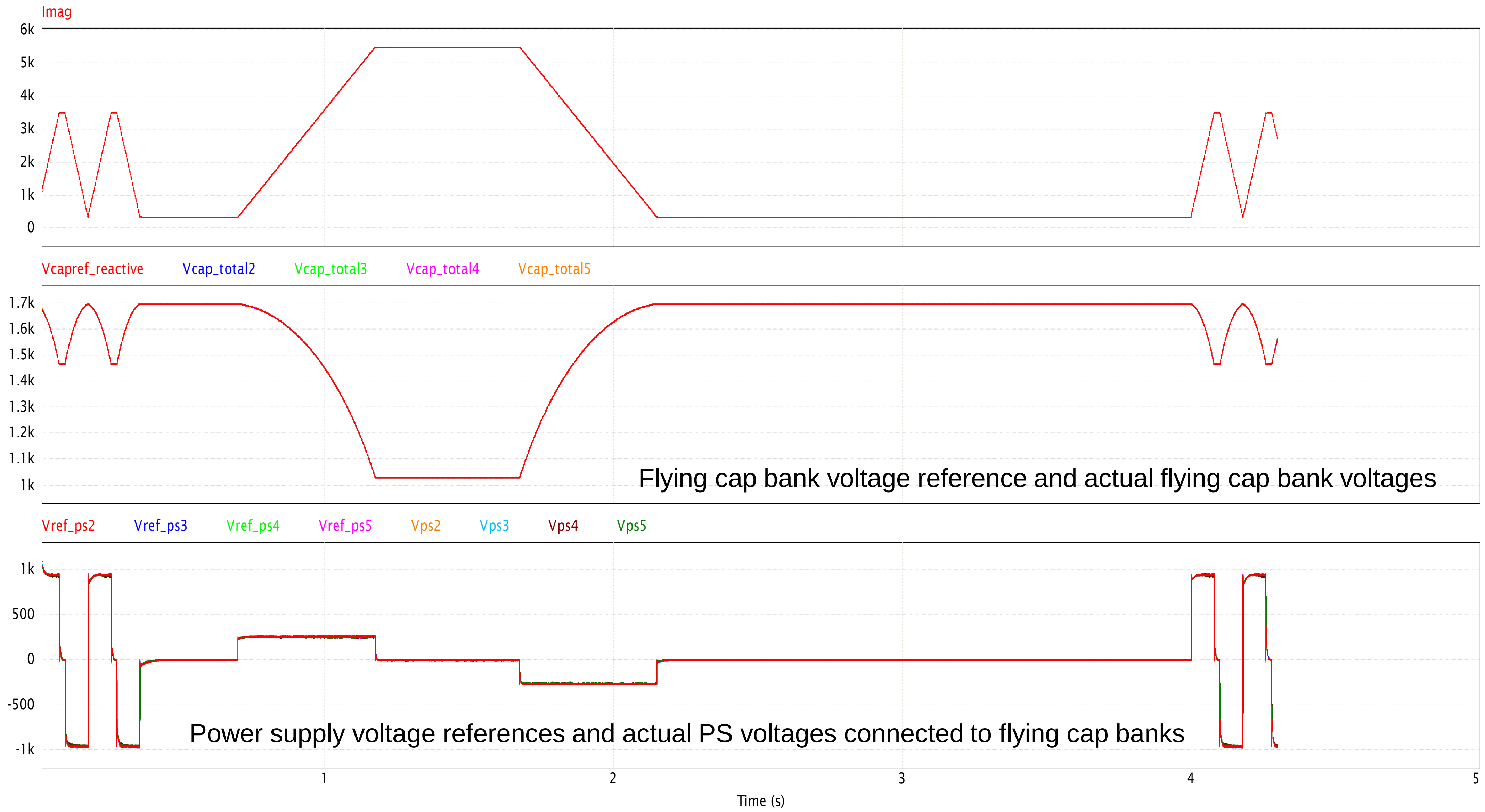
Simulation data Super cycle 1



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- OPS: the 60MW power converter for the PS accelerator: Control strategy and performances
  - Fulvio Boattini; Jean-Paul Burnet; Gregory Skawinski, CERN, Geneva, Switzerland.
- Discussions about ***POPS-B DC/DC Converter*** with Cern engineers and specifically with
  - Fulvio Boattini; CERN, Geneva, Switzerland.
- J-PARC Main Ring Upgrade toward High Repetition Rate Operation.
  - Yoshinori Kurimoto1 , Yuichi Morita1 , Tetsushi Shimogawa1 , Katsuki Miura1 and Ryu Sagawa2
  - 1 J-PARC Center, Tokai, Ibaraki 319-1195, Japan
  - 2 Universal Engineering, Mito, Ibaraki 310-0851, Japan
  - E-mail: kurimoto edit@post.j-parc.jp
- J-PARC Main Ring Upgrade toward High Repetition Rate Operation Yoshinori Kurimoto1 , Yuichi Morita1 , Tetsushi Shimogawa1 , Katsuki Miura1 and Ryu Sagawa2 1 J-PARC Center, Tokai, Ibaraki 319-1195, Japan 2Universal Engineering, Mito, Ibaraki 310-0851, JapanCapacitor 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.

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…

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Back up slides

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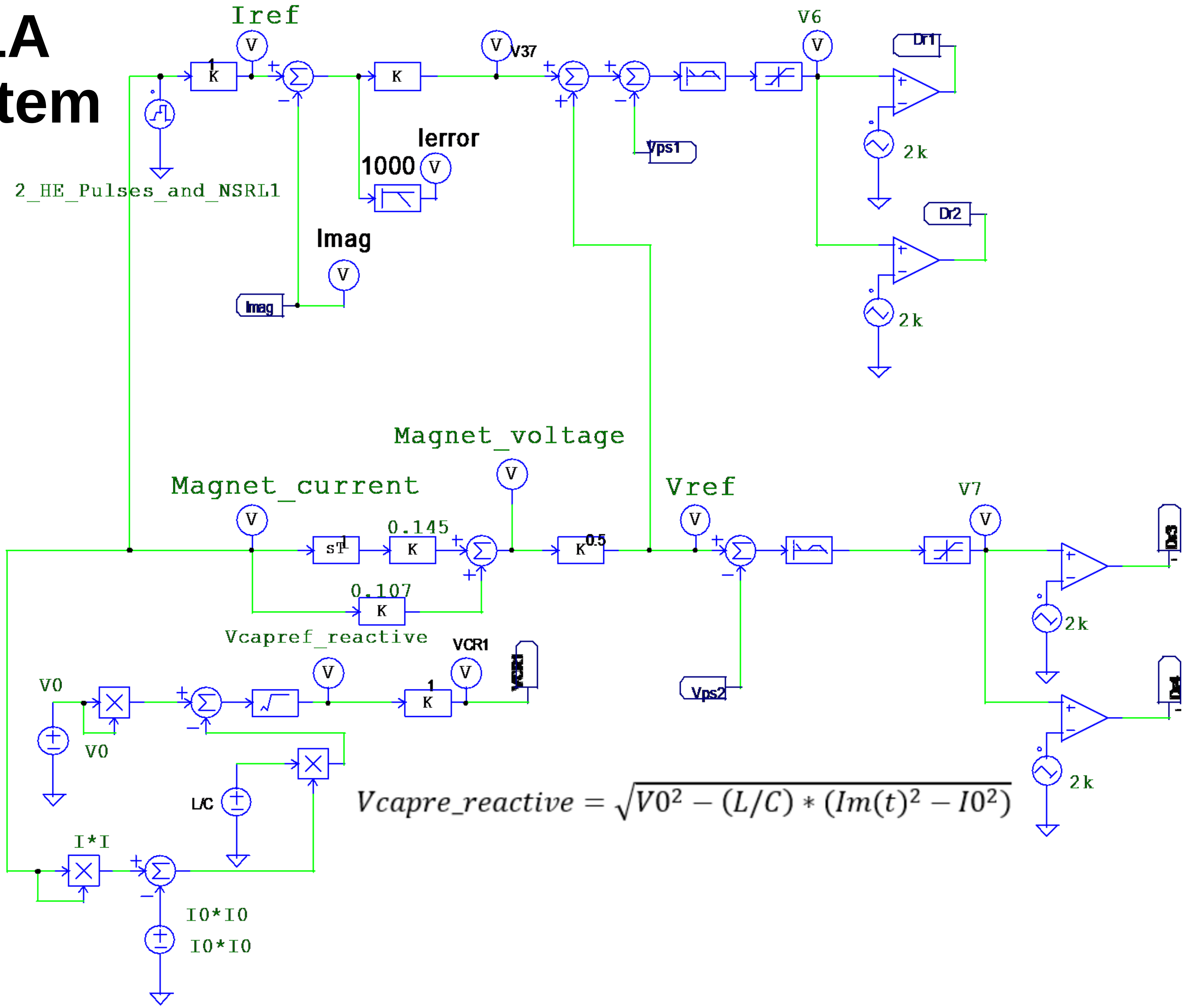
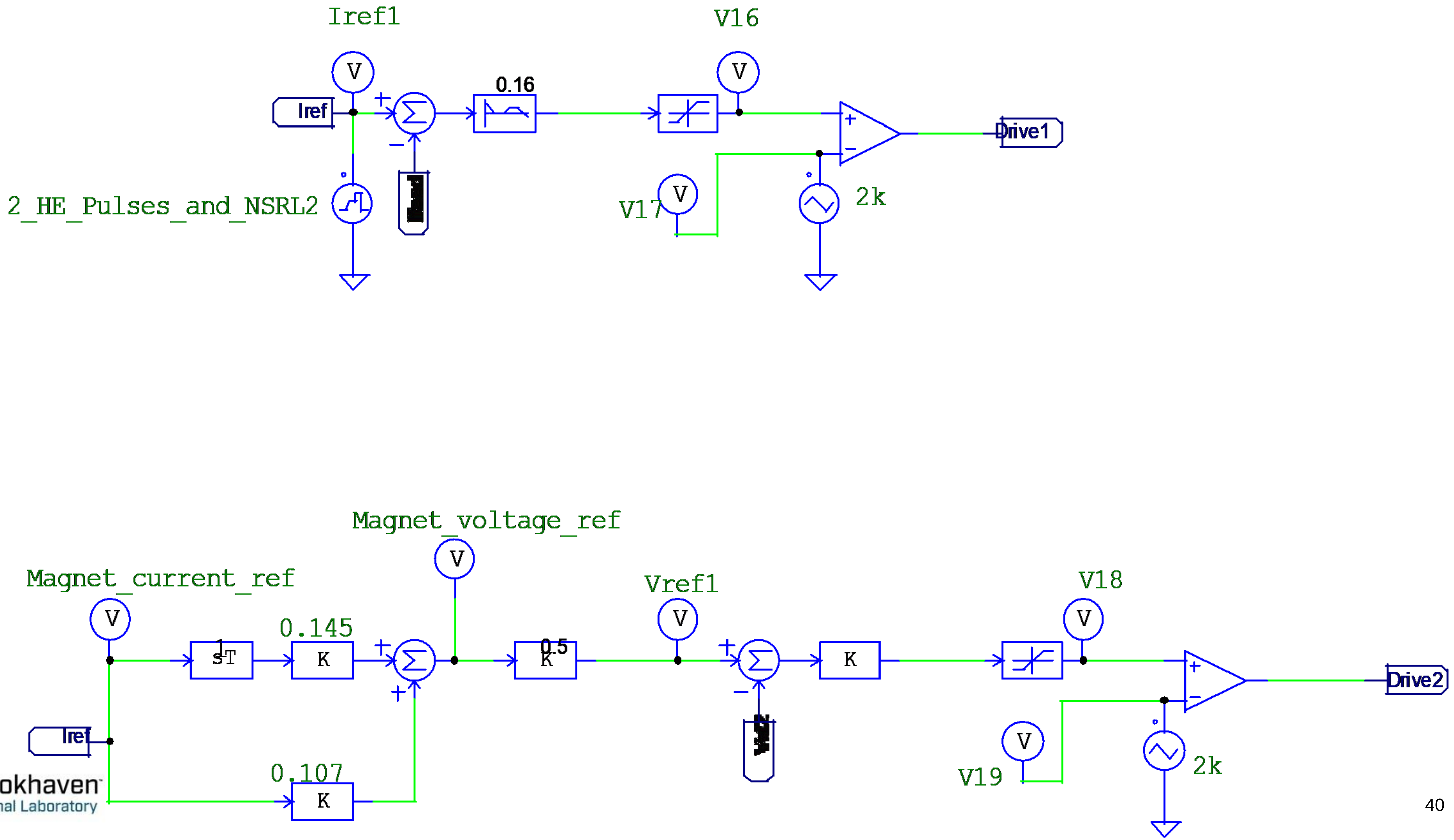
Solution 1A
Control system



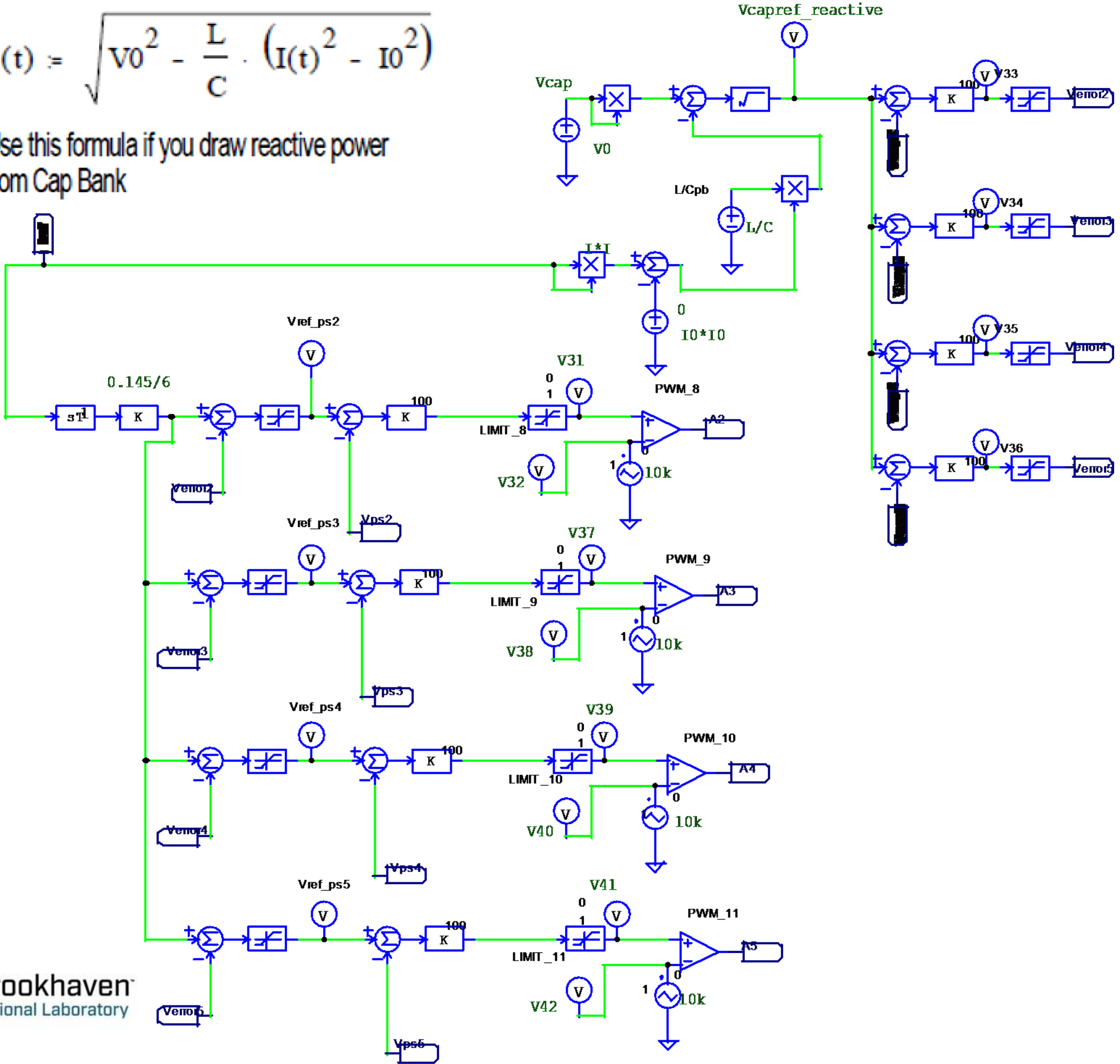
$$Vcapre\_reactive = \sqrt{V0^2 - (L/C) * (Im(t)^2 - I0^2)}$$

Solution 1B: Station 1 Current loop regulator, Station 2 voltage loop regulator



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

Use this formula if you draw reactive power from Cap Bank

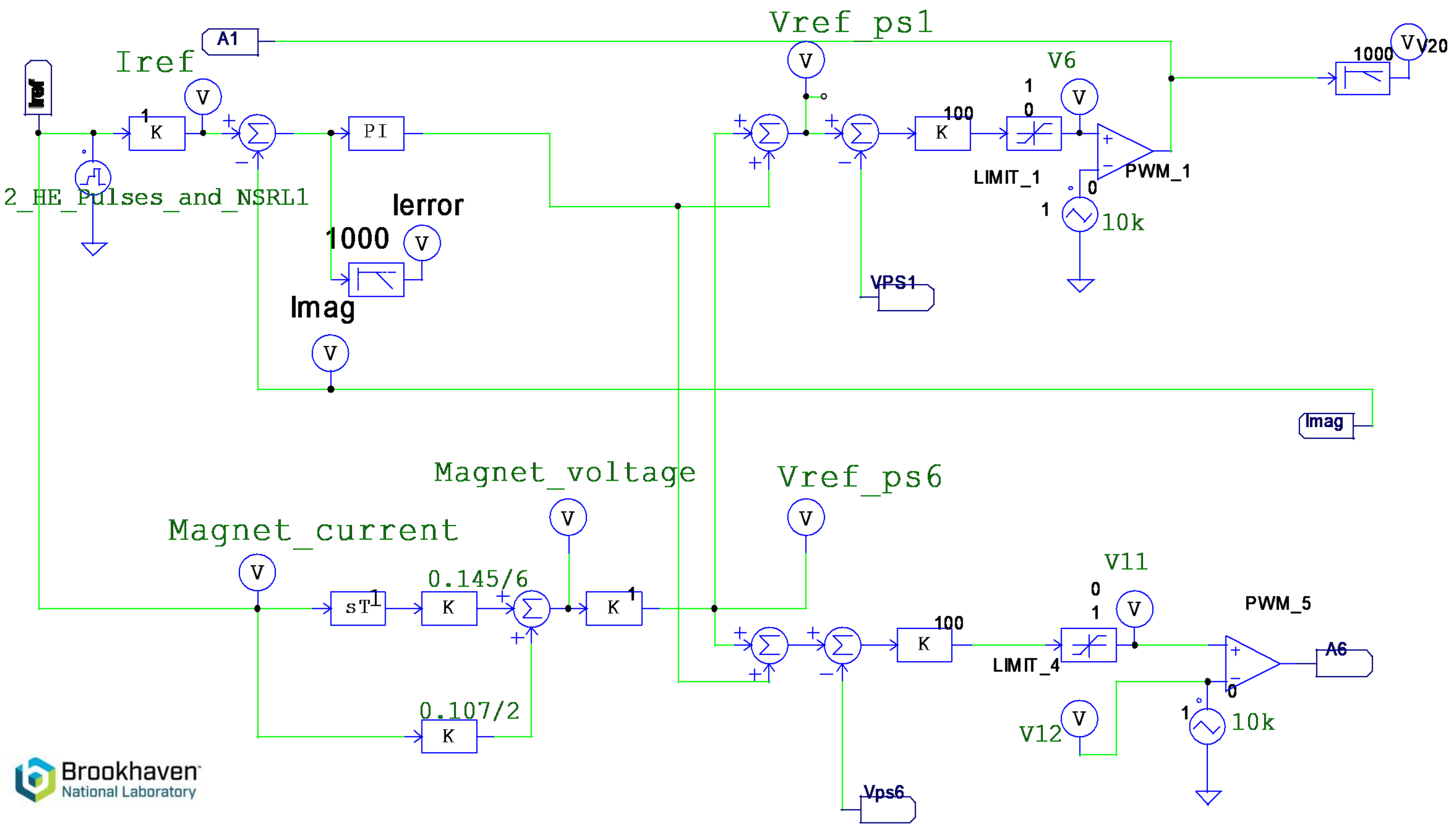


Solution 2

Flying Cap bank loops, are the outer loops.

Inner loops are voltage loops of PS's 2,3,4,5

Solution 2: Current and voltage loops of PS's 1 and 6



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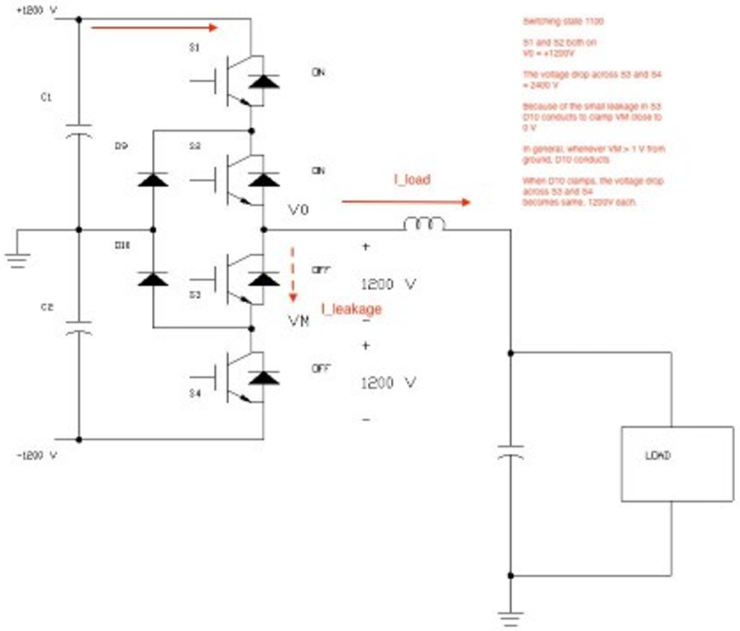
3-Level NPC



Some advantages for 3 – Level NPC Bridge with mid-point grounding
Wahfun NG

- One way to process high voltage when a suitable IGBT with the required rating cannot be found is to adopt a series connection of two or more devices.
- The applied voltage to the power IGBTs is one-half of that of that of the 2-level inverter or H bridge
- Voltage sharing among IGBTs. Neutral point inverter use clamping diodes to guarantee voltage sharing among power switches.
- Level shifted PWM can be easily implemented with simple hardware.
- Balancing of mid-point voltage is achieved by grounding the neutral point.
- One DC bus, voltage levels are produced by two capacitors in series.

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