EMR-Based Control of POLARIS Power Converter

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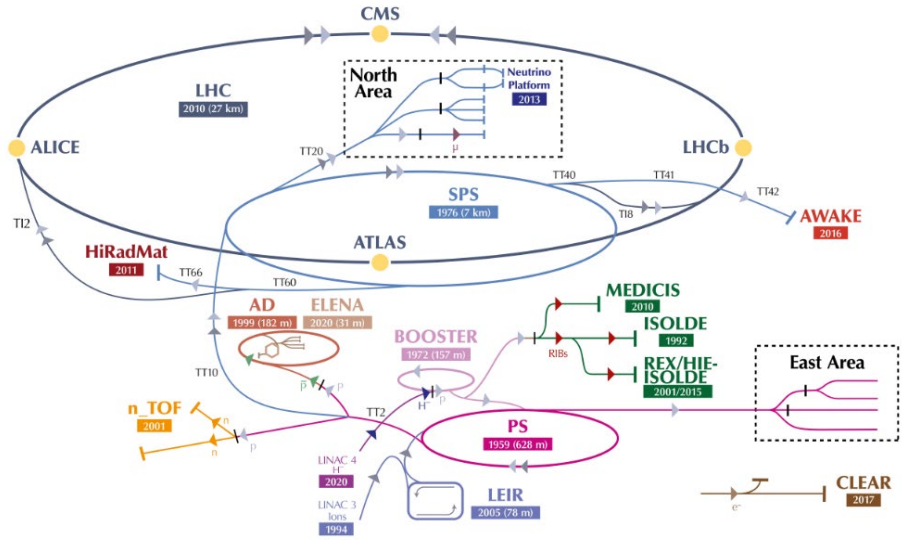
"The largest laboratory in the world that conducts research on fundamental physics"

CERN's mission is to:

- Provide particle accelerator facilities
- Perform research on fundamental physics
- Unite people through science
- Train the new generations of scientists



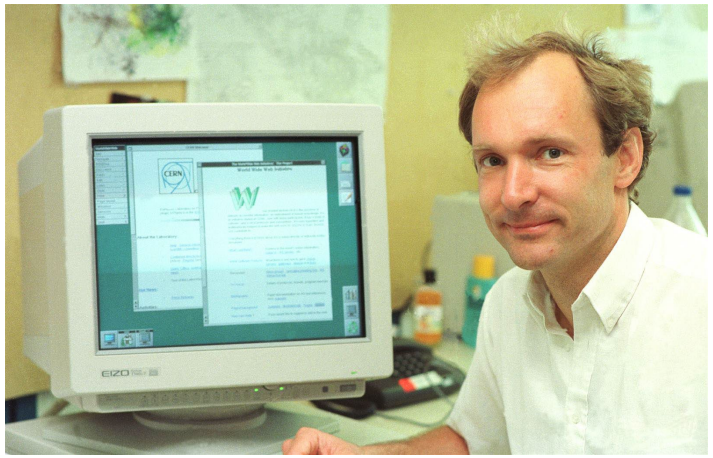
CERN Accelerator Complex

What you know about CERN…

Discovery of Higgs Boson, 2012

What you know about CERN…

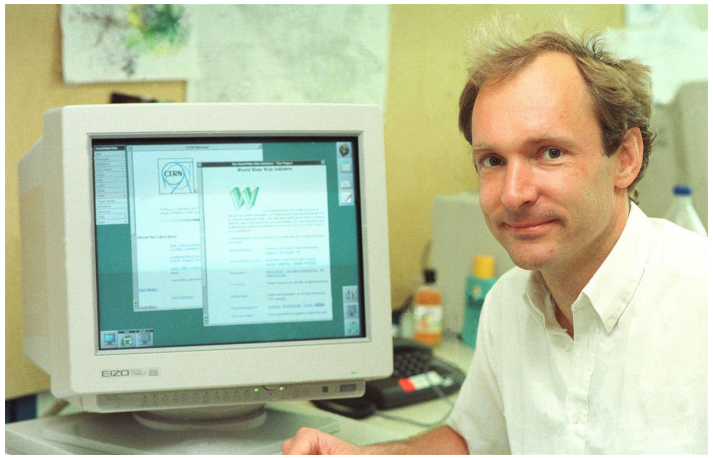
Discovery of Higgs Boson, 2012



Invention of the World Wide Web, 1989

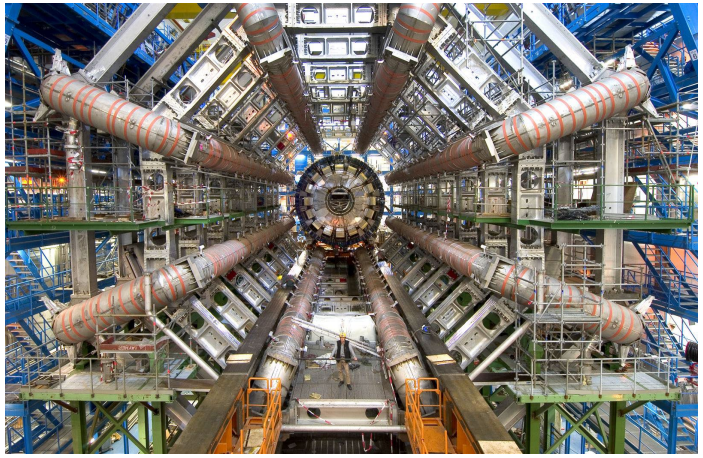
What you know about CERN…

Discovery of Higgs Boson, 2012



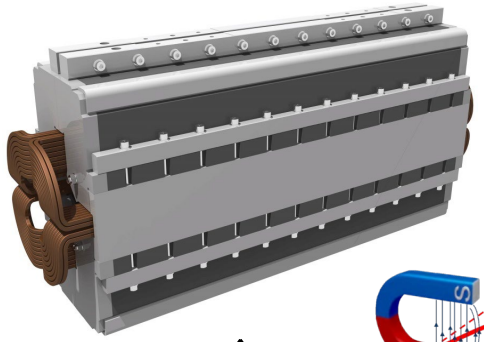
Invention of the World Wide Web, 1989

The Large Hadron Collider (LHC)

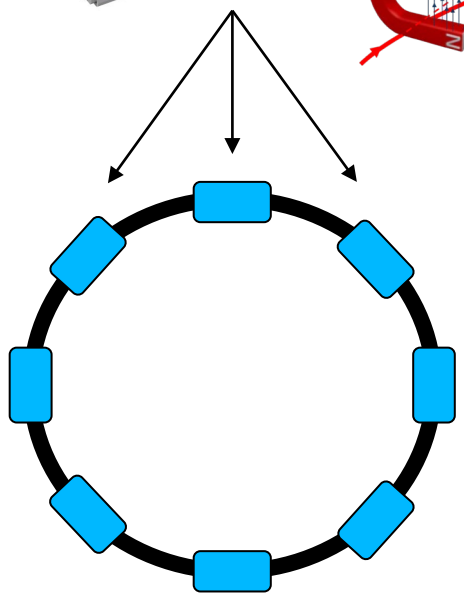


LHC Point 1: ATLAS Detector

What you DON'T know about CERN…



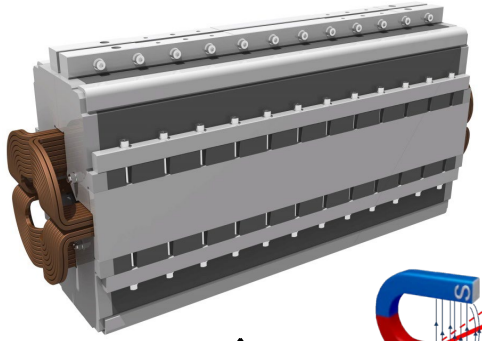
Electromagnets
Define the trajectory of particle beams



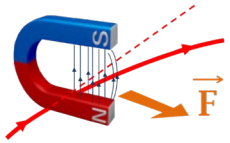
Particle Accelerator

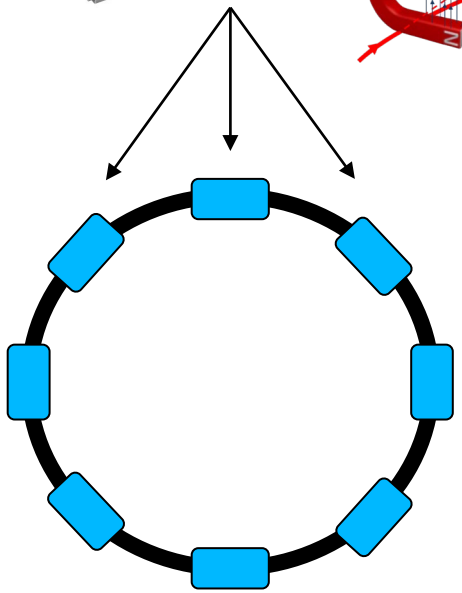
What you DON'T know about CERN…

Electric Current



Electromagnets
Define the trajectory of particle beams





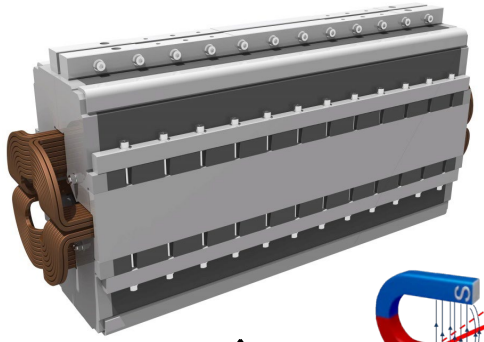
Particle Accelerator

Current Reference

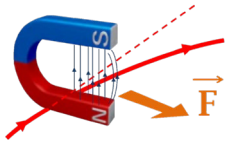
What you DON'T know about CERN…

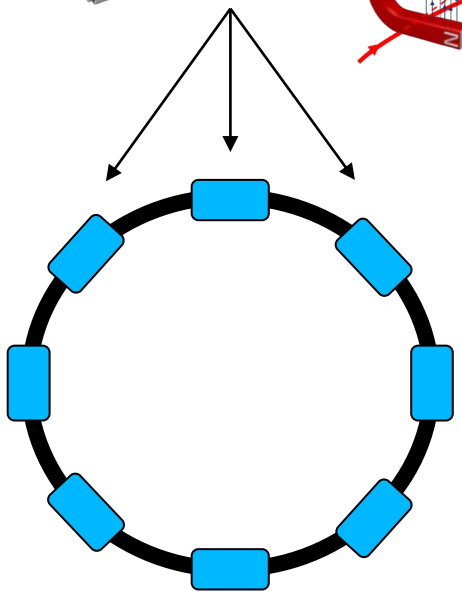
6000 Power Converters!

Electric Current



Electromagnets
Define the trajectory of particle beams



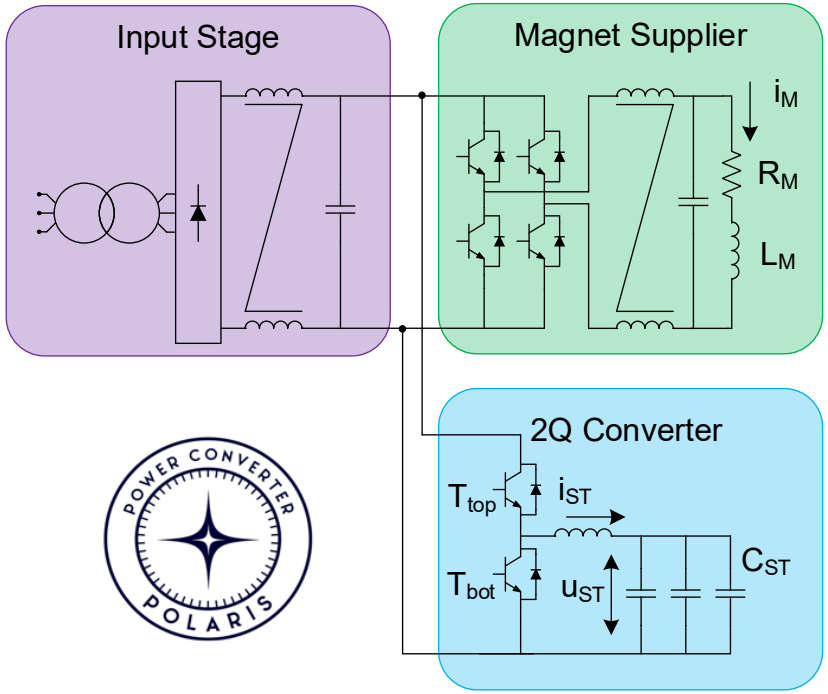


Particle Accelerator

Current Reference

POLARIS Power Converter

SINGLE BRICK TOPOLOGY

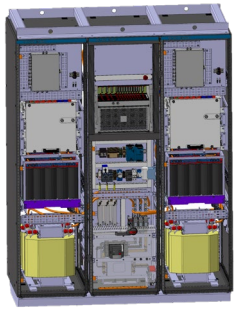


UP TO 4 BRICKS IN SERIES / PARALLEL

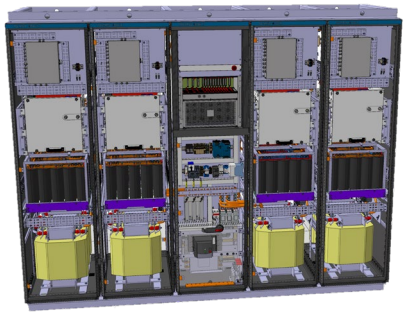
UP TO 1600 A / 1440 V / 200 kW

POLARIS CONVERTER TYPES

POLARIS S

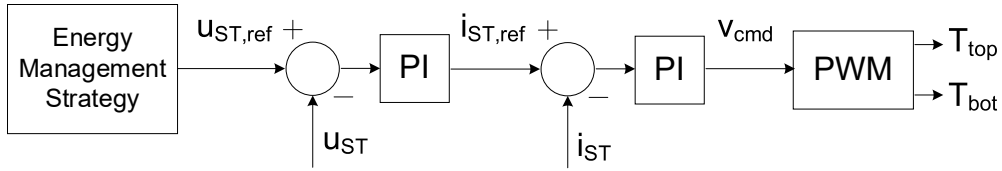


POLARIS 2P / 2S



POLARIS 4P / 4S / 2P2S

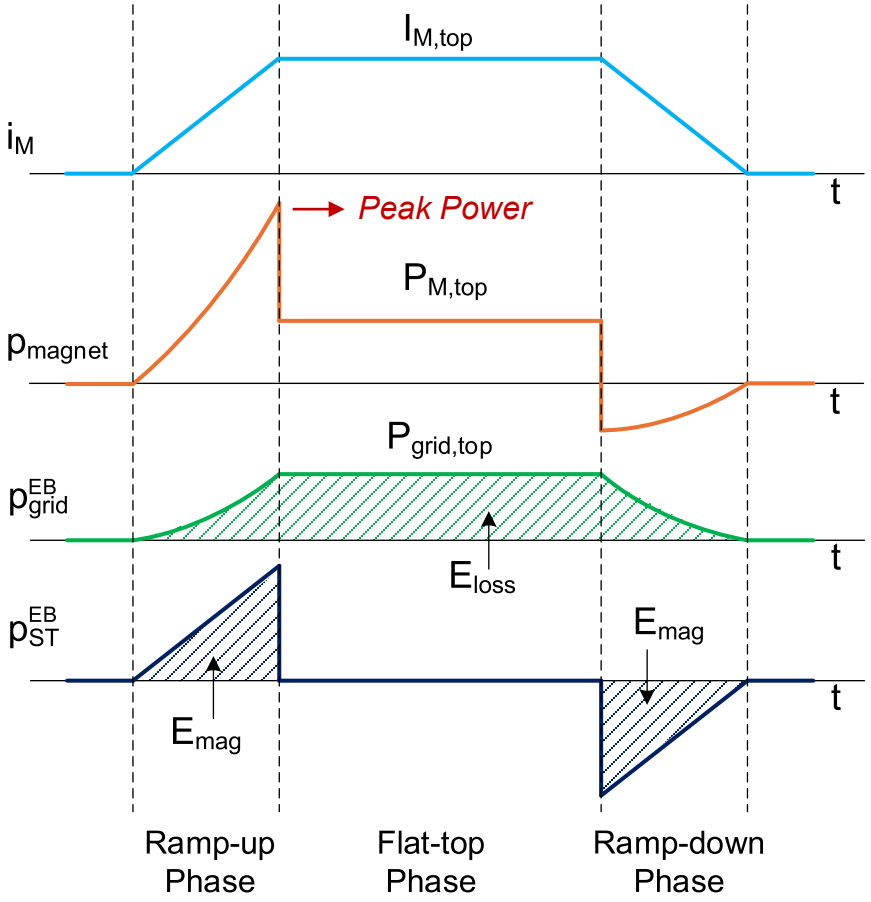
CONTROL OF THE ENERGY EXCHANGE BETWEEN MAGNET AND STORAGE



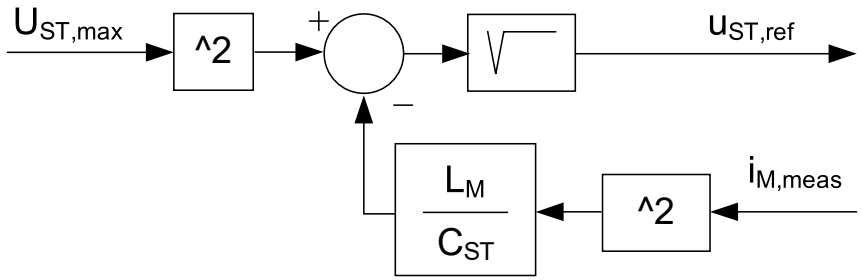
Uncontrolled Input Stage

Energy Balance (EB) Strategy

CURRENT & POWER WAVEFORMS FOR CYCLING MODE



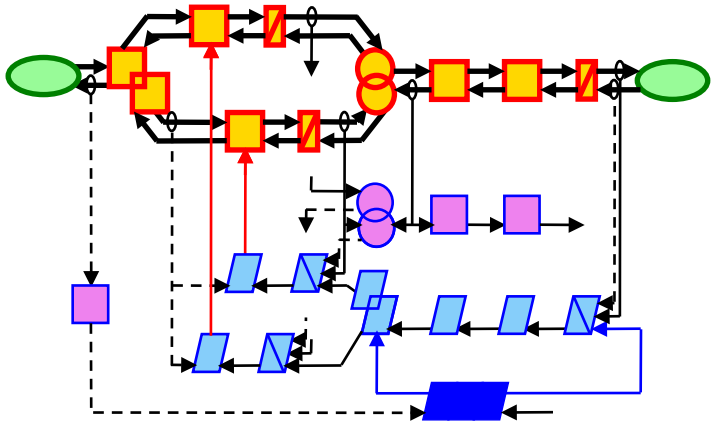
ENERGY STORAGE VOLTAGE WAVEFORM



- Simple Implementation
- Minimization of Grid Energy Consumption
- Grid Peak Power Shaving
- Minimization of AC Infrastructure Cost
- **Knowledge of L_{mag}, C_{st} is required**

L2EP & CERN Collaboration

Energetic Macroscopic Representation (EMR)



Internship at CERN

Master Student: Amel Baziz

Five-month duration supervised by both parties

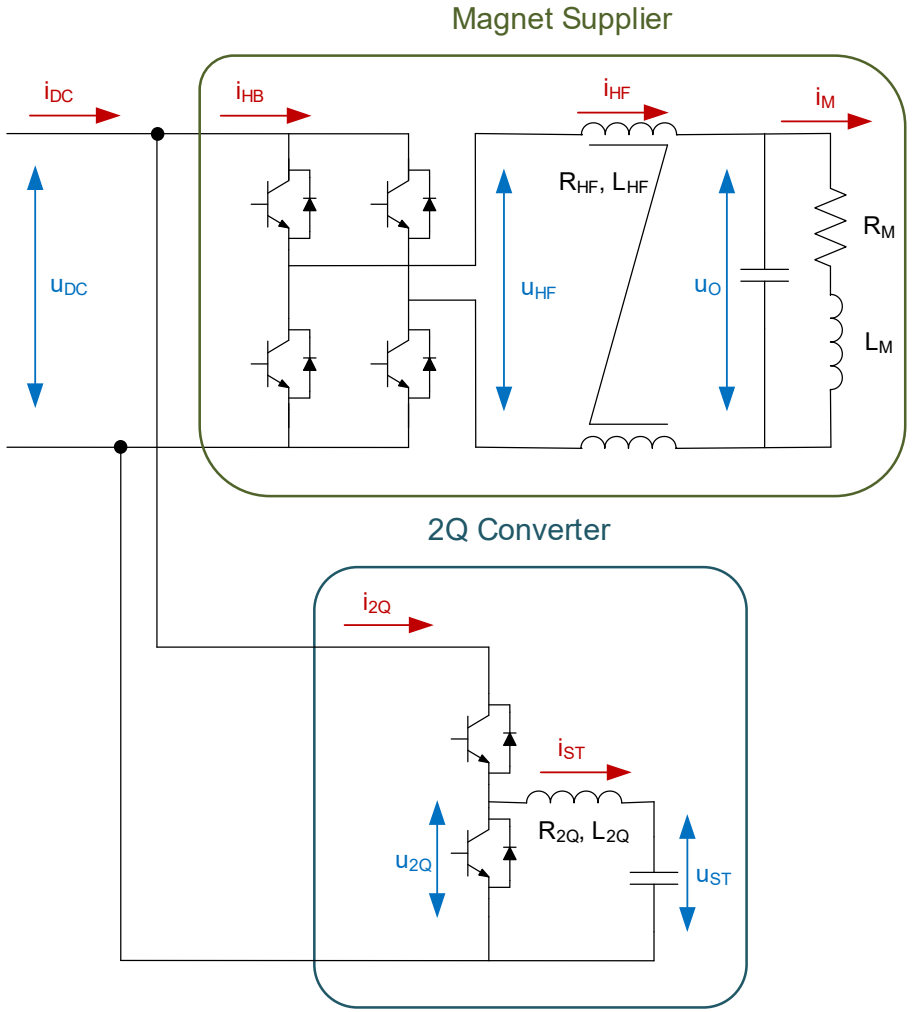
Investigation Areas

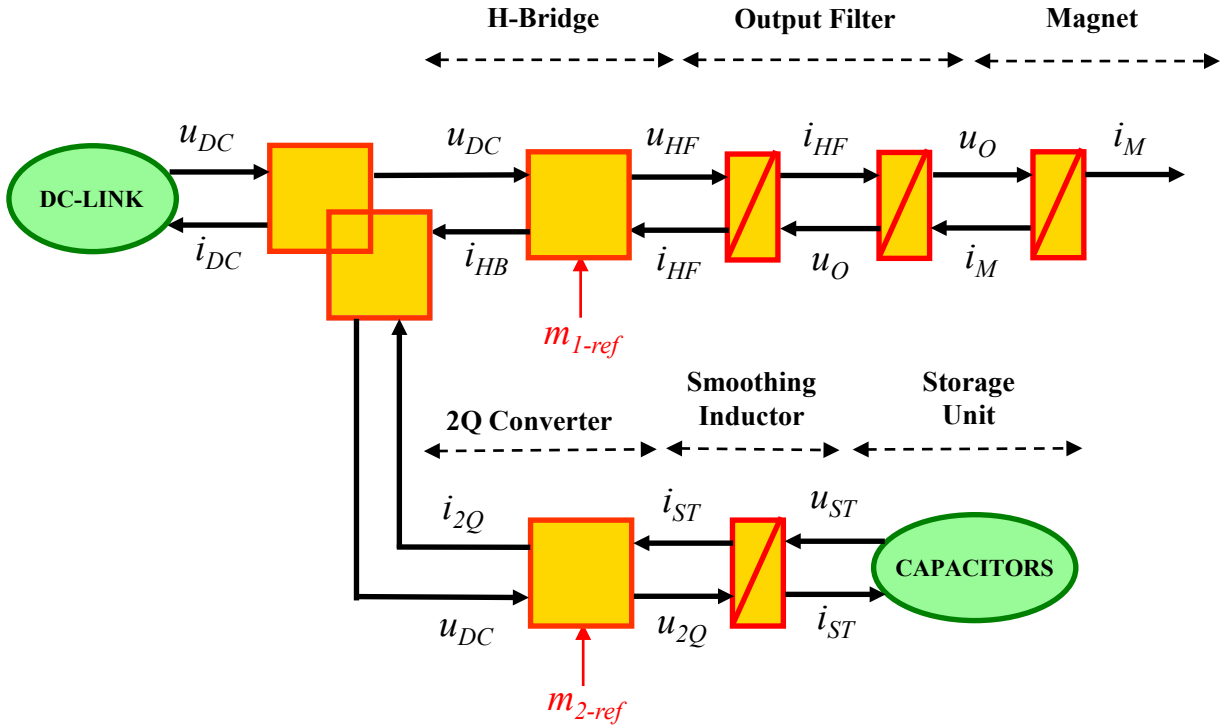
POLARIS representation using EMR

Alternative tuning paths for Input Stage Control

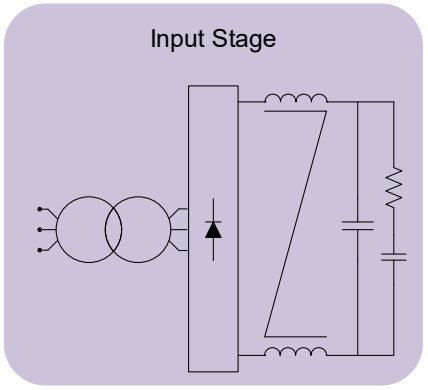
Alternative energy management implementation

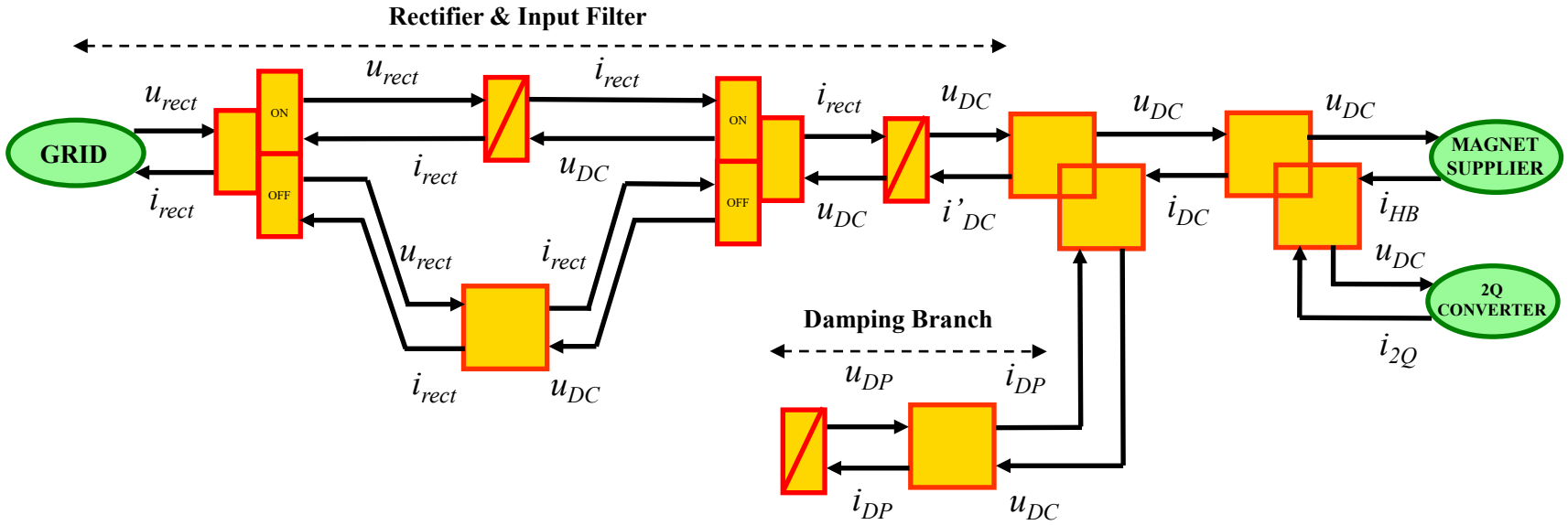
EMR Representation: Magnet Supplier & 2Q Converter

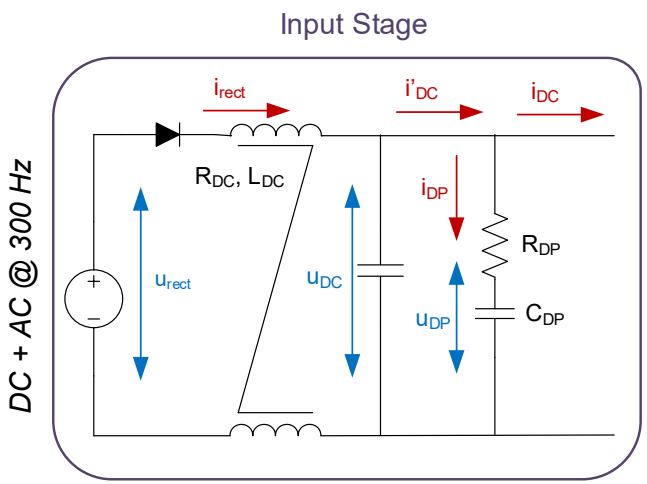




EMR Representation: Input Stage



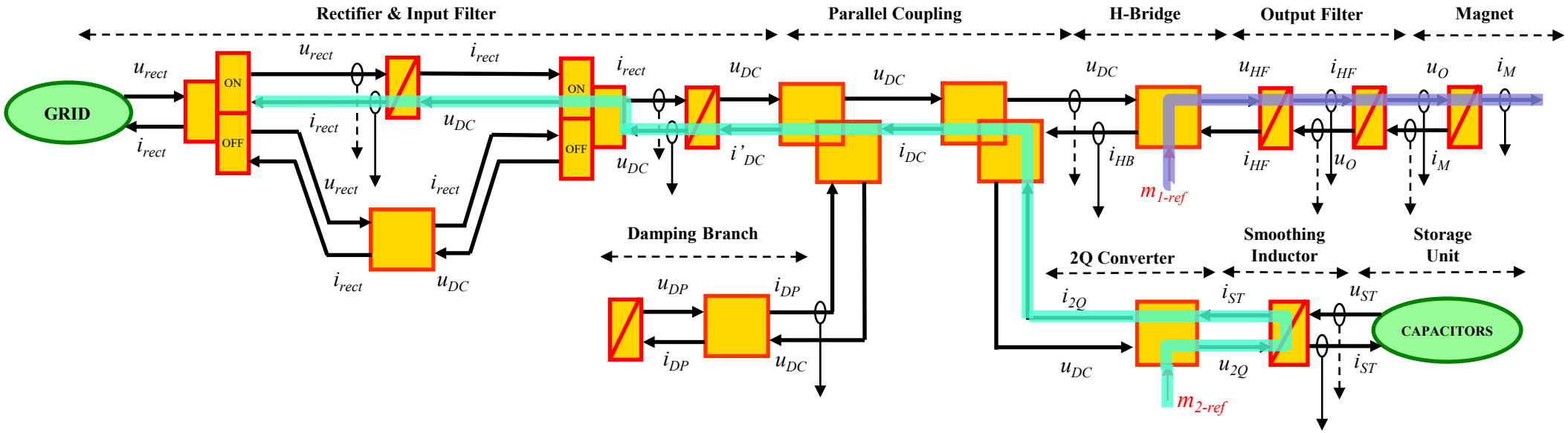




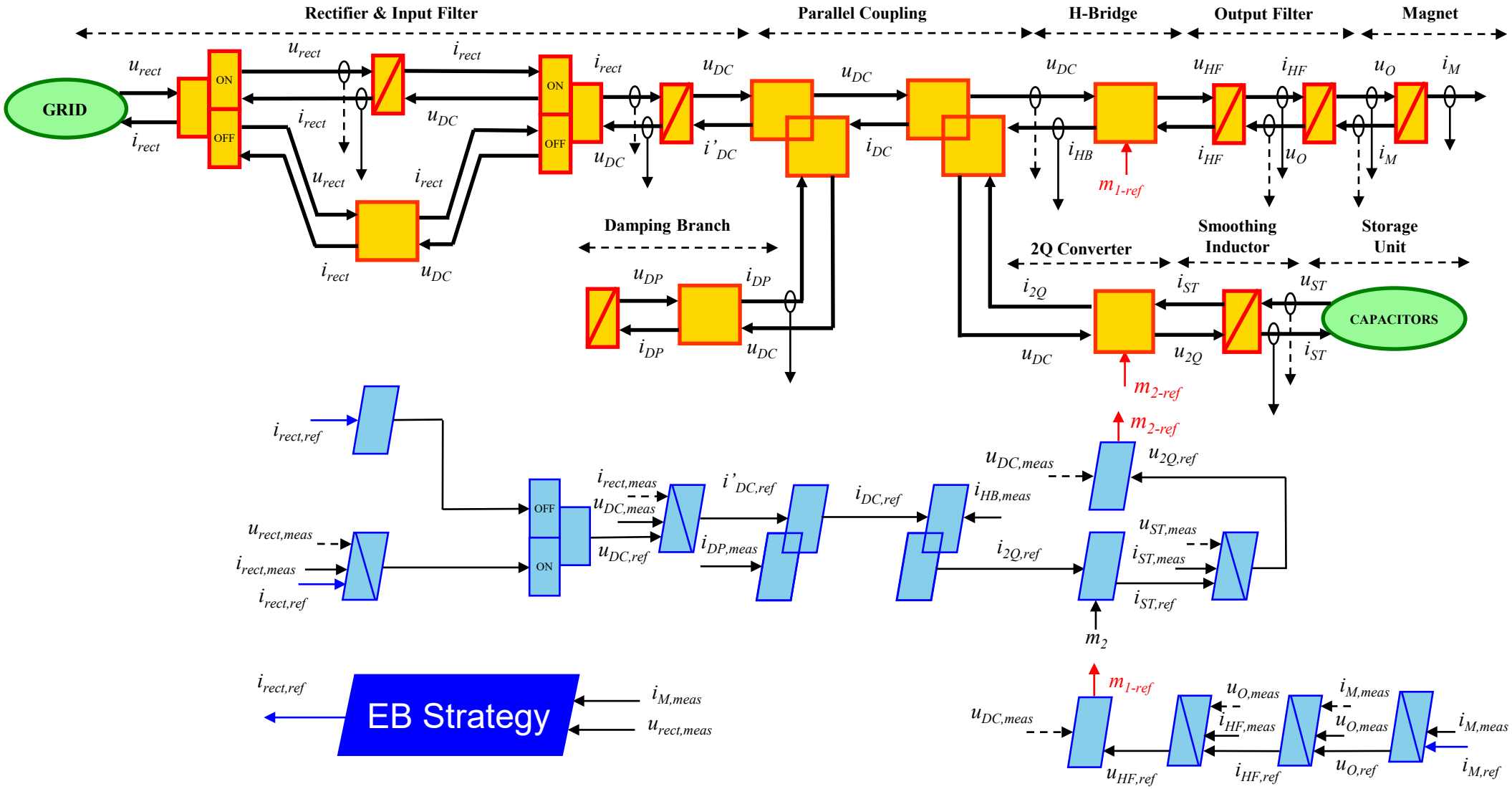
Uncontrolled Components

- *Transformer is excluded*
- *Rectifier represented as ON/OFF switch*

Tuning Paths

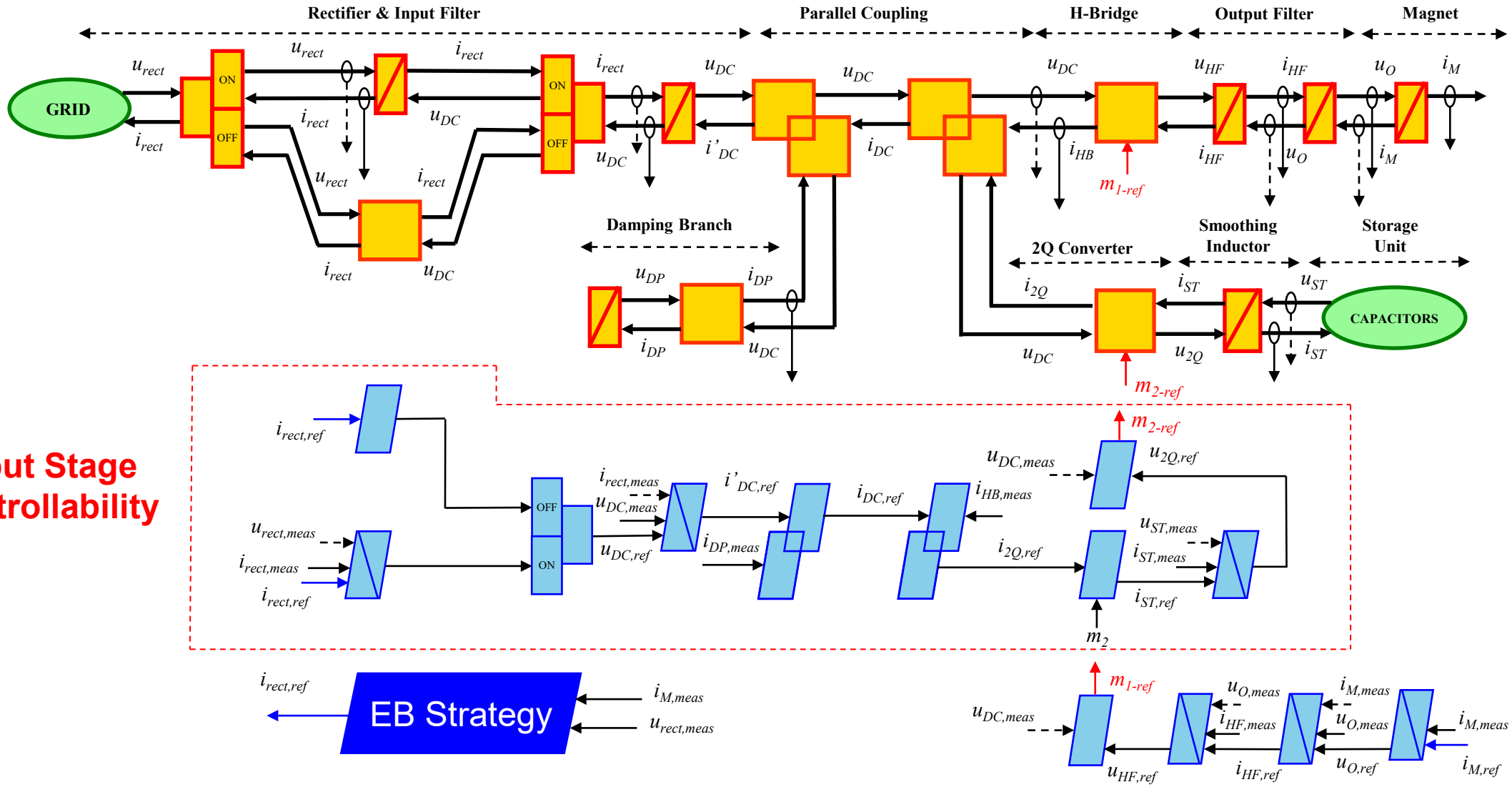


Control Structure: Initial



Control Structure: Initial

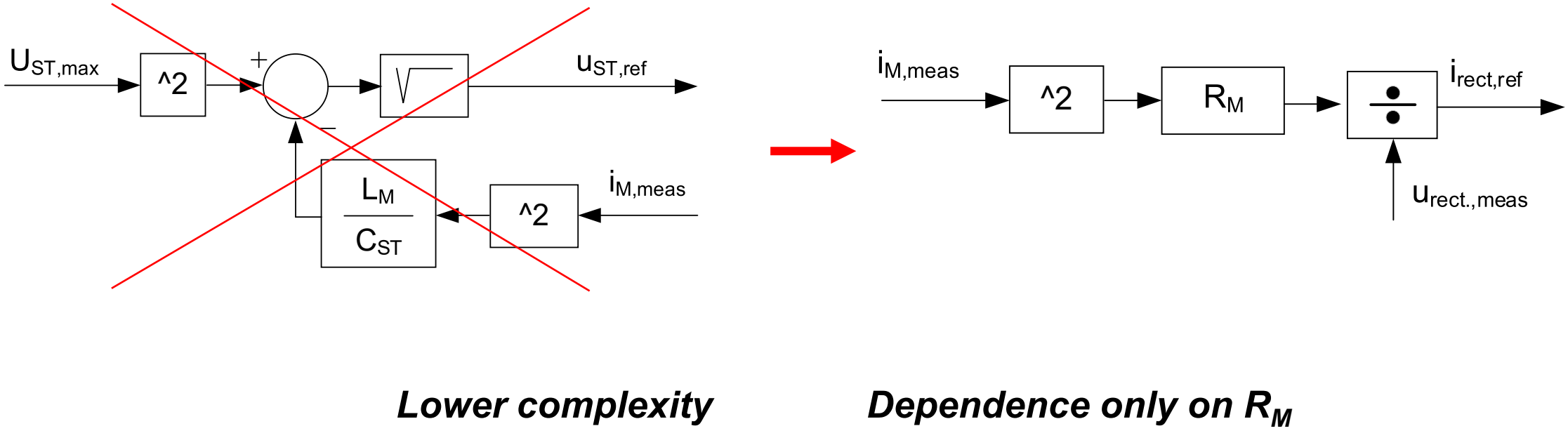
Input Stage Controllability



Alternative EB Strategy

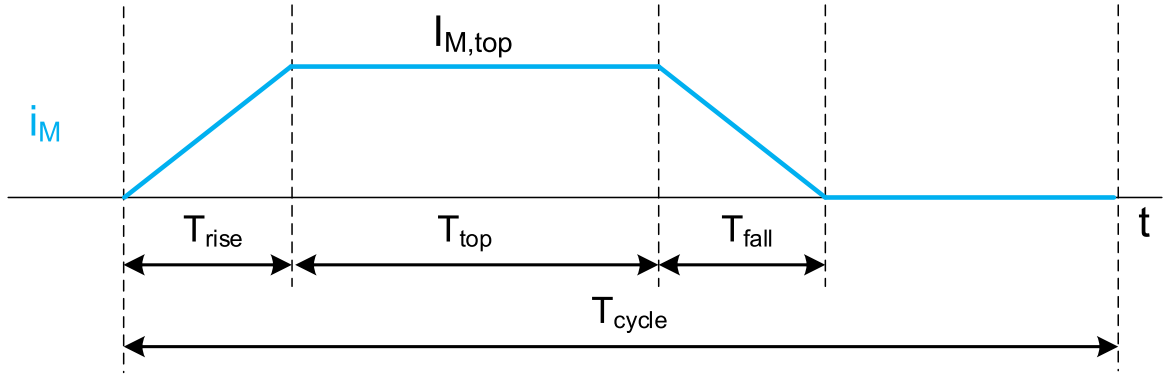
"The resistive losses of the magnet are provided by the grid"

$$P_{grid} = P_{M,loss} \rightarrow i_M^2 \cdot R_M = i_{rect} \cdot u_{rect} \rightarrow i_{rect} = \frac{i_M^2 \cdot R_M}{u_{rect}}$$



Lower complexity ***Dependence only on R_M***

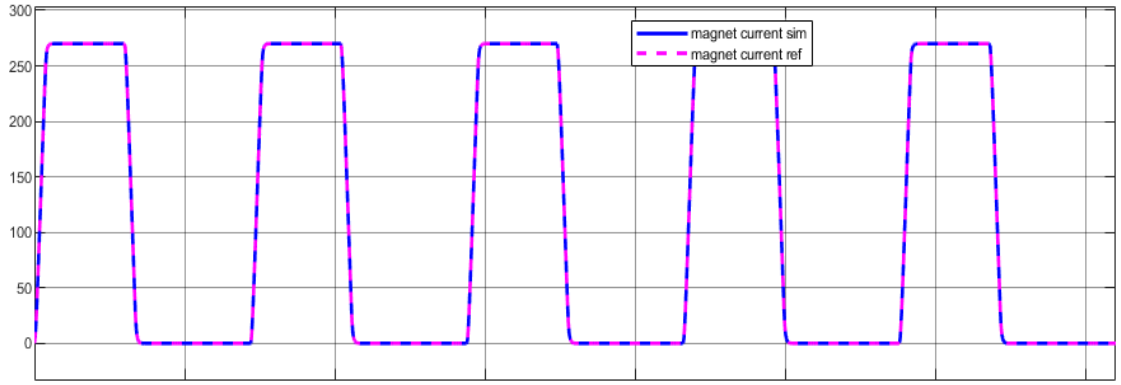
Simulation Results



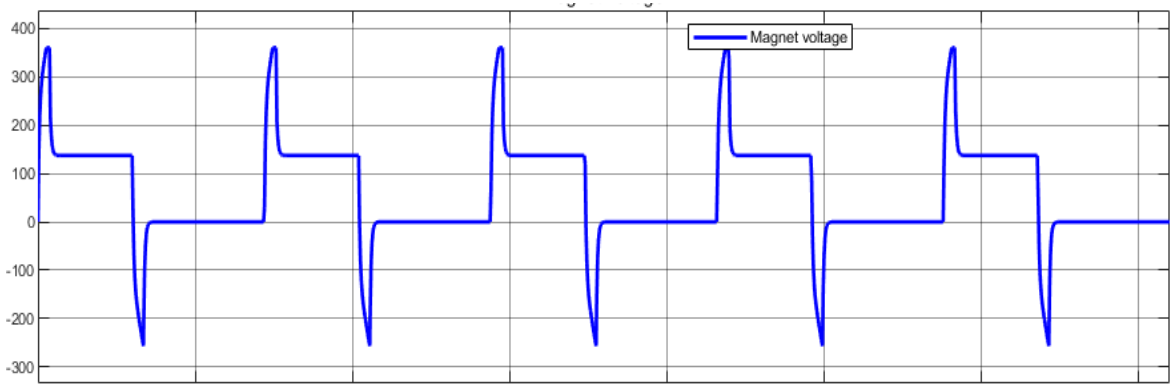
Simulation on MATLAB Simulink®

- R_M = 0.508 Ω, L_M = 0.771 H
- T_{top} = 5.3 s, T_{cycle} = 14.4 s
- $I_{M,top}$ = 270 A

Magnet Current, i_M

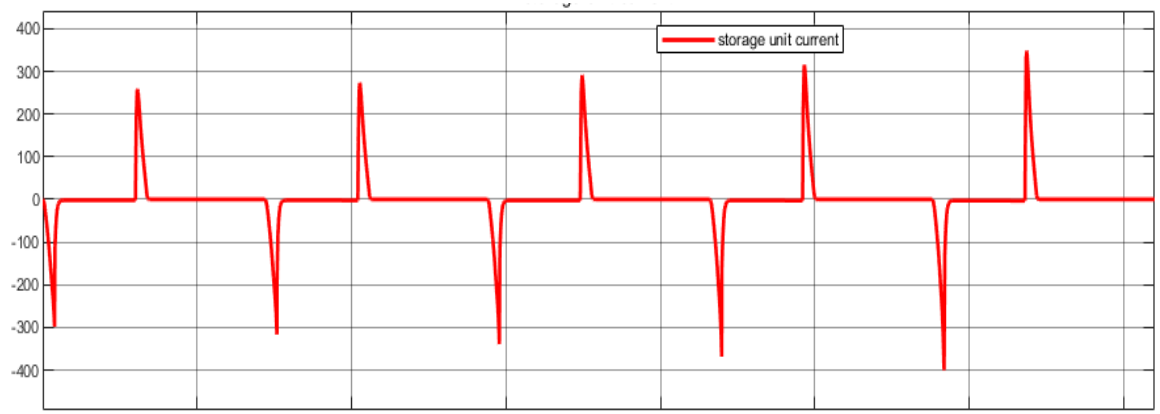


Magnet Voltage, u_O

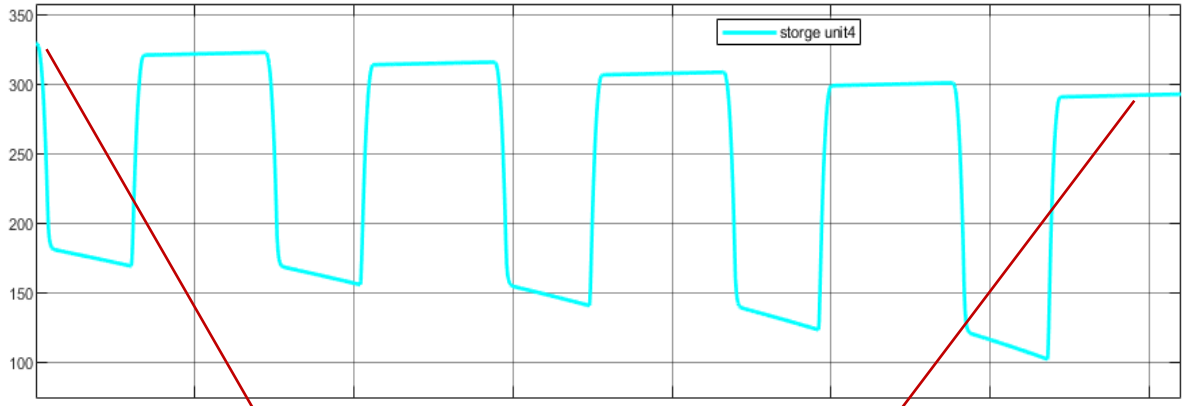


Simulation Results

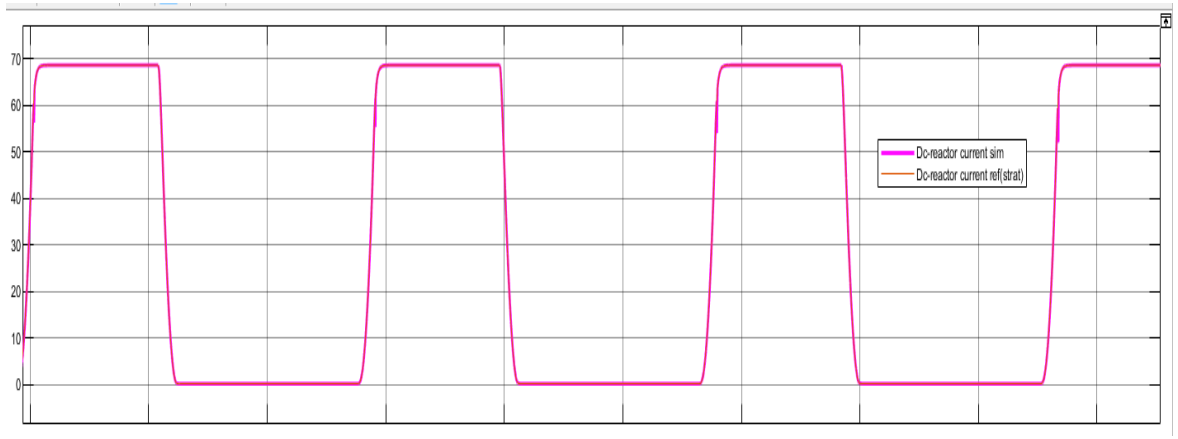
Energy Storage Current, i_{ST}



Energy Storage Voltage, u_{ST}



Input Inductor Current, i_{rect}

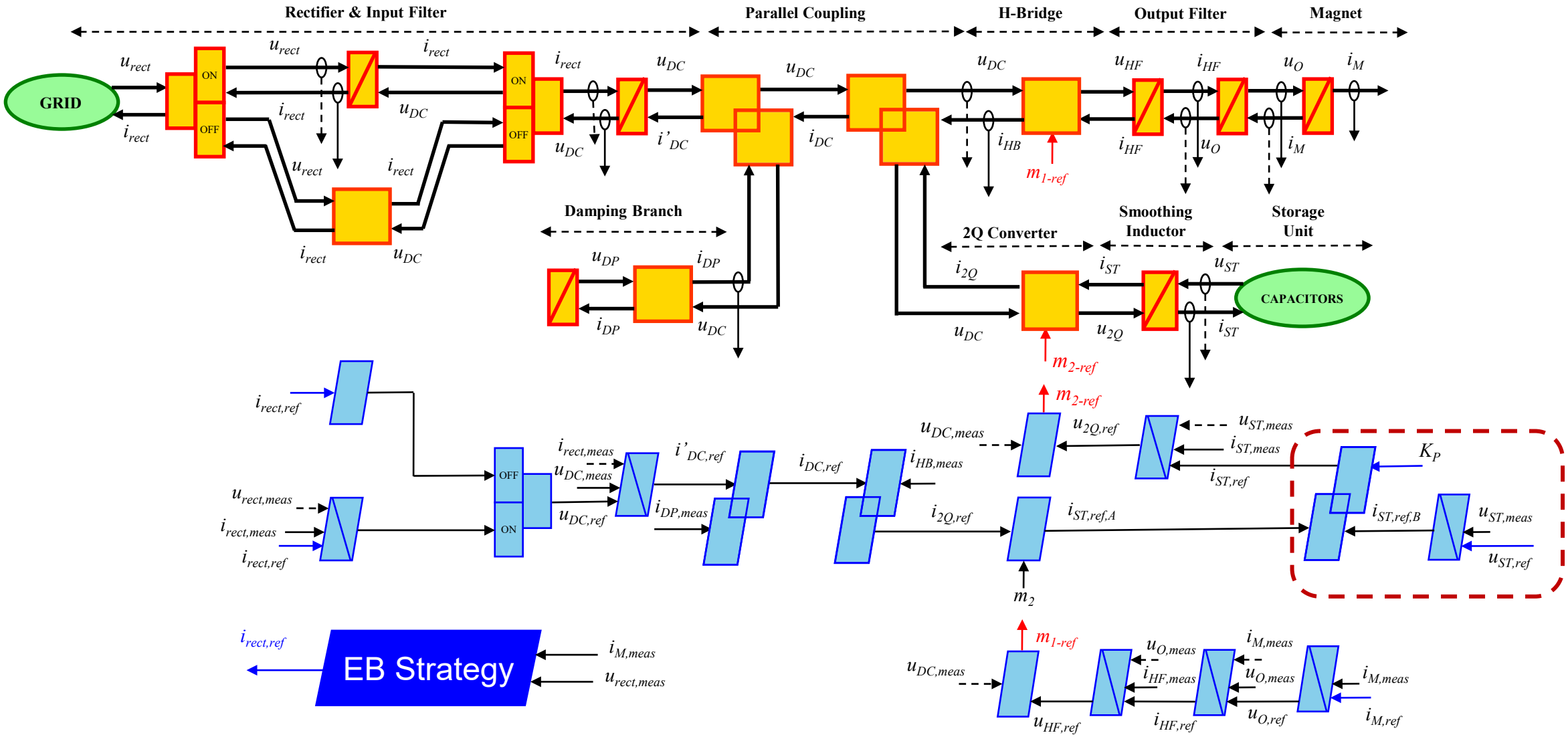


$u_{ST} = 330\ V$

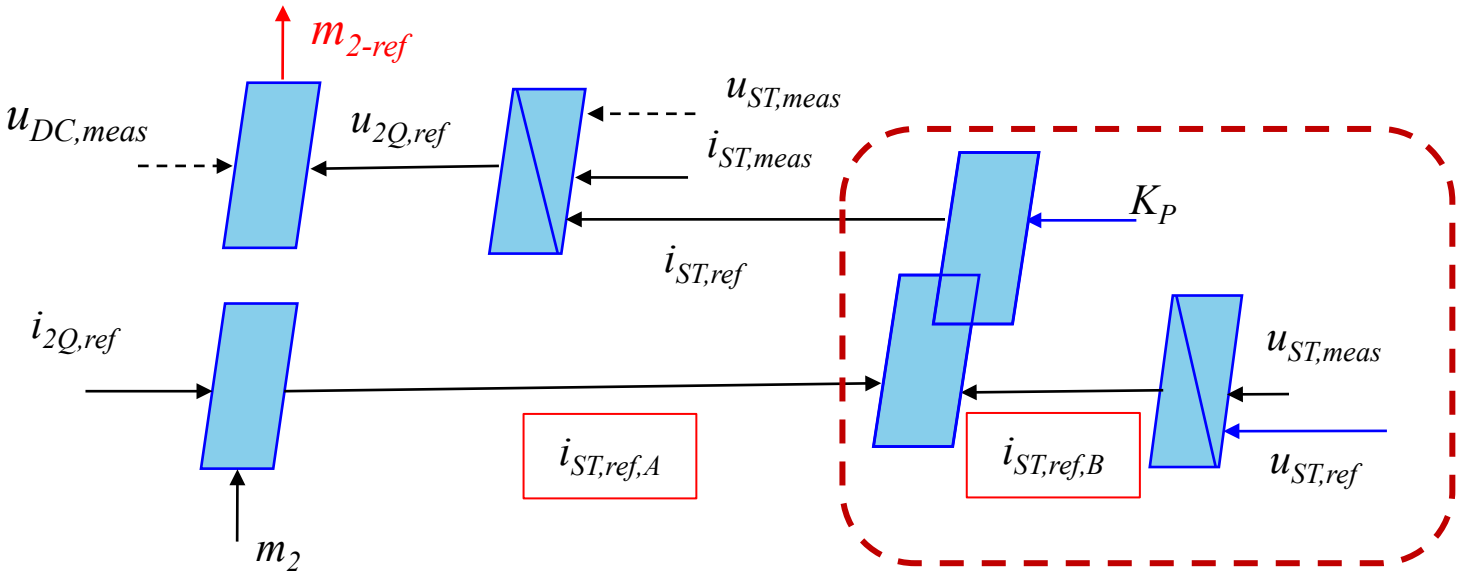
$u_{ST} < 330\ V$

Issue on the energy storage recovery due to power converter losses

Control Structure: Final



Merging Element

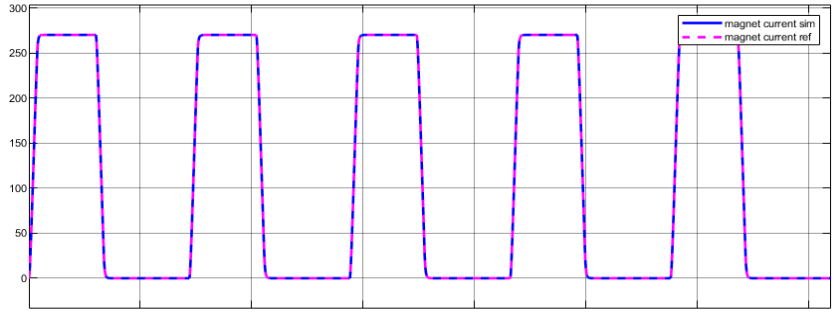


Additional Control Loop

- Slow controller for recharging
- Constant $u_{ST,ref}$ = 330 V
- K_P defines $i_{ST,ref,A}$ and $i_{ST,ref,B}$ weights

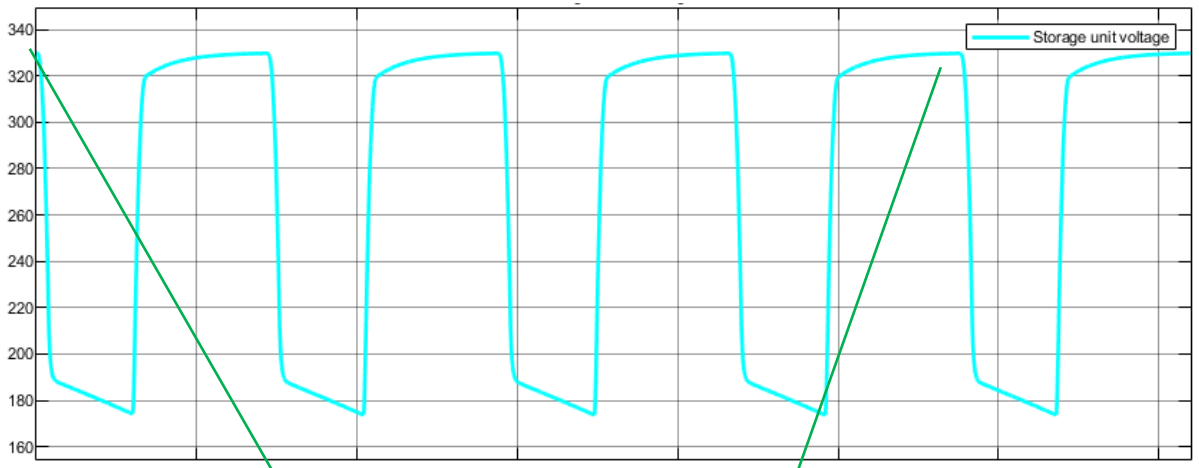
Simulation Results

Magnet Current, i_M



Energy Storage Current, i_{ST}

K_P = 0.85 *Energy Storage Voltage, u_{ST}*



u_{ST} = 330 V

u_{ST} = 330 V

Successful recharging of the energy storage

Summary

POLARIS converter model has been represented using EMR, highlighting energy exchanges

EMR offers a new insight on the 2Q tuning path with controllability of the input power

The new 2Q control loop simplifies the EB strategy which becomes independent of L_M, C_{ST}

It is not mature enough to be implemented in POLARIS (complexity, measurements, K_P definition)

Future subjects

Further investigation on K_P definition and reduction of complexity and measurements

Rejection of the 300 Hz ripple on the DC-link

Electronic damping of the DC-link

Thank you

EMR’25, Lille (France)

http://emrwebsite.org

CERN

L2EP
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