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Current development of [120kV, 40A, 1.5ms, 2hz] klystron modulators for CERN Linac 4

(A review of the state of the art in solid state technology)

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Power Converters Group)

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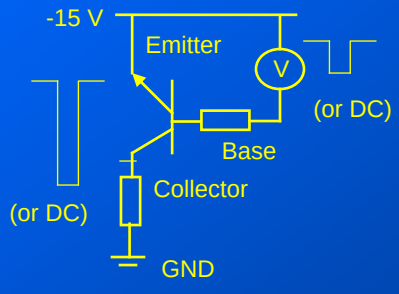
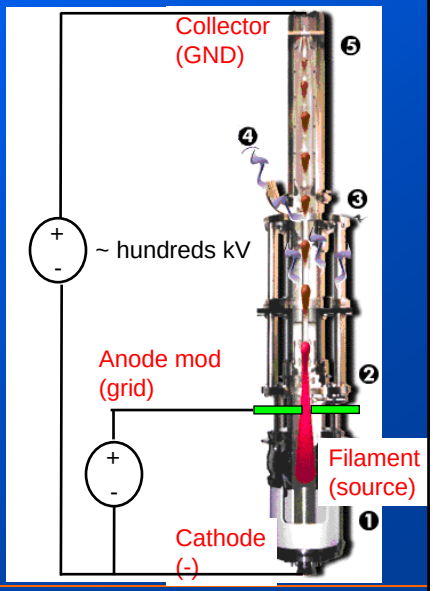
What is a Klystron?

It's an Electrical to RF power converter !!!

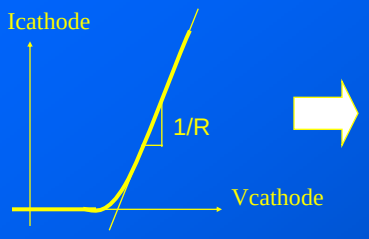
On the electrical "side", behaves like a transistor

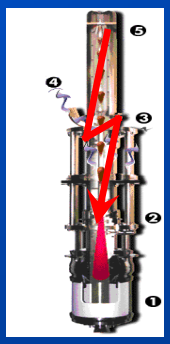




Klystron as an electrical load

Normal operation





Klystron arcing and protection

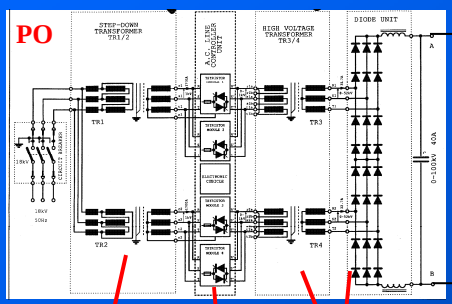
Arc: Behaves like a short circuit (arc voltage ~ 50V);

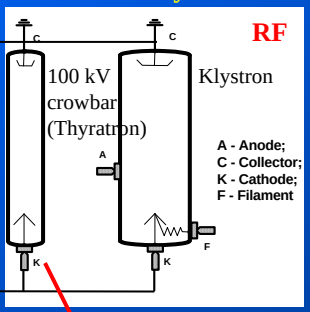
Maximum allowed energy in the arc: ~20 J

(Power supply has to be quiclky switched off or bypassed)

Past experience in klystron supply from Power Converters group at CERN.

100 kV, 40A, DC (CW) power converter for LHC klystrons



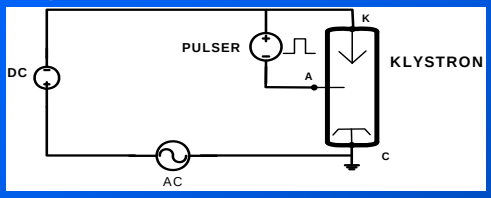


Thyratron
CROWBAR

Methods for klystron powering in pulsed mode

Two main approaches, depending on the klystron type:

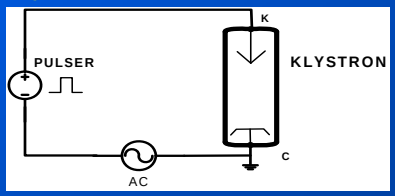
Klystrons with Anode Mod terminal



Limitations:

- Klystrons are more expensive and less reliable;
- Cathode voltage permanently applied - > insulation stress

Klystrons without Anode Mod terminal

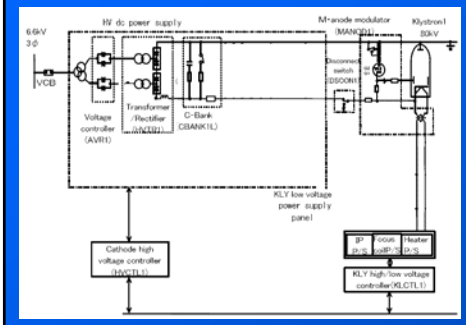


Challange:

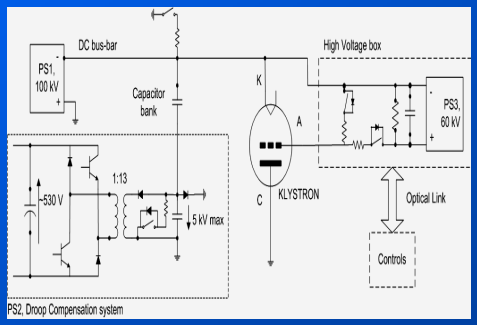
- Development of the “pulser” power supply;
- Power supply (converter) = klystron modulator

Klystron supply in pulsed mode. J-PARC, GSI topologies

With Anode mode terminal



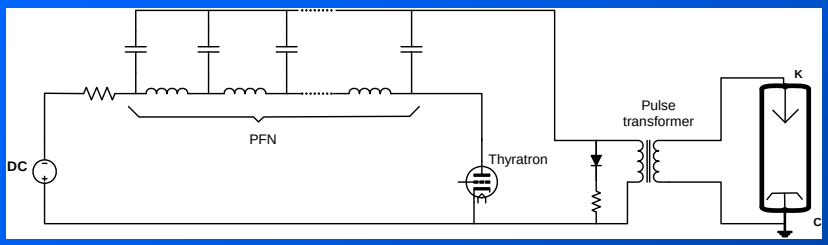
Ex: at J-PARC, Japan



Ex: at GSI, Germany

Klystron supply in pulsed mode. Traditional topologies

Without Anode Mod terminal (Thyratron + PFN based topology)



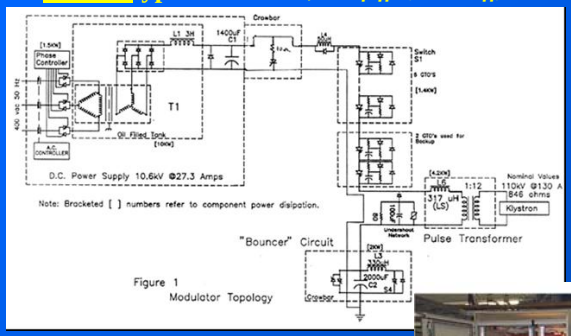
Ex: Linac 2, CTF3 at CERN

Limitations:

- Use of cathodic tubes (thyratrons, ignitrons);
  - ⇒ Limited lifetime with increased maintenance;
- Bulky and expensive system (PFN's with increasing number of cells for large pulse widths;
- Possible periodic PFN tuning required to compensate for ageing effects;

Klystron supply in pulsed mode. Some recent solid state topologies

The *TESLA* type modulator, *H. Pfeffer, D. Wolff, and Al.*, FERMILAB



Simplified electrical schematic, with pulse transformer

120 kV, 140A, 1.6ms, 5 Hz

(Without pulse transformer)

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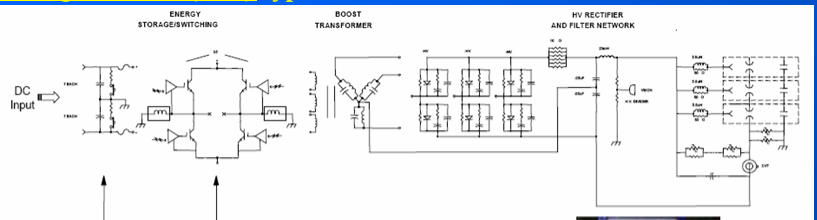
Klystron supply in pulsed mode. Some recent solid state topologies

The *Oak Ridge Nat Lab (SNS)* type modulator, *Bill Reass and Al.* Los Alamos Lab



High Voltage Converter Modulator

140 kV, 70A, 1.6ms, 60 Hz

Equipment Control Rack

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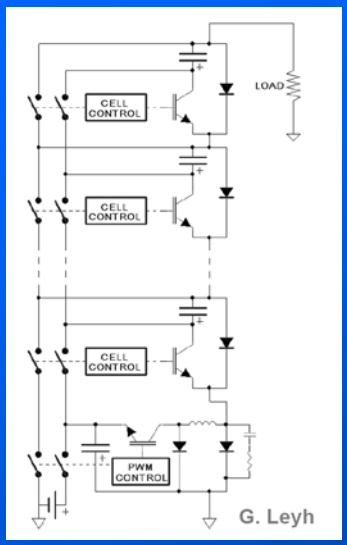
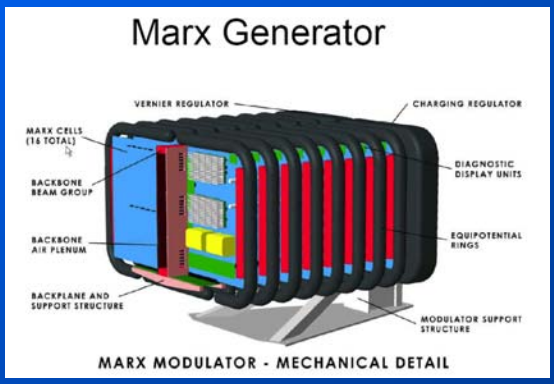
Klystron supply in pulsed mode. Some recent solid state topologies

The *SLAC* type modulator, *G. Leyh, R. Cassel and Al,* SLAC

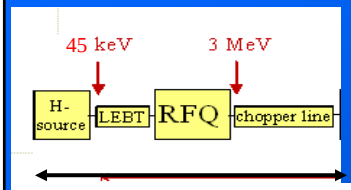


115 kV, 135A, 1.5 ms, 5 Hz

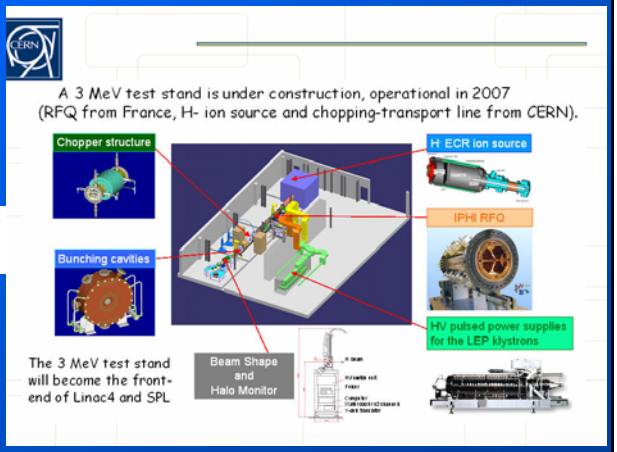


CERN 3 MeV Test Stand project
(Linac 4 Front End)

3 MeV Test Stand – Phase I (2007, 2008)



3 MeV Test Stand (end 2007)
1 klystron modulator

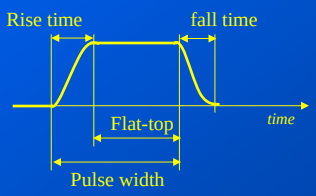


Due to the pulsed nature of the Linac,
a pulsed solution was chosen for the klystron modulator

Klystron modulator parameters for the 3 MeV Test Stand (LEP CW klystron)

Cathodes power supply

- Pulse width:	0.8 ms
- Flat-top duration	0.6 ms
- Precision at flat-top:	< 1%
- HF ripple at flat-top:	< 0.1%
- Repetition rate:	2 Hz
- Nominal voltage:	100kV
- Nominal current:	20A
- Rise/fall times:	150µs
- Cooling:	Air (natural and forced)
- Maximum energy in case of arc:	< 20 J



Anode Mode polarization power supplies

- Stability at flat-top:	< 1%
- HF ripple at flat-top:	< 0.1%
- Nominal voltage to cathode :	40..60 kV
- Nominal current:	5 mA

Filament heater power supplies

- Stability and ripple:	< 1%
- Nominal voltage:	30V
- Nominal current:	35A

- Floating withstand voltage to ground: 180kVdc for 1 min.

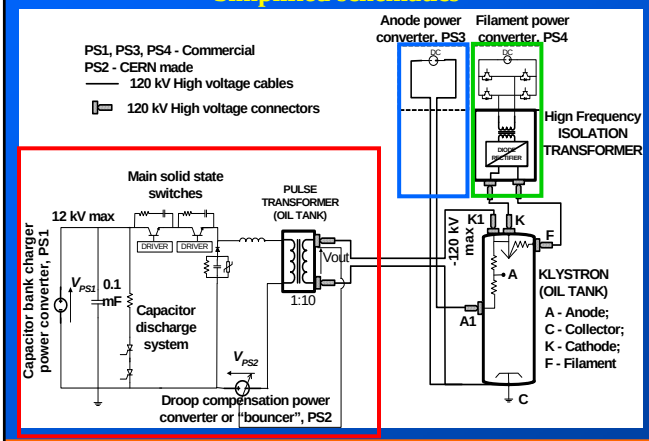
CERN prototype of solid state pulsed klystron modulator.

Proposed topology

(to be used in the 3 MeV Test Stand and Linac 4)

Ratings: 100 kV, 20A, pulsed 2 Hz, flat-top: 600 μs

Simplified schematics

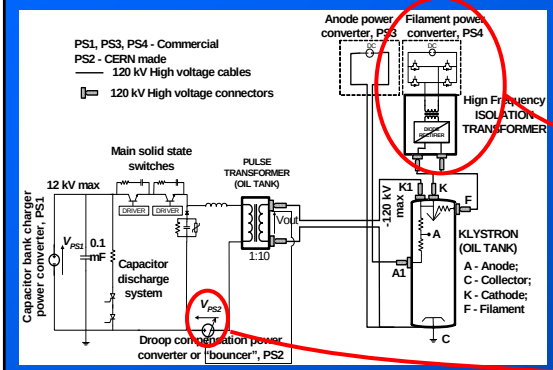


Description

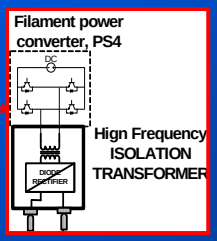
- Capacitor bank charged via a standard commercial power converter, *PS1*;
- Pulses formed by solid state medium-voltage switches;
- Step-up pulse transformer with oil insulation;
- Droop compensation system, *PS2*;
- Commercial anode and filament power converters, *PS3* and *PS4*, possibly with dry insulation;
- No CROWBAR needed in the HV line for klystron protection

CERN prototype of solid state pulsed klystron modulator.

Some new technological improvements

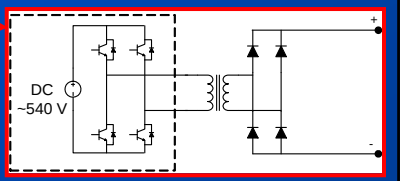


Switch mode filament heater power converter, *PS4*



Droop compensation system, *PS2*

- Today, still a "passive bouncer", but plans for active one:
  - Switch mode type;
  - Standard semi-conductor components;
  - Air insulation;
  - Fast closed loop feedback control



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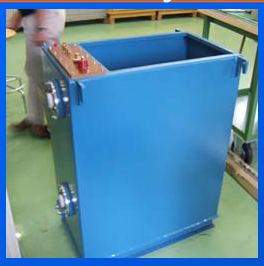
CERN prototype of solid state pulsed klystron modulator.

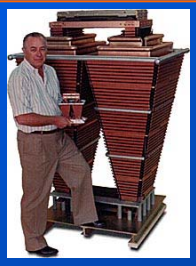
Main Components

Pulse transformer

- From STANGENES
- Oil insulation;

-10kV / 100kV;
- 200A / 20A;
- 800μs / 2 Hz

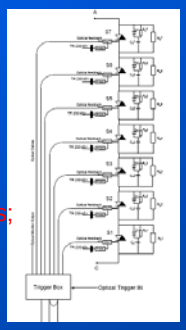




HV Main Solid state switch

- From ABB – Lenzburg;
- IGCT technology;

- 5 (+2 redundant) IGCT in series;
- 12 kV / 300A;
- 1.5 ms / 2 Hz



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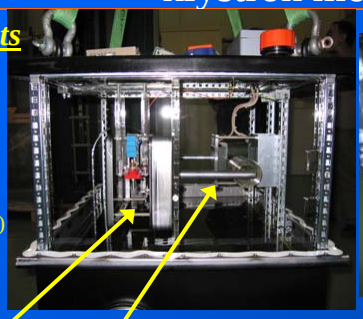
CERN prototype of solid state pulsed klystron modulator.

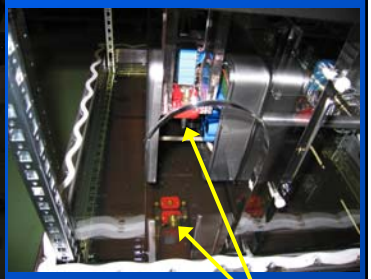
Main Components

Filament Heater Power Converter
(HV oil tank shown)

- From FUG;
- Oil (or Dry Siligal) insulation;

- 35V / 30A, DC;
- Floating at 120kV





Diode rectifier bridge and filter box

High-Frequency 180kVdc isolation transformer

HV output connectors

HV plug-in connectors

CERN prototype of solid state pulsed klystron modulator.

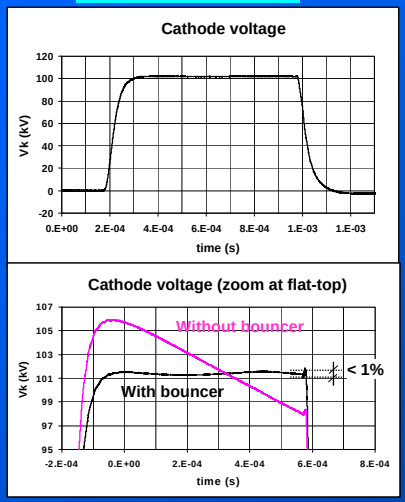
Cathode ratings: 100 kV, 20A, pulsed 2 Hz, flat-top: 600 µs

A global klystron supply solution: (Cathode, Anode, Filament) in one system

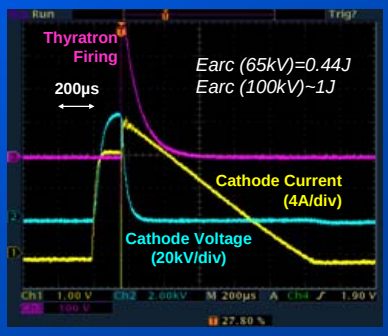
Test of the prototype in a dummy load

Cathode ratings: 100 kV, 20A, pulsed 2 Hz, flat-top: 600 µs

Normal Operation



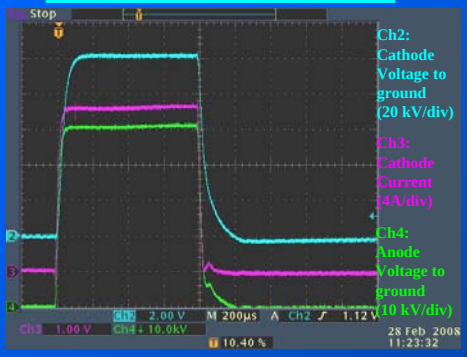
Arc protection (short circuit with Thyratron)



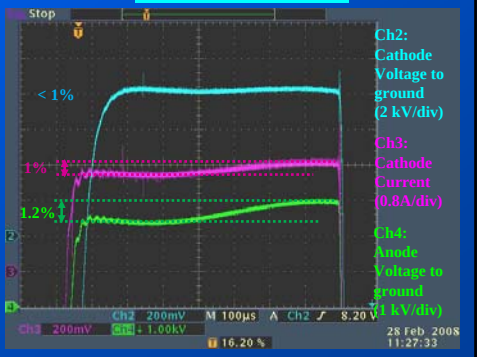
Test of the prototype with the LEP klystron

Cathode ratings: 100 kV, 20A, pulsed 2 Hz, flat-top: 600 µs

Normal Operation at nominal

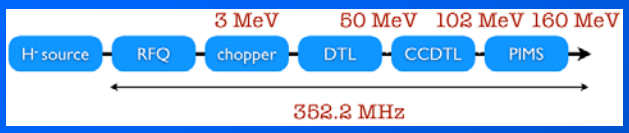


Zoom at flat-tops



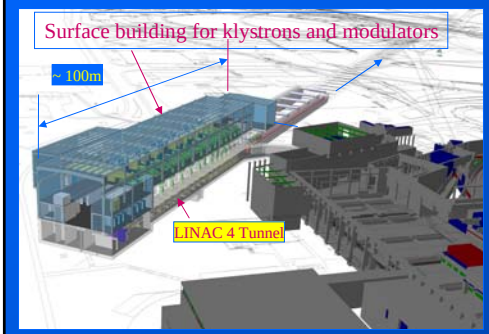
The CERN Linac 4 project

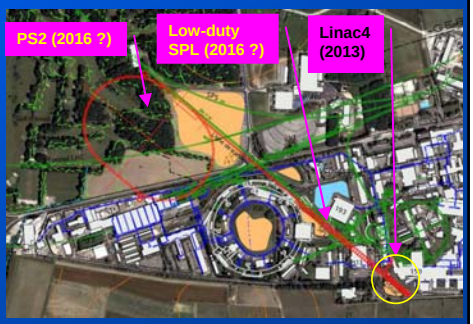
Linac 4 – Phase II (~ end 2012)



Linac 4

16 klystron modulators





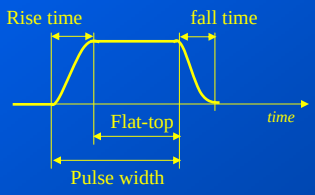
1st stage: Linac4 injects into the old PSB → increased brightness for LHC

2nd stage: Linac4 into SPL (and PS2) → renewed and improved LHC injection

Klystron modulator parameters for Linac 4 (LEP CW klystrons + new pulsed klystrons)

Cathodes power supply

- Pulse width:	1.5ms
- Flat-top duration	1.2 ms
- Precision at flat-top:	< 1%
- HF ripple at flat-top:	< 0.1%
- Repetition rate:	2 Hz
- Nominal voltage:	120kV *(*)*
- Nominal current:	2x20A *(*)*
- Rise/fall times:	150µs
- Cooling:	Air (natural or forced)
- Maximum energy in case of arc:	< 20 J



Anode Mode polarization power supplies

- Stability at flat-top:	< 1%
- HF ripple at flat-top:	< 0.1%
- Nominal voltage to cathode :	60 kV *(*)*
- Nominal current:	5 mA *(*)*

(*) to be confirmed, taking the new klystrons design into consideration

Filament heater power supplies

- Stability and ripple:	< 1%
- Nominal voltage:	30V *(*)*
- Nominal current:	35A *(*)*

- Floating withstand voltage to ground: 180kVdc for 1 min.

Klystron modulator for Linac 4 Choice of topology

Ratings: 120 kV, 40A, pulsed 2 Hz, flat-top: 1.2 ms

Proposed topology: Identical to the prototype one

Modifications

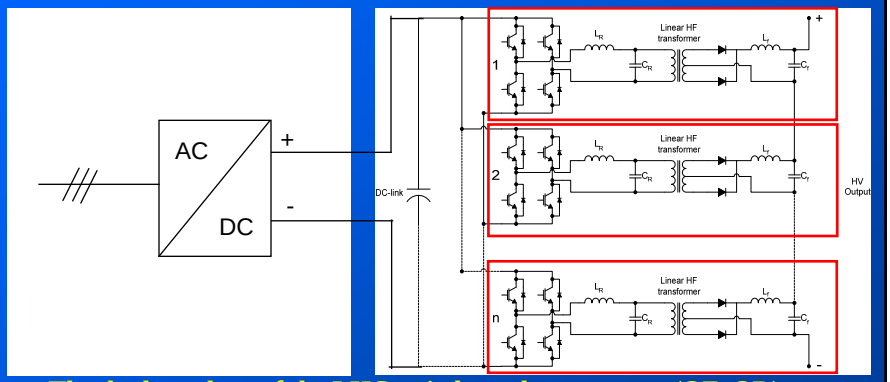
- Active droop compensation based on a fast switch-mode power converter (closed loop);
- HV part of the filament heater power converter placed in the klystron oil tank (saves 2 HV cables/connectors and one oil tank);
- One modulator will be able to supply one or two klystrons in parallel;

A possible klystron modulator topology for large average power (Full SPL at 50 Hz).

140 kV, 70A, 0.6ms?, 50 Hz

Capacitor charger: In surface building

Pulse former: In the tunnel



The dual topology of the LHC switch-mode converters (QF, QD):

LHC magnets : High current / Low voltage -> several modules in parallel

SPL klystrons: High voltage / Low current -> several modules in series