NEW GENERATION FOR HIGH-VOLTAGE-ALL-SOLID-STATE-MODULAR-POWER-SUPPLIES HIVOMOPS FOR FEL APPLICATIONS

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Abstract

A modular high-voltage source for Klystron supply is introduced in the following. The patented Transtechnik system, called *HiVoMoPS*, is capable of maintaining a maximum of 10 impulses per second each 10 ms in length at a voltage of 100 kV and a current flow of 24 A. Higher impulse repetition rates are possible with appropriately adapted voltage and power values.

It is possible to select an impulse value of between 20 and 100 kV. The impulse time, impulse repetition rate and impulse form can also be preset.

The HiVoMoPS is fed on the input side with 11 kV of direct current.

INTRODUCTION

The klystron modulator is an AC-to-High-Voltage-DC power converter. It is used as HV beam power supply for an 1 MW Klystron RF amplifier, which can be operated either in continuous duty mode or in pulse duty mode.

The klystron modulator consists of three main parts:

1. Primary power supply 11 kV 3AC to 11 kV DC
2. DC/DC Power Supply HiVoMoPS
   11 kV DC to 100 kV DC
3. Control section

Figure 1 shows the block diagram of the klystron modulator.

THE HIGH VOLTAGE POWER SUPPLY

Input Section: Primary Power Supply

The input section consists of transformer MTR1 with downstream rectifier. Transformer and rectifier are oil cooled. Input is 11 kV AC, directly connected from the medium voltage power grid.

Output is 12 kV DC with maximum current 10 A. The HVDC output is connected to Transtechnik's High Voltage Modular Power Supply TT-HiVoMoPS.

The most important operation signals (input voltage, output voltage, status signals) are wired to signal connector TB1 and may be monitored by an external monitoring- and control system.

The High Voltage Section: HiVoMoPS

The high-voltage modular power supply, subsequently referred to as *HPS*, serves to modulate klystrons as used in research centers in conjunction with linear accelerators. For this purpose, the HPS must be capable of maintaining,

– 10 times a second (max.), an impulse of
– 100 kV voltage (max.) at
– 24 A max. current flow over a period of
– 10 ms (max.).

The electrical output converted during an impulse is thus a maximum of 2.4 MW. The average electrical output with the named data is then a maximum of 240 kW.

All of the values given are maximum values. The real effective values can be set. Thus it is possible to select a voltage level of between 20 and 100 kV. The impulse time, impulse repetition rate and impulse form can also be preset.

The HPS is fed on the input side with 11 kV of direct current.

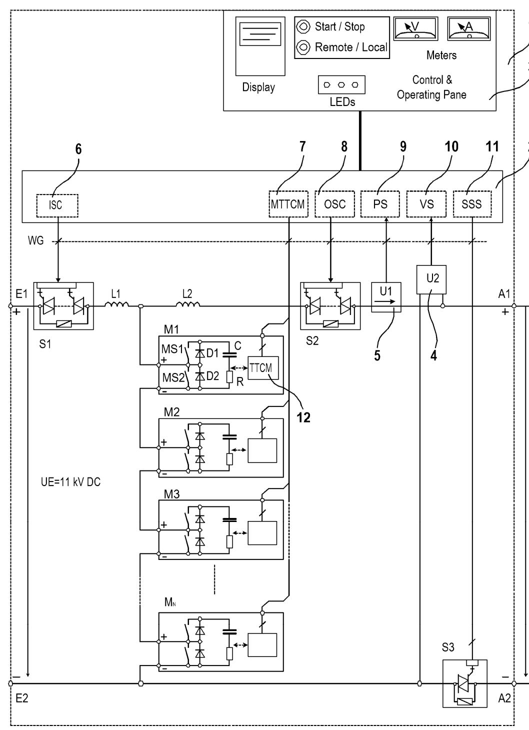

Figure 1: HV Power Supply with Control Unit.

Legend:

Callout	Abbr.	Designation
12	TTCM	2-terminal control module
7	MTTCM	Main two term. contr. mod.
6	ISC	Input switch control
	WG	Waveguide
8	OSC	Output switch control
5	CS	Current sensor
4	VS	Voltage sensor
11	SSS	Safety switch control

HOW HIVOMOPS WORKS

Two Terminal Network Energy Storage Unit

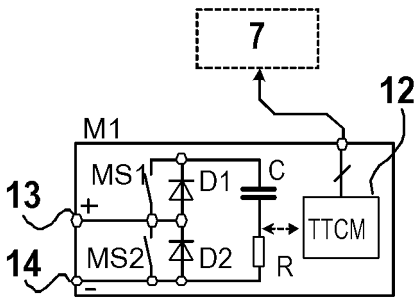

Figure 2: Two terminal network module.

The core is the two terminal energy store switch shown in figure 2 and described below. This is made up of a capacitor C and a charging and discharging switch for this capacitor. A low ohm (level, 1 Ohm) resistance R can, as is shown in figure 1, be connected upstream of the capacitor.

OPERATIONAL BEHAVIOUR

- If you apply direct current with correct polarity to the input terminals 13 (+) and 14 (–) and ensure that the switches MS1 and MS2 are open, the capacitor C is charged via the Diode D1.
- If you remove the charging voltage from the input terminals, the capacitor remains charged.
- After closing Switch S1 (see figure 1), the capacitor can be discharged again via the terminals 13 and 14.
- Using Switch S2 (see figure 1) short-circuits the input of the two terminals.
- The two terminal control 12 activates, when instructed by the main control unit, the switches S1 and S2.
- The two terminal switch functions without auxiliary power. The two terminal control 12 is supplied via the input terminals or, in the event that there is not input voltage, from the capacitor as long as this is charged.

SEVERAL TWO TERMINALS IN SERIES

Figure 3 shows two 2-terminal stores switched one after another. This is the simplest form of serial connection and serves to explain the principle behavior of a serial connection of the two terminal module.

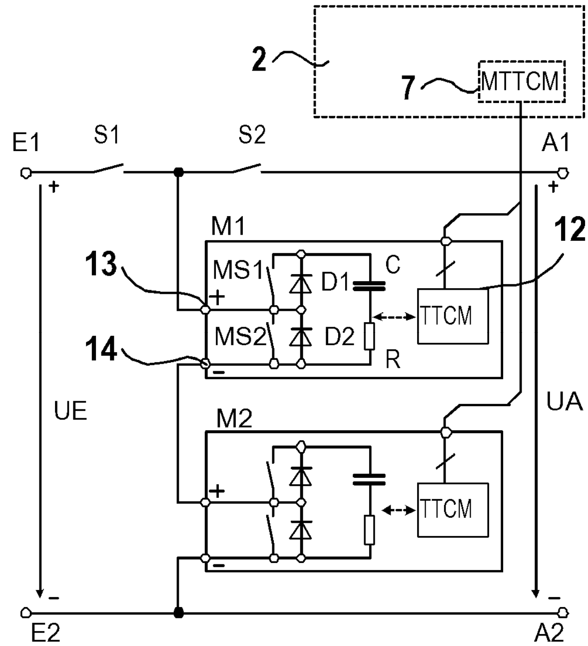

Figure 3: Two terminal network modules in series.

CHARGING THE CAPACITORS

- The input switch S1 (see figure 1) is closed (= ON) and the output switch S2 (see figure 1) is then forced open (OFF).
  The main control unit must guarantee blocking of S1 and S2.
- The voltage UE now charges the capacitors on the two 2-terminal modules via the D1 diodes. The two terminal modules form a capacitive potentiometer: The voltage at each terminal is ½ UE.
- After sufficient time has past, each of the two capacitors is charged to ½ UE voltage.
- The bypass switch MS2 on the two terminal module M2 is closed. Thus all voltage UE is now on M1. The capacitor on M1 is thus further charged to the voltage UE. It is assumed that the capacitors are capable of handling this voltage. Then the bypass switch MS2 on M2 is opened again.
- The bypass switch MS2 on the two terminal module M1 is closed. Thus all voltage UE is now on M2. The capacitor on M2 is thus further charged to the voltage UE. Then the bypass switch MS2 on M1 is opened again.

All of the capacitors in the serial connection is now charged to UE.

Output voltage build-up and discharging capacitors

1. The main control unit opens input switch S1. The 11 kV input is now disconnected from the serial connection.

2. The main control unit closes the discharge switch MS1 on both modules.
   Result: The voltage 2 UE is now available at the output.
3. After closing the output switch S2, the serial connection of the two terminal capacitor can be discharged via the klystron.

Using the principle

In principle, as many two terminal modules as required can be connected in series. With a chain of N two terminal modules, you have the following possibility:

– During the charging phase, deliberately bypassing of two terminal modules means that just enough capacitors are charged to ensure that the maximum permitted voltage is not exceeded at the capacitor.

  Example:
  If the capacitors are only capable of a maximum load of 1000 V and the input voltage is 11,000 V, then at least 11 capacitors must always be charged if you require the maximum output voltage (if you do not, it is sufficient to only charge the capacitors to a voltage of less than 1000 V). If the serial connection is made up of, for example, 180 two terminal modules, then a maximum of 169 modules may be bypassed by the main control unit (MS2 closed) during the charging process.

– With 180 capacitors connected in series, in theory it is possible to achieve a maximum of 180 kV by closing all discharging switches MS1 on the two terminal modules. This voltage would, however, only be available on discharge via the klystron at the point in time t=0, afterwards the voltage would drop exponentially in accordance with the time constant RC that is determined by the overall capacity of all capacitors and the ohm resistance in the circuit.

– When just a lower voltage is required, for example, 100 kV, and under the assumption that all capacitors of the serial connection are charged to 1000 V, at the time point t=0, only 100 two terminal modules will need to be switched using MS1 to discharge, and 80 further two terminal modules remain available for refreshing.

– Whenever the high voltage at the output drops under a certain value, the switching of new "fresh" two terminal modules can be used to raise it again until the reserve of the 80 modules are used up.

This enables a sudden drop in the outgoing impulse to be avoided. If you start out with, for example, 100 capacitors in series, each of which is charged to 1000 V the starting voltage is 100,000 V. As soon as the output voltage has dropped to 99,000 V, you switch another, capacitor that is still charged to 1000V into the series. The output voltage is now 100,000 V for a minute short period of time, and will then start to drop exponentially (with a slightly different RC time constant, as there are now 101 capacitors in the series which changes the overall capacity of the serial connection, and there are also 101 resistances in the serial connection which will change the overall resistance.

Quasi-Continuous Operation ("DC Mode")

HiVoMoPS is capable to generate up to 10 pulses per second, each with a pulse length of 10 ms maximum. To achieve quasi-continuous operation which would be similar to "DC mode", several HiVoMoPS installations are required. Figure 4 shows the overview.

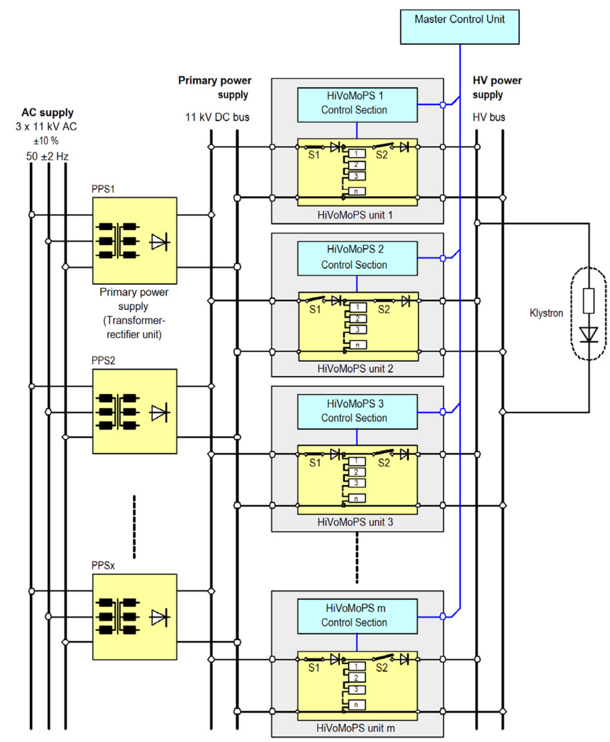

Figure 4: Sequential operation of several HiVoMoPS.

The klystron pulse can be extended to more than 10 ms by sequentially feeding the klystron HV bus with more than one HiVoMoPS unit (HMU). Each HiVoMoPS control unit is connected to the master control unit by the control bus. The interaction of all involved HMU is controlled by the master control unit. To achieve the "continuous output voltage mode" the outputs of several HMU are connected in parallel to the klystron HV bus. Only one HMU is feeding the HV bus at the same time (S2 closed, S1 open). The other units are in charge mode (S1 closed, S2 open).
When the first HMU is at the end of its capacity to maintain the output pulse with the desired parameters, the output of this unit is separated from the klystron HV bus. This is done by the master control unit which causes the active HMU control unit to open S2. Then the output of the next HMU will be connected to the klystron HV bus.

A MODULAR POWER SUPPLY FOR FEEDING KLYSTRON ACCESSORY

Overview

The modular DC power supply, called TT-MoPS, is used wherever regulated direct current must be made available with high levels of operational safety. Example applications are, for example, supply to particle accelerator magnets or klystron filament supply.

A TT-Mops cabinet operates with a least one and at most five supply units. In the event that one unit fails, these can be exchanged for another. Adjustment work is not necessary.

TT-MoPS can also be switched in parallel which allows the maximum output power available to be increased further. Figure 5 shows the 19" TT-MoPS cabinet with the maximum content, five parallel switched DC supply modules.

Typical installations examples: 3 units with 55 V and 250 A each, connected in parallel for 750 A max. current. May be extended up to 1250 A. Or e. g. 5 x 125 V / 133 A for 666 A max. current.

Short Description

TT-MoPS is a high-performance DC power supply system which is fed on the input side with local mains voltage, e. g. 3 x 400 V AC.

The structure of the TT-MoPS is modular.

A 19" cabinet houses

- an input module with EMI filter circuit, circuit breakers and absorption circuit
- the main rectifier unit
- up to five power supply units
- a control, display, monitoring and operating module with ±15-V electronics power supply

All power supply units outputs are usually connected in parallel to the DC output bus. However, several different power supply units can be installed in the same rack, e. g. two units with 25 V for filament supply and three units with 125 V for magnet supply.

The units are made as drawers. They can easily plugged in and out. Connection to the in- and output buses as well as the control bus is made by use of special connectors on the rear side of the units.

Figure 6 shows the block diagram.

Figure 5: Modular power supply 19" rack.

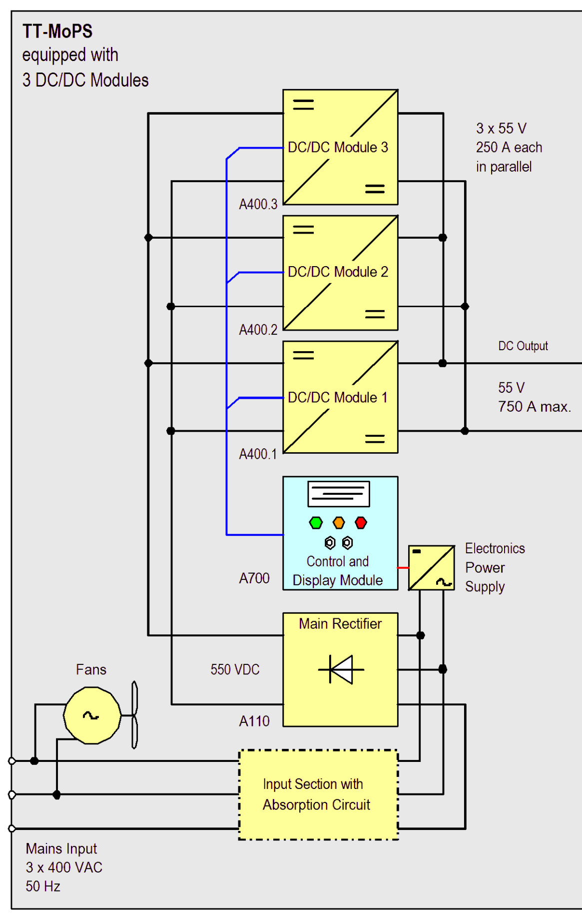

Figure 6: Block diagram of the modular power supply.