Novel Short Pulse Modulator for High Power Microwave Tubes

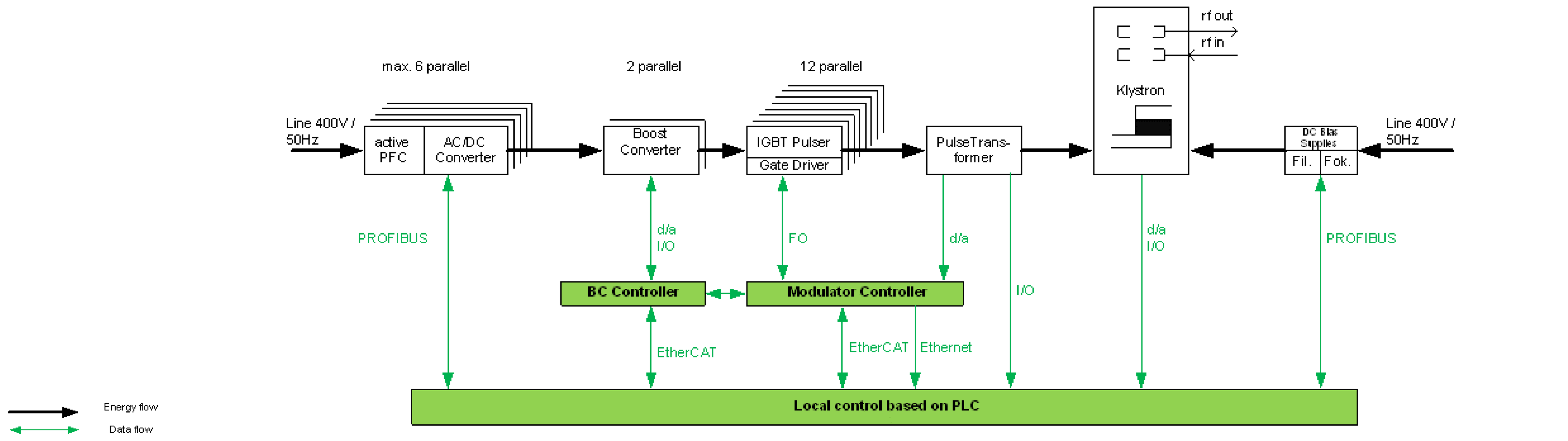
Test Results for SwissFEL

Guido Blokesch, Wolfgang Kaesler, Günter Böhm, Michael Osemann, Dirk Kraemer,
Marcel Frei, Michael Bader, Adreas Epp and Etienne Möri (Ampegon)
Dominic Gerber, Jürgen Biela (ETH Zürich, Switzerland)

Introduction

Ampegon, in collaboration with the Laboratory for High Power Electronic Systems HPE/ETH Zürich, has developed a novel short pulse modulator based on a matrix transformer for high power microwave klystrons. This new system meets future requirements for the next generation of particle accelerators, such as Free Electron Lasers (FELs) for research, medical and industrial applications; prioritizing reliability, efficiency and precision. Special emphasis has been given to a modular and scalable design, providing a high level of redundancy and easy maintenance. This is achieved with a clear and extendable system layout, which allows access to all components, and the use of COTS (commercial off the shelf) elements. The pulse-to-pulse stability and high system efficiency, in combination with a fast voltage rise time, meets the demanding requirements of efficient future accelerator designs. A full scale industrialized modulator, based on the C-band RF station specification of the SwissFEL project (PSI, Paul Scherrer Institute, CH), has been built and fully load tested with a Toshiba E37212 klystron in the Ampegon factory in 2014. Our poster reviews the system concept and test results.

The Modulator Principle



Mechanical Layout

The modulator consists of the following mechanical units

1 modulator tank, housing the oil immersed pulse transformer, HV divider and current measurement

2 12 pulse power modules (IGBT modules), including pre-magnetisation circuits

3 modulator control, HV earthing, cap bank discharge, oil supervision and water manifold

4 19" rack housing the control system and klystron auxiliary power supplies

5 19" rack housing the active PFC power supplies, precision boost converter and focus power supplies

6 400 VAC / 50 Hz mains input and distribution cabinet and current measurement

Pulse Shape

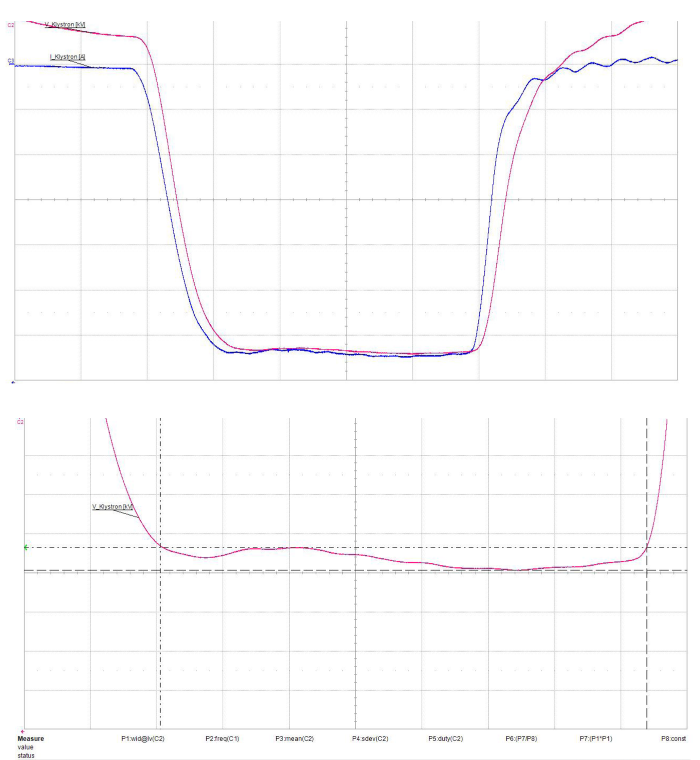


Figure 1: Pulse Shape Measurement on Klystron E37212 Toshiba

Figure 2: Pulse Power Module with Press Pack IGBT´s

Technical Highlights

- Short rise and fall time due to low stray inductance leads to high pulse efficiency
- Relatively high primary voltage and the active pre-magnetisation supports the high transformer efficiency and reduces the current in the IGBTs
- Consequent use of Standard IGBT for HVDC transmission lines as switching elements leads to a long product life cycle
- High pulse to pulse accuracy
- High maintainability due to accessibility and modularity providing redundancy
- Flexible layout capability due to the use of standard 19" racks
- Robust design providing high safety margin regarding high voltage
- Convectional oil cooling
- Risetime and overshoot can be optimized
- If required, a bouncer circuit for droop compensation is available

Acceptance Test Results with Klystron

Specification	SwissFEL Requirement	SAT Measurement
Efficiency	-	78 % at 3 µs flat top
		82 % at 5 µs flat top
Cos phi	≥ 0.92	0.98 at 100 Hz
		0.97 at 50 Hz
		0.90 at 10 Hz
Total phase current asymmetry	20 ARMS	9.5 A at 100 Hz
		8.0 A at 50 Hz
		4.3 A at 10 Hz
THD current	-	<5 % at 100 Hz
Output voltage	370 kV	370 kV
Output current	344 A	344 A
Reverse voltage	<40 kV	12 kV
Switching on time	≤ 0.8 µs	0.8 µs
Switching off time	≤ 1.7 µs	1.4 µs
Pulse to pulse stability	≤ 20 ppm	≤ 20 ppm
Voltage flat top ripple and droop	± 1 %	± 0.8 %
Voltage flat top (within the ± 1 % ripple and droop band)	≥ 3 µs	4.6 µs
Voltage Pulse Width at 76 % level for 3 µs flat top	≤ 6.2 µs	4.0 µs
Acustic noise level	< 72 dBA (wish)	78 dBA
Repetition rate	1 – 100 Hz	0.1 – 100 Hz

Charging Power Supply

A remote control system controls the two interleaved resonant boost converter, which charges the capacitors of the PPMD. The resonant design allows high efficiency, accurate charging, high switching frequency of 70 kHz to 200 kHz, low electromagnetic interferences and 40kW output power. The converter operates in boundary conduction mode in order to achieve zero voltage switching.

Figure 3: High Precision Charging Power System

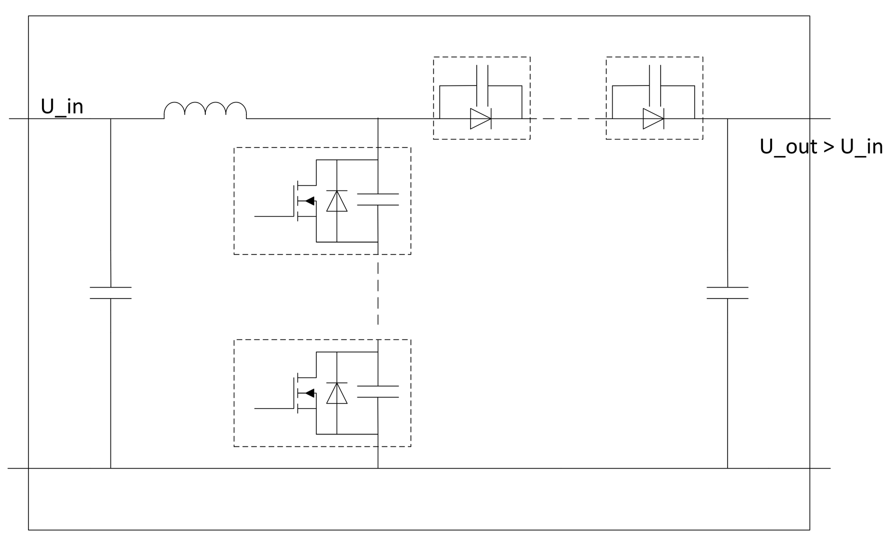


Figure 4: Boost Converter Circuit Diagram

© Copyright 2015 Ampegon AG. All rights reserved.