A NEW PROTOTYPE MODULATOR FOR THE EUROPEAN XFEL PROJECT IN PULSE STEP MODULATOR TECHNOLOGY

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Abstract

The European XFEL project at DESY in Germany requires 27 RF stations capable of 10 MW RF power each. Each RF station needs one high voltage modulator that generates pulses up to 12 kV and 2 kA with a duration of 1.7 ms and a nominal repetition rate of 10 Hz. DESY decided to investigate new modulator prototypes and Thomson was awarded to design and build one of these prototype modulators. The Thomson modulator is based on the pulse step modulator (PSM) principle. This technology allows the regulation of the pulse voltage during the pulses, thus achieving a good flatness. In addition to the common PSM technology this modulator design includes additional features. The first one is a constant power regulation system to prevent a 10 Hz loading of the mains. The second one is the extension for 2-quadrant operation in order to demagnetise the core of the pulse transformer between the pulses. The modulator was delivered to the modulator test facility at the DESY Zeuthen site in July 2008 and is now under test. The paper will give a detailed overview on the system and shows the results of the factory and site tests.

SYSTEM OVERVIEW

The modulator provides high voltage pulses to supply the klystron during the machine pulse. At XFEL the klystrons will be placed in the accelerator tunnel whereas all modulators will be placed in a central modulator hall at the beginning of the accelerator section. As the maximum length will be 1700 m, an impedance matched system is needed for the interconnection. This is achieved by using 4 coaxial cables, each with a nominal impedance of 28 ohms in parallel, resulting in an effective cable impedance of 7 ohms.

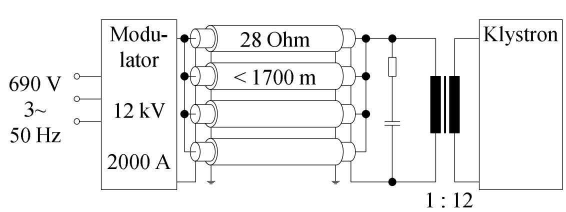

Figure 1: System overview.

Figure 1 shows a simplified block diagram of the overall system. More details are available in [1].

SYSTEM DETAILS

PSM technology permits regulation of the pulse voltage during the pulse. This allows full compensation of the voltage droop on the storage capacitors. No other compensation means is needed. The modulator is comprised of 24 active modules. The system is able to operate with 22 modules at full performance, resulting in a redundancy of 2 modules. Each module is equipped with a 20 mF storage capacitor charged up to 700 V prior to the pulse. A full energy pulse discharges it down to 550 V. For the demagnetisation of the pulse transformer between the pulses and for dissipating the inductive stored energy under klystron arcing conditions 4 modules are paired with additional switching modules in a two phase configuration, allowing inverse voltage operation. This makes it possible to set a negative voltage down to 4 modules voltages, which is sufficient for the required operation.

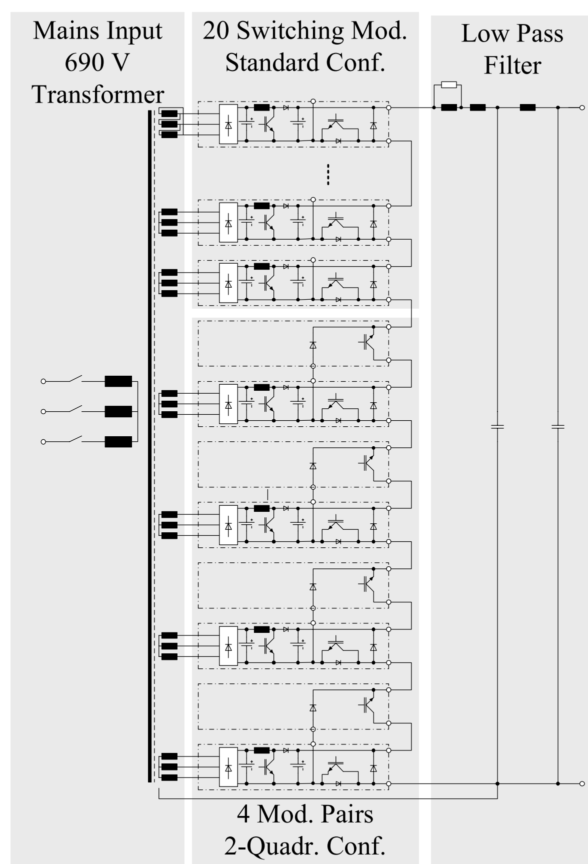

Figure 2: Modulator block diagram.

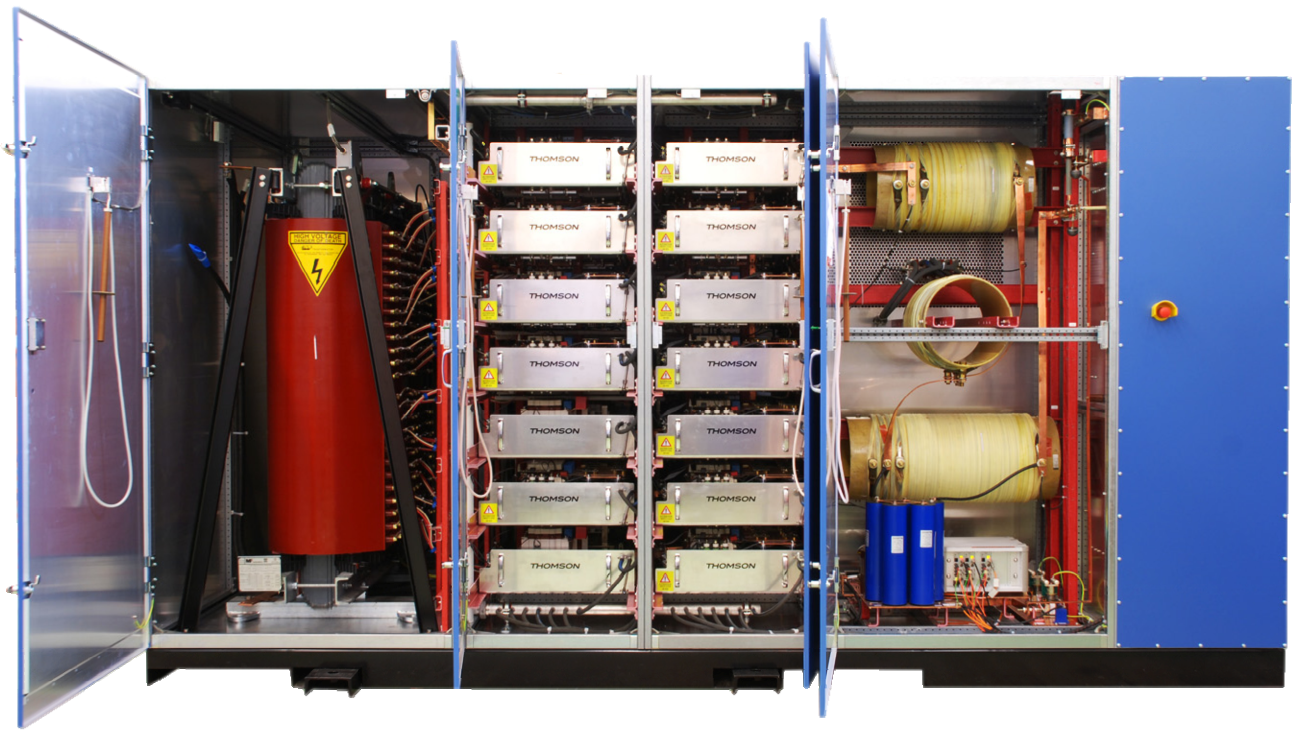

Figure 3: Complete system view.

The Switching Modules

The switching modules are designed as pluggable units. As main switching element a 1200 V / 2400 A IGBT transistor module form Semikron is used. The constant power consumption is achieved with a boost converter realised with a 1200 V / 400 A IGBT. All semiconductors are placed on a single water cooled heat sink.

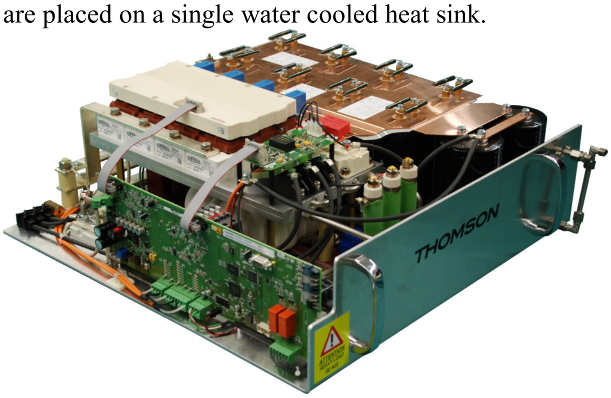

Figure 4: Power module.

The Control System

The control system is based on a Compact-PCI computer running Windows XP Embedded. The control software is based on TINE [2]. This allows easy remote access from the DESY control system.

The pulse waveform is sampled by the control system with a sample rate of 1 MS/s and is also accessible via the TINE protocol. This enables very easy checking of the modulator performance without the need of additional test equipment.

Local control is made by a touch-screen display. Additionally a keyboard / mouse in a drawer is also available.

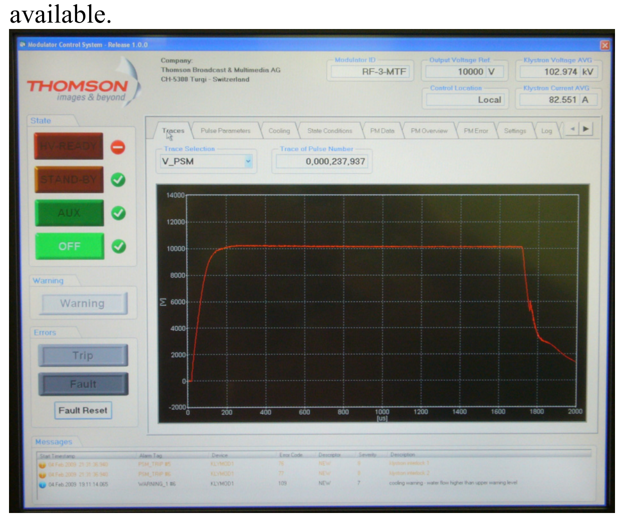

Figure 5: Control system screen with pulse waveform.

Pulse Voltage Control

The pulse is formed with a PWM modulation of 480 kHz. This results in a switching frequency of 20 kHz for each individual module. During the pulse the voltage droop on the storage capacitors is compensated by increasing the PWM modulation. The switching frequency and harmonics are filtered out by the output filter network. As the klystron load is a nonlinear load and the system is designed to operate different tube types with different Perveance, it is not possible to design a filter with optimum performance under all load conditions.

Thus some over- or undershoot may result depending on the klystron. This is compensated by a tuneable pre-compensation filter, which allows tuning of the pulse start for optimum performance.

Mechanics

The complete system is integrated into a single cabinet. The side view in figure 3 shows the transformer, half of the modules and the output filter. The other modules and the control system are placed on the opposite side. The system has an integrated closed loop air ventilation with an air-to-water heat exchanger. This reduces the heat load to the building and helps to keep the system dust-free.

TEST RESULTS

The modulator was intensively tested on a resistive load at the Thomson facility at full power and full pulse repetition frequency. As a result a well tested system has been delivered to DESY in August 2008. The system was installed at Zeuthen and connected to a 5 MW klystron. It took less than 2 weeks of commissioning and testing to have the system in full operation and accepted by DESY. The test results are shown on following figures.

Nominal Pulse

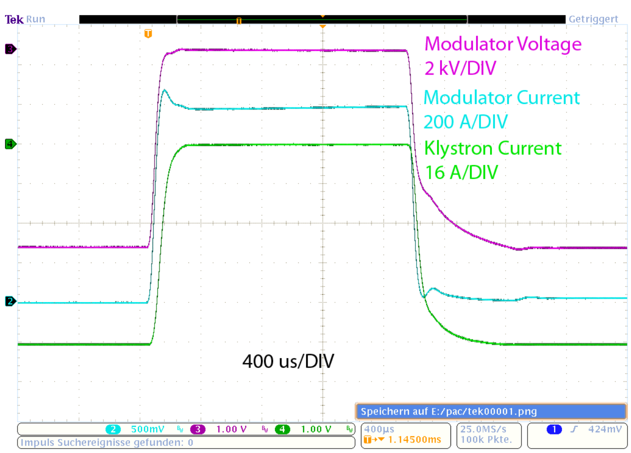

Figure 6: Pulse 10.5 kV / 1000 A.

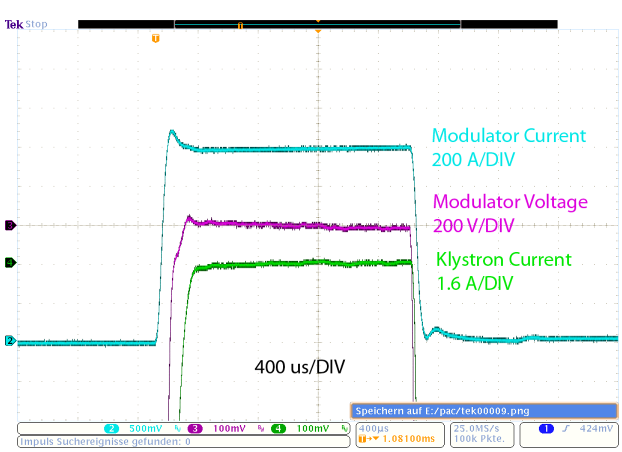

Figure 7: Pulse 10.5 kV / 1000 A with zoomed traces.

The performance under a nominal pulse condition of the 5 MW klystron is shown on figure 7 and figure 8. The droop on the voltage is well inside the specified data.

Transformer Demagnetisation

The transformer is demagnetised by switching off all IGBT of a 2-phase module pair. Consequently the current has to conduct through the parallel diodes, resulting in a voltage, which is always in opposite direction than the current, and thus in a negative power flow. Any inductive stored energy, including the energy from the pulse transformer main inductance, is charged back into the storage capacitor. Figure 8 shows the voltage trace including the demagnetisation phase. The demagnetisation is quite fast compared to the pulse repetition period. When the current reaches zero the voltage automatically goes to zero as well.

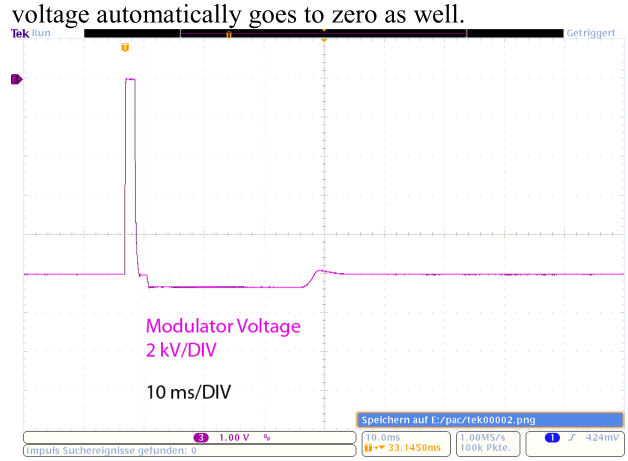

Figure 8: Transformer demagnetisation.

NEXT STEPS

The next steps for the testing of the modulator will be:

- Test on a 10 MW multi-beam klystron
- Short circuit tests with measurement of the short circuit energy
- Tests at 30 Hz repetition rate

CONCLUSION

The results look very promising. It was shown that it is possible with the PSM technology to achieve a flat pulse voltage for a long pulse modulator. The tests at Zeuthen will continue this year in order to verify the suitability of this modulator technology for the XFEL project.

REFERENCES

[1] J. Alex et al, “A New Klystron Modulator for XFEL based on PSM Technology“, PAC’07, Albuquerque, June 2007

[2] DESY, “TINE API for Console Applications”, http://tine.desy.de