CORRECTION MAGNET POWER SUPPLIES

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Abstract

Correction magnet power supplies are used to supply currents with a 17 bit precision to the superconducting correction magnets inside the TESLA linear accelerator. The required magnet current of up to 100A is achieved by a parallel connection of boards in EURO card size with an output current of 25A each. Additional cards provide redundancy in case of failures. By means of a 50kHz transformer the 325V DC input voltage is galvanically isolated to the ±10V output voltage on each board. The compact design includes a new polarity changing MOSFET output rectifier with a high efficiency free wheeling path and a new frequency PWM (FPWM) steered by an ALTERA chip to minimize switching losses at low output voltages. The ALTERA FPGA includes a digital regulation. Regulation parameters, reference values, temperatures and status signals are exchanged via RS232 port with a PC which provides the power supply data to the Internet. All data will be accessible by normal net browsers.

1 INTRODUCTION

At DESY a new type of correction magnet power supply will be used for the linear particle accelerator TESLA. The inductance ranges form 0.3H to 3H water cooled or superconductive magnets with a current of 10A to 100A. The TESLA tunnel will be 33 km long. Up to 3000 correction magnet power supplies will be installed inside the TESLA tunnel. Therefore the new power supplies offer special features to simplify maintenance and reduce failures.

2 POWER PART

The power supplies consist of small boards with an input voltage of 325V DC and a rated output current of ±25A at ±10V each. By applying the maximum output voltage of ±17V to the magnet the desired current is reached rapidly. The boards are connected in parallel to fit to the special application. Pluggable small light weight boards in EURO card size come into use for easy handling and fast maintenance. No error will be searched inside the tunnel. In any case of an error the boards are changed. By using more boards than needed redundancy increases the time before failure. Relays in the outputs disconnect broken boards. Galvanic isolation between mains and load by a 50kHz planar transformer provides operation even with one short to ground inside a magnet. The output rectifier includes a polarity changing circuit. No external polarity changing circuit is needed. The small amount of components increases the mean time between failures MTBF.

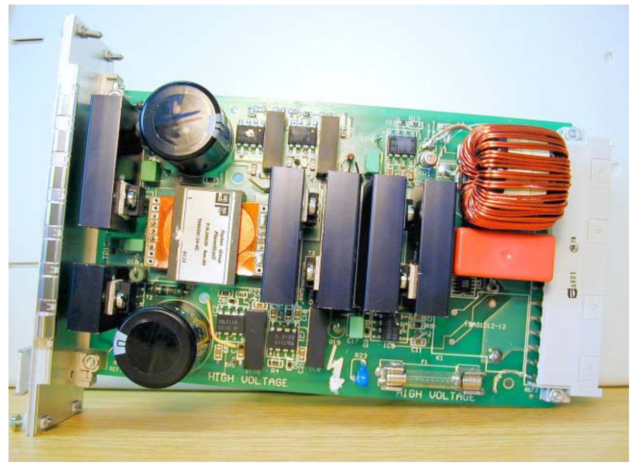

Figure 1: 25A, ±10V power supply board

2.1 Power tests

The power supply has been tested with up to 38A at 8,88V and with input overvoltages of up to 390V. The maximum temperatures at 30.4A, 13.7V (416.48W) were: MOSFET 76°C, transformer 80,5°C and power choke 65,7°C at an ambient temperature of 25°C and forced cooling. The efficiency is above 92%. The electrical circuit protection has been tested by turning a primary or secondary MOSFET permanently on or off during normal operation. The MOSFETs have been protected successfully. 100A output current with 4 or 5 power supply boards have been tested. The power supply boards consist of a primary halfbridge, a transformer, a MOSFET rectifier and an output filter.

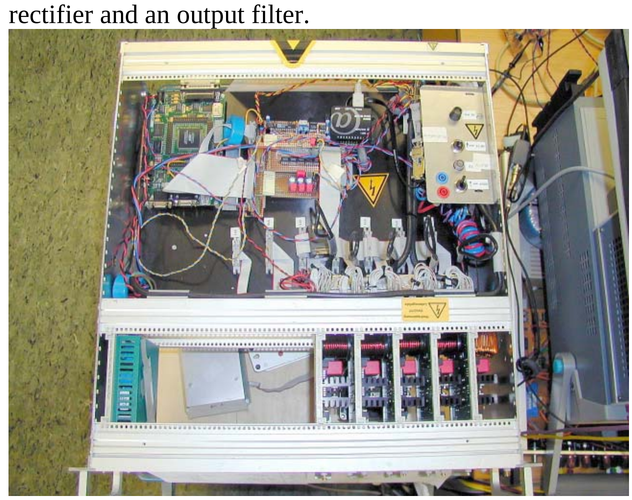

Figure 2: 100A, ±10V test rack

2.2 Double freewheeling path decreases losses

During the freewheeling time t_{off} (A) in Figure 3 the secundary MOSFETs are turned on. Both secondary transformer windings and both secondary MOSFETs are connected in parallel. Half of the resistance causes half of the conduction losses in the transformer and in the MOSFETs. The current in the secondary windings of the transformer flows into opposite directions. Therefore it is ensured that the transformer does not saturate.

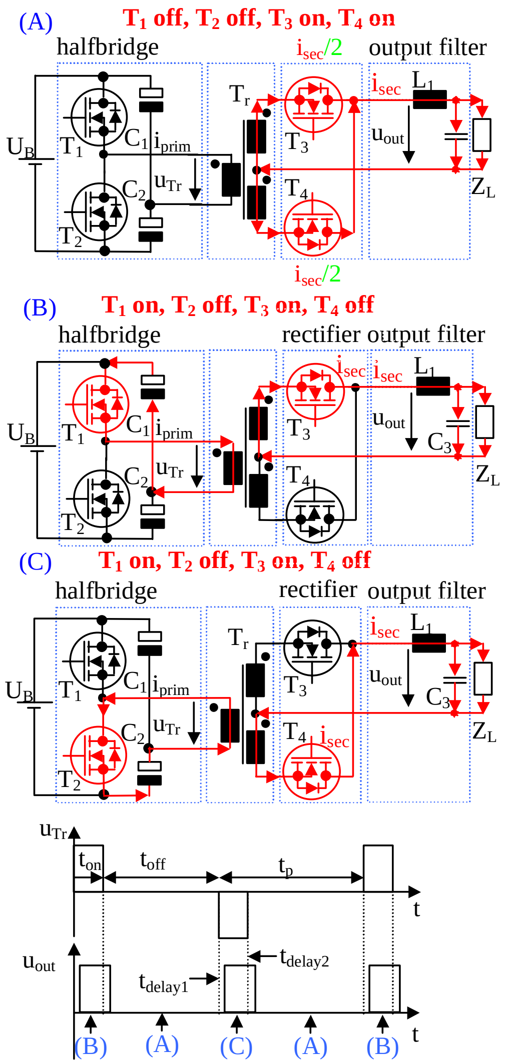

Figure 3: Power supply schematic and timing

2.3 Correct timing increases efficiency

To create an output pulse u_{out} T_1 is turned on. Due to the stray inductances of the transformer it takes some time t_{delay1} until the current of T_4 is zero (zero current switching at turn off) and until the current of T_3 raises to i_{sec}. After this delay time T_4 is turned off. When T_4 is turned off too early the internal slow diode will conduct. It causes a snap off voltage spike when the diode stops conducting. When T_4 is turned off too late the reverse current in T_4 causes voltage spikes. The delay time t_{delay1} is linearly dependent on the output current i_{sec}. On the power supply board t_{delay1} is in the order of 0ns … 60ns at 0A … 41A. Due to the low turn off voltage spikes it is possible to use low voltage MOSFETs with low on resistance. The correct timing increases the efficiency. Afterwards T_1 is turned off. After t_{delay2} the voltage of T_4 is zero volts (zero voltage switching at turn on) and T_4 is turned on again creating the high efficiency freewheeling path. The next switching step is shown in (C). When the average output voltage is low the high efficient freewheeling time t_{off} (A) is long and the efficiency of the power supply is very high. For this reason the power supply is specially well suited for low voltage superconducting magnets.

3 DIGITAL STEERING

For the steering of the MOSFETs and the regulation of the power part an ALTERA FPGA is used. By means of a fast error detection and turn off system no failure (e.g. shorted MOSFET) will destroy other components (e.g. other MOSFETs). Switching times t_{delay1} and t_{delay2} are varied in steps of 20ns according to the output current.

3.1 FPWM steering increases efficiency

A new frequency pulse width modulation FPWM signal is used to minimize the switching frequency and therefore minimizing switching losses. At low output voltages PWM steering is used. The switching frequency $1/t_p$ for the power supply boards is constant ¼ of the maximum switching frequency what is the lowest possible value due to the output filter values. The Pulses t_{on} are varied between zero and maximum pulsewidth limited by the saturation of the transformer. Switching losses are reduced to ¼ of the maximum switching losses. At higher output voltages the pulsewidth t_{on} is the maximum pulsewidth of the transformer (constant). The frequency is varied (FM) up to the maximum frequency limited by the deadtime for toggeling the primary halfbridge.

4 FPGA CONNECTION TO COMPUTER

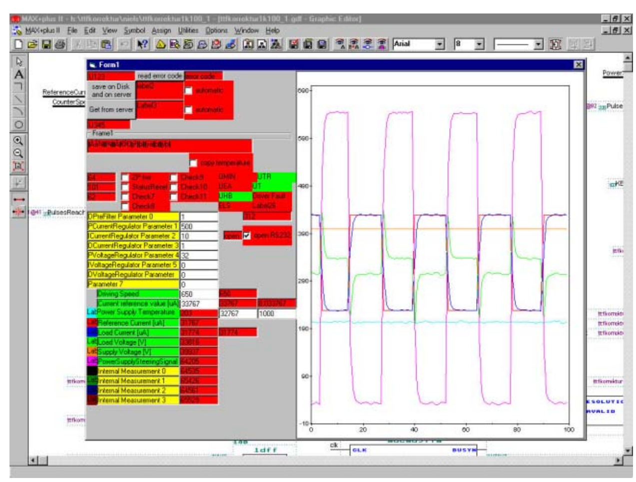

Figure 4: ALTERA FPGA RS232 connection to visual basic on a conventional computer

The FPGA includes a RS232 communication software which offers the visualization of all analog and digital parameters of the power supply.

5 FPGA CONNECTION TO SINGLE CHIP COMPUTER

The IPC@CHIP DK40 (80186 processor) is a single IC which includes two RS232 ports, an Ethernet port and some IO pins. It offers a WEB server for HTML pages, a FTP server and a TELNET connection. By this chip all power supply parameters (currents, voltages, temperatures, status signals) are visible in the internet, e.g. on a WAP mobil. The power supply parameters may be changed in the internet. In case of a power supply failure the chip will send the actual power supply status to an e- mail recipient, e.g. a SMS to a mobil.

Figure 5: FPGA connection to single chip WEB server

In Figure 6 the internet is connected to the Ethernet. Each power supply performs the Ethernet communication by the single chip WEB server. The WEB server exchanges all power supply data via RS232 connection with the FPGA. All measurements and parameters are exchanged with the internet. This offers proper failure diagnosis and reduces the time of maintenance for power supplies which may be located far away.

6 DIGITAL REGULATION

One standard regulation board fits to all kinds of magnets since the regulation parameters may be changed and optimized online on the internet page or by FTP. The second order output filter on the power supply boards and the first order load result in a third order system to be regulated. The regulation consists of a superior current PI regulator which ensures that the load current equals the desired reference current. The subsequent P regulator includes the load voltage to get the third order system stable. Droops in the intermediate voltage are main disturbance in the system. The intermediate voltage is taken into account in the pre- filter (which is an ordinary divider). The resulting system of power supply and pre-filter is independent of the intermediate voltage. Therefore the regulation parameters are well suited with any intermediate voltage. The high precision current measurement of 17 bits absolute resolution includes a digital self calibration. This is an important feature since an adjustment of up to 3000 TESLA correction magnet power supplies and the variation by time and by temperature would result in problems when potentiometers are used. Due to the in system programmability the whole regulation structure inside the FPGA is changeable.

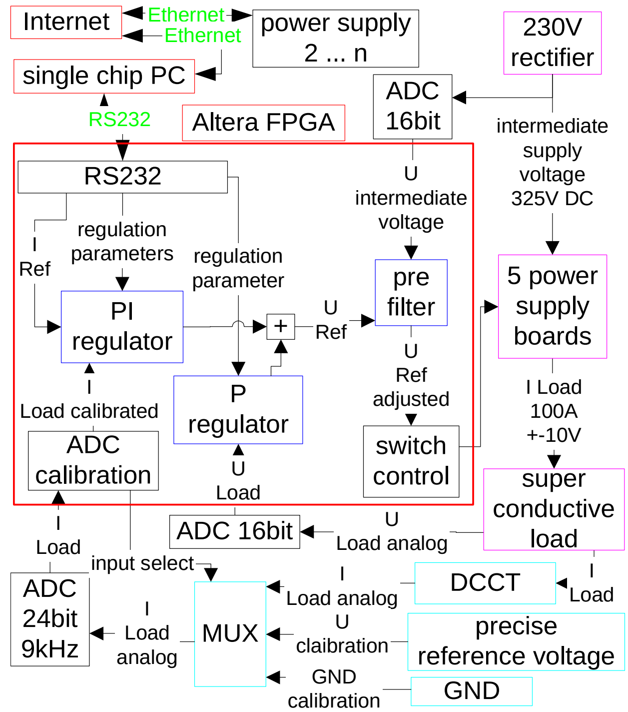

Figure 6: Digital regulation scheme

7 SUMMARY

A small light weight power supply board has been developed for the future use in TESLA. The overcurrent tests, overvoltage tests, failure tests and temperature measurements indicate an uncritical behavior of the power supply. For that reason long lifetime and low MTBF can be achieved. Redundancy in the power supply boards will furthermore decrease the time for maintenance. Correct switching times permit the use of high efficient MOSFETs. The FPWM steering reduces switching losses downto 25%. The double freewheeling path reduces freewheeling losses by the factor of 2. FPWM steering and double freewheeling path have advantages especially when supplying low voltage superconducting magnets. An internet connection has been tested with a single chip web server which is able to solve the communication problem of 3000 correction magnet power supplies inside the 33km long TESLA tunnel.