HIGH VOLTAGE DECOUPLED HIGH-CURRENT POWER SUPPLY

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Abstract

10 kW power supply (PS) with smooth adjustment of the load current from zero up to 2 kA is described. The operating mode with load current stability up to 0.1% and long-term instability of 0.01% is possible. PS includes the controlled rectifier with the power factor correction, the high-frequency invertor, 35 kV decoupled transformer-rectifier module and the control block.

INTRODUCTION

The new power sources with high stability, wide adjustment range of target parameters, with small weight and overall dimensions are necessary for development of accelerator magnetic systems and elements power supply. Moreover, to meet the requirements of IEEE 519-92, IEC-555 and 61000-3-2 specifications, a low level of total harmonic distortion should be created in the mains. The power mains decoupling of tens kilovolt is necessary for some applications, therefore, the choice among available designs [1], [2] is sharply restricted. The design of 10 kW power source with up to 35 kV mains decoupling for carbide-uranium target heating is described.

STATEMENT OF PROBLEM

The modern power supplies with low weight parameters can be performed with use of high-frequency conversion schemes only. The low output voltage (up to 5 V) and the high output current (up to 2 kA) of the developed source, and also the load high-voltage decoupling requirement predetermine the using of the step-down transformer. At high transformation ratio the transformer leakage inductance is critical; it limits an available conversion frequency range. Thus, the transformer is the most labour-consuming part of the projected system. The level of minimization of the transformer parasitic parameters defines the frequency and weight parameters of power supply in the whole.

TRANSFORMER – RECTIFIER MODULE

It is known [6], that the minimal leakage inductance of the transformer is achievable with the solid turn configuration of either primary or secondary winding. At the same time the using of toroidal magnetic core essentially simplifies the solid turn manufacturing, and also allows to reduce considerably the leakage magnetic field inside the volume due to complete use of the primary winding length.

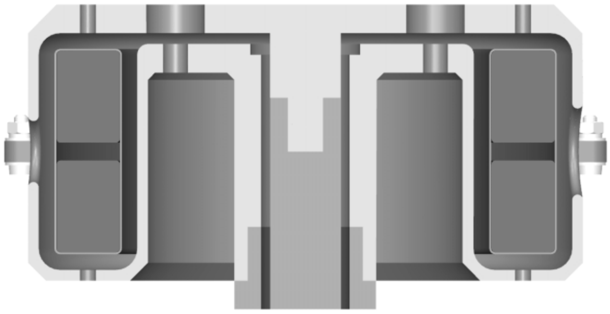

Figure 1: Transformer cross-section.

Two TX140x106x25 rings of 3C90 ferrite by FerroxCube firm are used as a magnetic core (a cross-section on Fig. 1). The primary winding of 25 turns is wound directly on the core by three copper busses with size of 0.5x3 mm in parallel. The transformer secondary winding is performed from two parts in the solid turn form (Fig. 2). The gap between two windings is chosen to be 4.5 mm from a reason of the adequacy, defined by allowable electric field intensity in the isolation gap with the transformer oil (Fig. 1). The energy concentrated in all leakage field volume can be estimated under the expression [6]:

$$W \approx \frac{\mu_0 i^2 w^2 p}{2h}\left(\Delta_{12} + \frac{d_1 + d_2}{3}\right)$$

where Δ_{12} - distance between windings, d_1 - primary wire thickness, d_2 - solid turn wall thickness, p - winding average perimeter, h - winding length, w - number of turns. Therefore, leakage inductance of the transformer with the solid turn configuration, resulted in the secondary side:

$$L_S \approx \frac{\mu_0 p}{h}\left(\Delta_{12} + \frac{d_1 + d_2}{3}\right)$$

At solid turn thickness of 3 mm L_S = 3 nH.

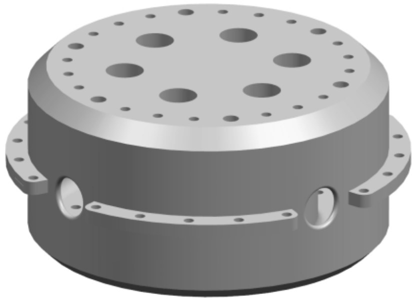

Figure 2: Solid turn.

Between two ferrite rings of the transformer is the heat-removing ring which simultaneously is their fixing element and one of the primary winding terminals in addition. The given structure is located in the tank with the transformer oil. Necessary holes (Fig. 2) are stipulated in the solid turn for oil circulation due to the temperature gradient between the top and bottom parts of a tank. High current rectifier is performed under the symmetric current doubler scheme (elements D5, D6, L1, L2 on Fig. 3). Six 440CNQ030 diode half bridges (International Rectifier) are mounted on the top part of the solid turn. The tank and half bridges cooling are carried out through the ribbed radiator with mandatory ventilation (Fig .6).

HIGH-FREQUENCY INVERTOR

Following demands are made to the high-frequency invertor:

- A wide range of load regulation: modes from idling to short circuit
- Ensuring of fast load current change
- High efficiency

Resonant and quasi-resonant invertor topologies have a number of essential disadvantages [3], [4]. The new topology (Fig. 3), meeting the requirements, is the PS-ZVZCS-FB (Phase Shifted Zero Voltage Zero Current Switching Full Bridge).

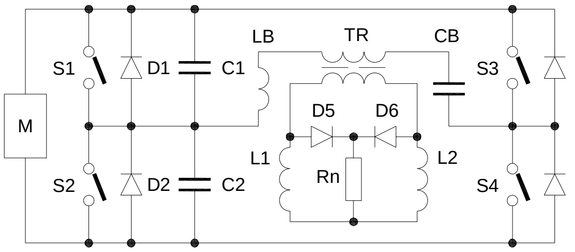

Figure 3: High-frequency invertor.

The given topology allows to adjust the load current by change of a phase shift between power switch control signals of the bridge arms. Unlike ZVS-PS-FB invertors, the serial blocking capacitor and saturated inductor are included in series with primary winding in the given scheme. Snabber capacitors $C1$, $C2$ are required for the left bridge arm only. The main idea consists in realization of such control algorithm by power switches at which the left bridge arm will be switched at a zero switch voltage and the right arm - at a zero switch current.

Idealized control signals and some voltage and current curves are presented below.

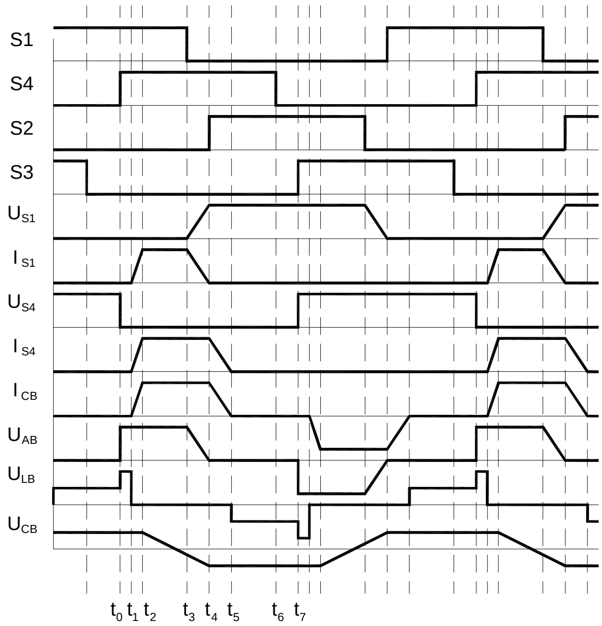

Figure 4: Control signals, current and voltage curve diagram.

$t_0 - t_1$: At the time t_0 the switch S_4 is turned on, while the switch S_1 was already switched on. The still unsaturated inductor limits the rise of the switch current at a very low value. A soft turn-on is achieved in this way. The intermediate circuit d.c. voltage is across the saturable inductor now and the ferrite core becomes saturated.

$t_1 - t_2$: The bridge diagonal current is rising linearly towards the reflected output current, limited through the leakage inductance of the transformer.

$t_2 - t_3$: During this time interval the energy transfer from intermediate d.c. circuit into the load takes place. The voltage across the blocking capacitor C_B is changing nearly linearly. The capacitor blocks any occurring d.c. voltage across the transformer resulted from unequal overlap angles between the on - times of the switches in both bridge diagonals. Period is finished when S_1 is turned off.

$t_3 - t_4$: The snubber capacitors C_1 and C_2 recharged by the bridge diagonal current. For this reason the rise of the S_1 switch voltage is limited and the transistor is turning off softly.

$t_4 - t_5$: The recharging of snubber capacitors is finished at this time. Therefore, switch S_2 can be turned off with the zero voltage.

$t_5 - t_6$: The inductor L_B is not saturated any more. Therefore it is blocking the diagonal current on very low values and the discharge of the blocking capacitor is prevented. The switch S_4 can be turned off with a current close to zero.

$t_6 - t_7$**:** This time interval is necessary to allow the S_4 switch to restore parameters.

CONTROLLED RECTIFIER

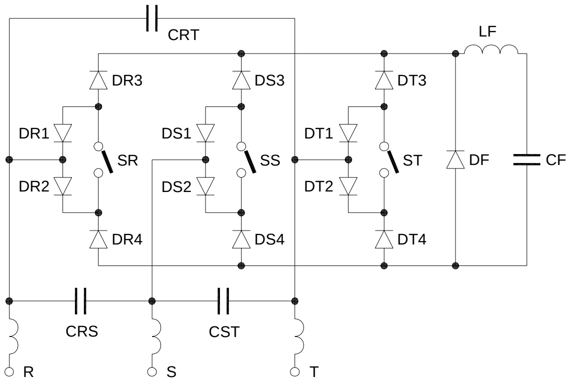

Figure 5: Power factor correction scheme.

Controlled rectifier is derived from the Vienna Rectifier topology. The scheme provides full regulation of the output voltage with ripple of 2 % and carries out correction of the power factor. Output parameters are stable with unbalanced power mains and one of the phases failure. Total harmonic distortion less than 4 % and power factor 0.99 are achievable at load of 10 kW [5].

CONCLUSIONS

The power supply control circuit is realized on the CPLD base by "ALTERA" firm. The operating energy transformation frequency is 30-40 kHz. The algorithm is developed for transistor soft switching at a full range of load changing and output current precision stabilization. All assemblies cooling performed with mandatory ventilation. The control is carried out locally and remotely through the CAN-interface. Calculated efficiency drop on transformator-rectifier module is 13 %, high-frequency invertor is 5 %, and the controlled rectifier is 4 %. The source efficiency is about 78 %, the weight of 56 kg (by use of water cooling it is possibly to decrease a weight on 35 %), with overall dimensions of 418 x 248 x 440. At the present moment the project is in manufacturing stage (Fig. 6).

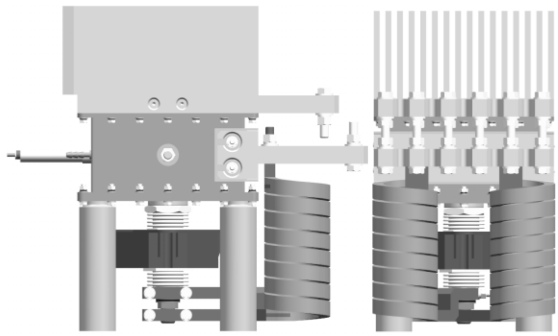

Figure 6: Power source general view.

REFERENCES

[1] F. Bordry, V. Montabonnet, H. Thiesen. Soft Switching High Current, Low Voltage Modular Power Converter [13kA, 16V]. Workshop on LHC Powering, 27th to 29th November, 2000.

[2] F. Bordry, A. Dupaquier, G. Fernqvist. High Current, Low Voltage Power Converter [20 kA, 6 V]. Workshop on LHC Powering, 27th to 29th November, 2000.

[3] G. Hua, F. Lee. Soft-switching PWM techniques and their applications. EPE '93, Brighton, 1993.

[4] W. Chen, F. Lee. A comparative study of a class of full bridge Zero-Voltage-Switched PWM converters. IEEE Transactions of Power Electronics, 1995.

[5] J. Kolar. A Novel Concept for Mains Voltage Proportional Input Current Shaping of a VIENNA Rectifier. Proceedings of the 16th IEEE Applied Power Electronics Conference, 2001.

[6] S.S.Vdovin. Energoatomizdat, 1991(in Russian).