MODULATOR POWER SUPPLY FOR 200 kV ELECTRON GUN OF THE VEPP-5 INJECTION COMPLEX

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The 200 kV electron gun modulator power supply based on the half-bridge converter providing the high frequency partial charge of the capacitive energy storage element is described. The algorithm developed for the power supply driving allows one to provide the soft switching of charging circuits and to achieve a high efficiency of the power supply. The data obtained at operation of the capacitive loaded 300 W power supply are presented. The prospects of developing such type tens-kilowatts power supply are discussed.

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1. INTRODUCTION

During exploitation of the complex VEPP-5 modulators the disadvantages of the pulse forming network (PFN) resonant charge scheme were discovered [1], [2]:

- while the voltage on the filter capacitors is constant the charge voltage on the PFN depends on the repetition rate of the modulators. At the repetition rate 1 Hz the voltage on the PFN decreases to 70…80% of the nominal level. It occurs due to the discharge through the leakage resistors of the scheme elements;
- the large overall dimensions of the power supply and a negative influence on the mains.

Taking into the account the above said it seems very perspective to use the power supplies (PS) based on the high-frequency converters providing the charge of the storage capacitance by the low energy portions obtained with a frequency of few tens (in some cases hundreds) kilohertz. Such schemes due to the stabilized boost charge of the capacitance provide the high charging voltage stability independently on the modulator repetition rate. There are many modifications of such schemes. They are converters providing the constant current charge, the constant power charge, based on the resonant or other type inverters.

The resonant converters based on the series resonance have found a wide application. They have such advantages like the soft switching and the possibility to achieve (with some complication of the driving algorithm) the zero voltage switching. The leaders on the high-power PS market, companies Maxwell Laboratories Inc. and Electronic Measurements Inc. use the resonant bridge converter scheme providing the constant current charge [3]. The efficiency of such current source devices is varying from 85 to 92% at a different output power.

The high-frequency partial charge half-bridge-based converter describing here can be used as a current source as well. The 300W PS has showed the high efficiency and allowed us to study questionable moments of the scheme operation. The PS has the simple and simultaneously reliable driving scheme that provides the soft switching. So the possibility of developing the VEPP-5 complex modulators PS based on the above-described scheme can be considered.

2. 200 kV ELECTRON GUN MODULATOR 300 W POWER SUPPLY

The 300W PS developed on the basis of the high-frequency partial charge half-bridge-based converter is presented in fig.1. In the future such a device will be used for the 200 kV electron gun modulator power supply [4]. In the nominal mode of operation the PS has to provide 3 kV of the output voltage at the 50 Hz repetition rate. The converter switching frequency increases from 5 kHz at the beginning of the storage capacitance charging up to 30 kHz at the charging completion.

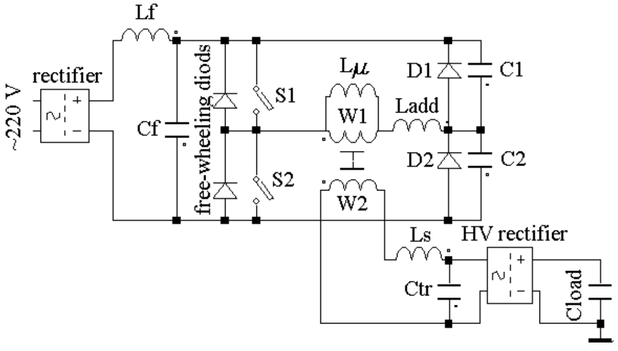

Fig.1. The high-frequency partial charge half-bridge based converter scheme with taking into the account the parasitic parameters of the transformer

The field-effect transistors produced by International Rectifier (USA) were used as the converter's switches.

3. THE OPERATIONAL FEATURES OF THE HIGH-FREQUENCY PARTIAL CHARGE HALF-BRIDGE-BASED CONVERTER

There is no evident resonant circuit setting the switching frequency of the converter. The part of the charge circuit is supposed to be played by the transformer leakage inductance (Ls) (fig. 1), the additional inductor (Ladd), the dosing capacitors (C1 or C2) and the storage capacitance (Cload). W1, W2 are the transformer primary and secondary windings, respectively, Lμ is the magnetizing inductance and Ctr is the capacitance of the transformer. Fig. 2 shows the waveforms of the primary current (Iw1), the voltage across the switch S2 (Us2) and the voltage across the capacitor C2 (Uc2) taken during the 300W PS operation with the capacitive load (scheme is in fig.1). When the switch S1 is turned on the current charging the dosing capacitor C2 flows (the negative part of the current Iw1). The voltage on C2 increases up to the rectified supply voltage level UCf, after that (moment t1) the current stops to charge C2 and is carried by D1. This current will flow until the total energy accumulated in the inductances Ls and Ladd goes in the load. At this moment (t2) S1 has to be turned off while S2 is turned on. C2 charged to the voltage UCf is being discharged while C1 is being charged. At the moment t3 the voltage across C1 is equal to UCf, after that the current is carried by D2. At the moment t4 S2 is off while S1 is on and the process goes on.

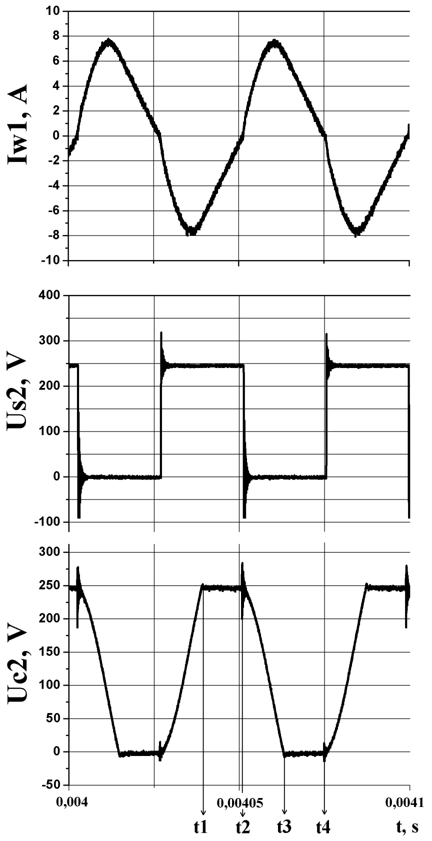

Fig.2. 300W PS current and voltages waveforms

The initial conditions of the charging scheme change along with the load voltage. It makes the converter switching frequency to increase while Cload charges from zero to the nominal voltage level. During the Cload charging period the pulse duration of the switching current decreases from 200 μs to 30 μs. In order to obtain the soft switching the turning off/on processes of the switches have to be done at the zero current. The soft switching in the scheme described can be obtained either by the switching frequency setting below its minimal level or by the switching frequency varying during the charging period. The second way seems to be more preferable.

The switching frequency varying is achieved by the Iw1 current measuring. The switching frequency is determined by the duration of two different-polarity Iw1 current pulses. The rise time of the current Iw1 is determined by the parameters of the L1-C1 (or C2) circuit (L1=Ls+Ladd), it does not change during the Cload charging. The fall time of the current Iw1 decreases when the voltage across Cload increases and the current flowing through L1 decreases. Varying the switching frequency in concordance with the current Iw1 behavior the soft switching conditions can be obtained.

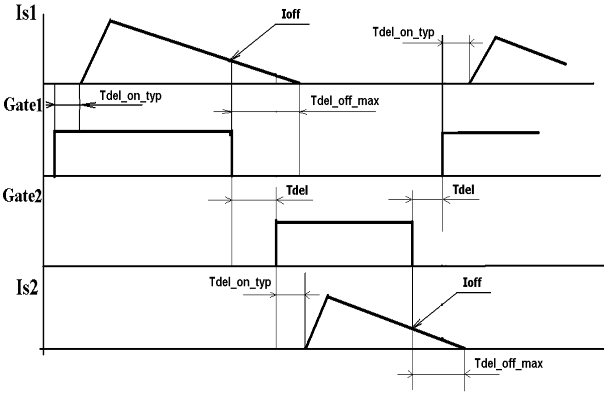

Fig.3. Illustration of the PS driving operation

The driving scheme algorithm is shown in fig.2. As the current flowing through the switch (Is1 or Is2) decreases to the determined “zero” level, called Ioff, the corresponding gate signal is turned off. After the specified time delay determined by the switch turn-on delay time (Tdel_on_typ) the gate signal of another switch is turned on. The Ioff level determination depends on the maximum switch turn-off delay time (Tdel_off_max) and the maximum time during which the switch current decreases from Ioff to zero. Ioff does not change during the Cload charging while the switch current fall time decreases, so the pause between the one switch turn-off and another one turn-on increases. When such pauses appear the Ctr discharge through the free-wheeling diodes of switches takes place. It can result in the switch overheating.

At present the driving scheme providing the measurements of the switch current slope steepness at the zero point is tested at the PS prototype. The slope steepness determines the moment at which the switch current goes to zero. Using it and taking into account the turn on/off delay time corrections the soft switching can be realized. Applying such an operation to the every single current pulse the switching pauses can be excluded. So the most optimal mode of the converter operation during all the charging period can be obtained. The driving scheme using such an algorithm is realized on the “ALTERA” PLIC base.

4. THE INFLUENCE OF TRANSFORMER PARASITIC PARAMETERS ON THE CONVERTER OPERATION

The transformer parasitic parameters such as Lμ and Ctr exert negative influence on the converter operation. The energy accumulated in Lμ during every cycle of the Cload dosed charging dissipates in the resistances of the diodes D1 (or D2), the switches S1 (or S2) and the primary winding. The resistance of the mentioned elements is comparatively low, so the time of the Lμ energy dissipation is too long. Thus, the current stored in Lμ (ILμ) continues to flow when the basic charging current is over. The current of Lμ has to be cut off by the switches turning-off. The soft switching is broken. Therefore one should to decrease the current of Lμ as much as possible by increasing the value of Lμ. If value of ILμ is low the switching losses caused by the current ILμ cutting-off can be ignored. At the same time, Lμ is shunted by Ctr, so the ILμ cutting-off does not cause an undesirable over voltage on the switches and the primary winding.

However, Ctr influences negatively on the converter operation as well. Ctr should be recharged at the every cycle of the Cload dosed charging, it requires the extra energy consumption.

The transformer leakage inductance Ls and the inductance Ladd play the part of the charging circuit inductance. If the value of Ls is enough for the PS reliable operation the use of Ladd is not necessary.

5. CONCLUSION

The 300W PS operation measurements have confirmed the calculations and allowed us to find out the weak spots of the converter operation connected first of all with the influence of Lμ and the switches turning on/off process without the pauses. The problems were successfully decided. As a whole the 300W PS test during one workday has brought the positive results and proved the converter reliability. The transformer volt-second area alteration during the charging period is kept approximately at the level of ±10% of the mean value. It can be considered as an advantage. The converter efficiency measured during the nominal mode of operation is ≥90%.

The following conclusion can be made. The high-frequency partial charge half-bridge-based converter can be used for the VEPP-5 complex modulators power supply. It will allow us to decrease the overall dimensions of the modulator power supply as well as the PFN charging voltage stability at any modulators repetition rate. The estimated efficiency of modulators PS is ≥93%. The basic power losses are expected to be in the step-up transformer (1000W), the dosing capacitors (2·450=900W) and the switches (2·300=600W). The parameters of the capacitors K78-21A produced by the "Elkod" (Russia) and the IGBT FF800R12KL4C produced by the "Eupec" (Germany) have been taken into the account in the estimations.

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ЗАРЯДНОЕ УСТРОЙСТВО ДЛЯ ПИТАНИЯ 200 кВ ЭЛЕКТРОННОЙ ПУШКИ ИНЖЕКЦИОННОГО КОМПЛЕКСА ВЭПП-5

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Описано устройство высокочастотного порционного заряда емкостного накопителя энергии для питания 200 кВ электронной пушки. Специально разработанный алгоритм управления позволяет обеспечить мягкую коммутацию ключей зарядных контуров, добиться высокого КПД зарядного устройства. Приведены экспериментальные данные, снятые при работе зарядного устройства на емкостную нагрузку мощностью 300 Вт. Обсуждаются перспективы создания зарядных устройств такого типа мощностью десятки киловатт.

ЗАРЯДНИЙ ПРИСТРІЙ ДЛЯ ЖИВЛЕННЯ 200 кВ ЕЛЕКТРОННОЇ ГАРМАТИ ІНЖЕКЦІЙНОГО КОМПЛЕКСУ ВЕПП-5

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Описано пристрій високочастотного порціонного заряду ємнісного накопичувача енергії для живлення 200 кВ електронної гармати. Спеціально розроблений алгоритм керування дозволяє забезпечити м'яку комутацію ключів зарядних контурів, домогтися високого ККД зарядного пристрою. Приведено експериментальні дані, зняті при роботі зарядного пристрою на ємнісне навантаження потужністю 300 Вт. Обговорюються перспективи створення зарядних пристроїв такого типу потужністю десятки кіловат.