A HIGH-VOLTAGE RESONANT CONVERTER FOR PULSED MAGNETS

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Abstract

To get high di/dt at pulsed magnets a high-voltage power supply is necessary. A 500W, 25kV, parallel-loaded resonant converter has been built in order to feed the LNLS ring kicker magnets. The resonant technique is an interesting option because it significantly reduces the EMI levels and the circuit losses. The use of high frequency permits reduction of the transformer and filter sizes. The tank components are the transformer leakage inductance and winding capacitance. The switching frequency is 20kHz, limited by the tank circuit characteristic. The load is an LC Pulse-Forming Network, which is discharged on the load by a thyratron tube. The current pulse rise and fall times are about 100 ns and the flat top is 200 ns, at 800 A.

1. INTRODUCTION

The pulser for the LNLS UVX2 ring kicker magnets [1] has the following characteristics:

Flat top:	200 ns
Rise time:	100 ns
Fall time:	150 ns
Peak current:	800 A
Load inductance:	2.5 μH

To get an 8 kA/μs di/dt, one needs a 20 kV supply. The repetition rate required is 33 Hz, determined by the injection parameters. The average power dissipated at the magnet is 211W (16 MW peak).

The pulser is basicly an LC forming network, which is charged up to 20 kV and discharged on the load by a thyratron tube, as is showed in figure 1.

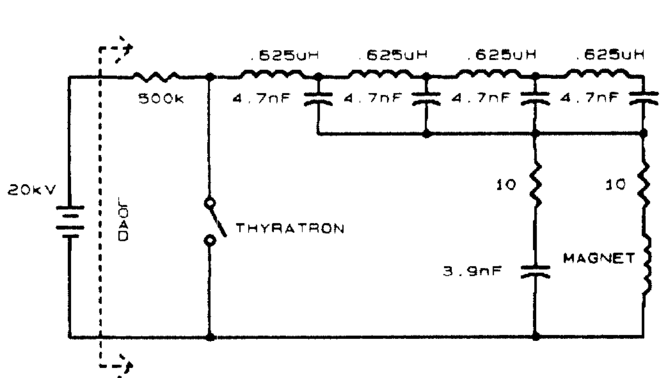

Figure 1. Electric diagram of the pulser

The four-cell delay line was calculated for 400 ns, including the fall and rise times. The 500 kΩ resistor limits the charging current.

Concerning the high-voltage converter, the load is composed of the magnet, the LC network, the limiting resistor and the thyratron, what means it is a variable load, varying from 500 kΩ (when the LC line starts to charge) to an open circuit (when the line is full-charged).

2. HIGH-VOLTAGE RESONANT CONVERTER

The large turns-ratio of high-voltage transformers is usually a problem for dc-to-dc converters because the leakage inductance and the winding capacitance affect the converter behavior.

Considering the switched-mode power converters for high-voltage applications, the fly-back converter is the most popular, but the hard-commutation of the power transistor is a drawback, ultimately limiting the switching frequency. The resonant converter families are the ones which present significant increase in the efficiency because the power devices commutation is non-dissipative. Furthermore, the soft-commutation allows for the reduction of the electric-magnetic interference produced by the converter. An inconvenience of resonant converters is that the output voltage is frequency-dependent, which is a drawback to determine an efficient control system, in order to get a wide-range output voltage. In this application the output voltage is fixed and some adjustment has to be done only to compensate mains variation.

On the other hand, the wave-shape of the voltage applied to the transformer is less disturbed by harmonics, contributing to the reduction of the transformer losses, allowing for the increase in the switching frequency, reducing the transformer and filter sizes.

The choice of an adequate resonant circuit is based in its behavior in high-voltage applications [2], especially concerning the transformer parasitic elements.

Figure 2 shows a lumped element high-voltage transformer model, including the leakage inductance, the magnetizing inductance, the winding capacitance and an ideal transformer. In fact, the leakage inductance and the winding capacitance are distributed parameters and this model is valid up to some hundreds of kilohertz.

The ideal topology which uses the transformer non-idealities is the parallel-loaded series resonant converter, shown in figure 3. Note that the leakage inductance and the winding capacitance are used as resonant elements. Eventually they alone make up the tank circuit. The capacitors, which divide the input DC voltage, ensure that the primary current has a null mean value.

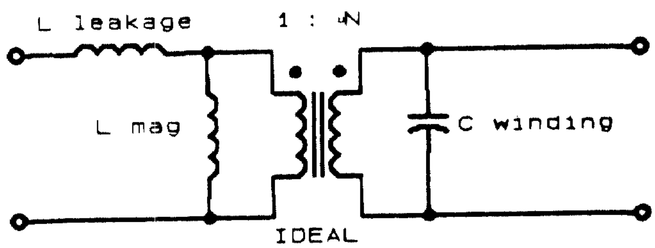

Figure 2. High-voltage transformer model

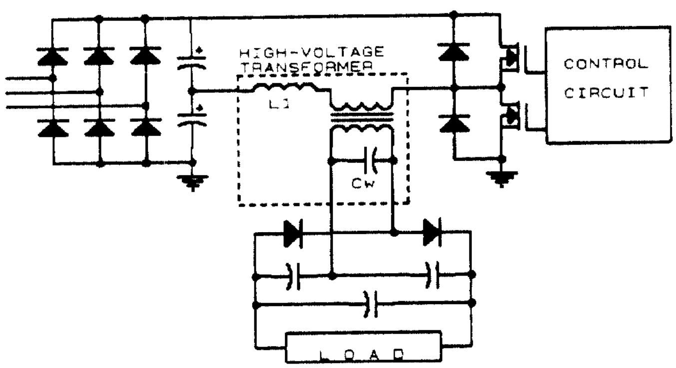

Figure 3. Half-bridge parallel-loaded series resonant converter

The high-voltage side of the transformer feeds a voltage doubler (in order to reduce the secondary turns) in which the load is connected. The output voltage is determined by the peak voltage.

In the discontinuous mode of operation [3], the peak voltage is dependent on the tank circuit quality factor, which is influenced by the reflected load. This means that it is not possible to control the primary peak voltage by changing the switching frequency. So, to control the output voltage it is necessary to vary the input voltage, for example, using a SCR bridge. The slow response of this kind of circuit is not a problem considering the low pulse repetition rate.

In the continuous mode of operation, it is possible to vary the peak voltage adjusting the switching frequency. The drawback is that one of the transistor's commutation will be dissipative, increasing the circuit losses.

To test the kicker the circuit has worked in open loop and in the discontinuous mode of operation.

3. EXPERIMENTAL RESULTS

A 500 W, 25 kV, half-bridge resonant converter has been built. The resonance frequency is about 40 kHz and the tank circuit is wholly composed of the transformer parasitic elements. The input is gotten directly from the mains.

The transformer is epoxy encased. It uses a ferrite core and its turn-ratio is 1:40. The Bode plot of the input impedance (module and phase), with the load connected, is shown in figure 4.

The effects of the magnetizing inductance, Lm, (at low-frequencies), effective winding capacitances, Cw, (between 20 and 40 kHz) and effective leakage inductance, Ll, (at high-frequencies) are clear. Their respective values are: 70 μH, 1.1 μF and 13 μH, referred to the primary.

There is a parallel resonance between Lm and Cw at 17.8 kHz and a series resonance between Cw and Ll at 40 kHz.

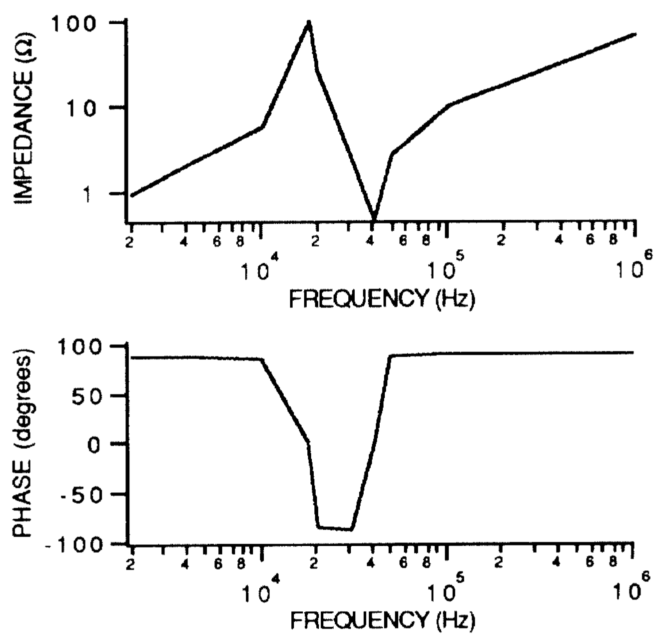

Figure 4. Primary impedance of the high-voltage transformer

Figure 5 shows the primary current and the secondary voltage. When a transistor is fired the tank circuit produces a current with a sine wave form. The damping depends on the reflected load. The negative part of the current flows through the reverse diode. The transistor turn-off occurs while this diode conducts (at zero current and almost zero voltage) and the turn-on occurs when the current is null (the tank circuit initial condition). There are no switching losses. The oscillation observed in the current is produced by the reverse diode recombination current, which, interacting with the circuit parasitic inductances, causes this small ringing. If the secondary is open-circuited, the amplitude of both peaks in each half-period would be the same. When the load increases, the current that flows through the diode is reduced because, at this interval ,energy is transferred from the tank circuit to the load. To assure no-loss commutation, the tank circuit has to be designed to allow the current reversion. The wave-shape of the secondary voltage has low harmonic distortion, which reduces the transformer core losses (in comparison with a squared-wave voltage, typical of hard-commutation circuits) and the EMI.

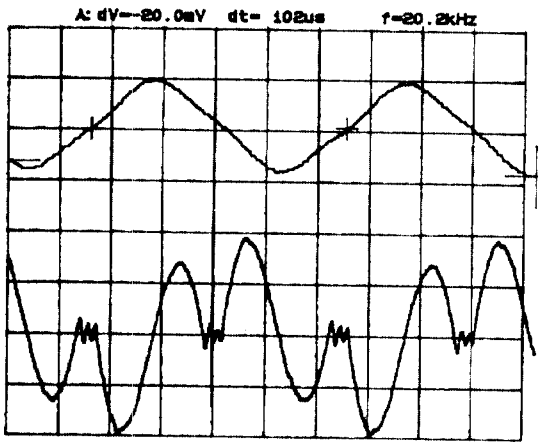

Figure 5. Secondary voltage (1kV/div) and primary current (2A/div), with reduced voltage and light load
Time base: 10μs/div

Figure 6 shows the effect of the thyratron firing on the current. When the valve is fired, the LC network is discharged and restarts the charging process. Initially the primary current increases to recharge the line. The current is reduced as the voltage increases.

Figure 7 shows the pulser current, with reduced voltage, which shows the expected waveform.

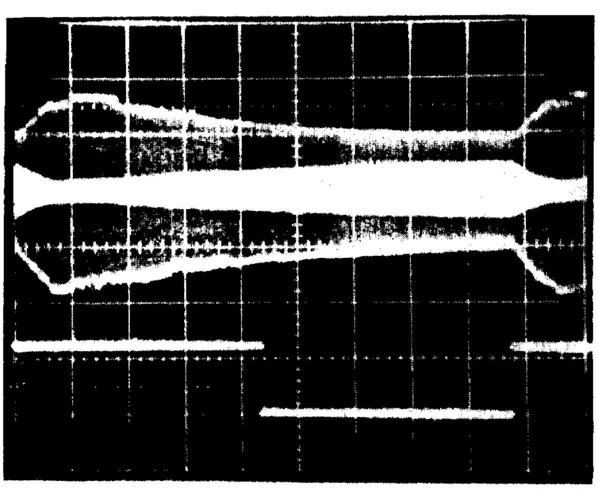

Figure 6. Top trace: Primary current (2 A/div).
Bottom trace: Thyratron firing signal (5 V/div)
Time base: 10 ms/div

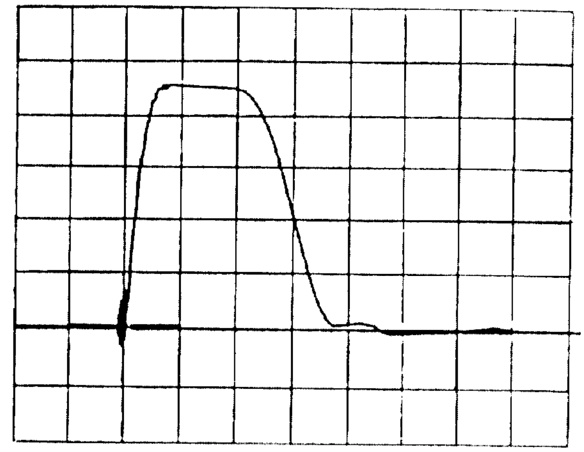

Figure 7. Pulser current (50 A/div). Time base: 200 ns/div

4. CONCLUSIONS

The parallel-loaded resonant converter performance is quite adequate for high-voltage applications. The complete uses of the transformer parasitic elements is an important aspect to allow an easier design of the converter.

The small losses at the power semiconductors permit the use of a small heat-sink, which is another positive aspect, allowing one to reduce the size and the mass of the power supply.

The next step of this work is to close the control loop in order to stabilize the output voltage. Both presented strategies (input voltage variation and continuous mode operation with frequency modulation) will be studied and tested.

5. REFERENCES

[1] Rafael,F.S. and M.Akuma, "Injection Kicker for the LNLS Storage Ring", These proceedings.

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[3] Kang, Y. and Upadhyay,A.K., "Analysis and Design of a Half Bridge Parallel Resonant Converter.", IEEE PESC, 1987, pp.231-243