

## COMPACT DIGITAL HIGH VOLTAGE CHARGER\*

Ge Li<sup>#</sup>, Dept. of Electrical Engineering, Shanghai Jiao Tong University, PR. China  
 Yingui Zhou, National Synchrotron Radiation Lab, University of Sci. & Tech. of China, PRC

### Abstract

The high voltage (HV) charger for modulators and accelerators is investigated with classical resonant circuit working at over 30 kHz and zero-current-switching (ZCS) condition, which charges the loads more accurately for the increased voltage steps by working in higher frequency. The compact charger is composed by low voltage (LV) control panel and HV transformer, which can work in the modes of DC charging or bursts whenever necessary. Comparing with conventional pulse width modulation (PWM) method, the switch losses of power devices are significantly decreased by above ZCS soft switch approach used in the resonant circuit. The experimental setup with above topology is tested at 69 kHz. The high speed IGBT drivers, which cut the turn-on and turn-off times of the commercial drivers from 1 $\mu$ s to 0.1 $\mu$ s, are developed and implemented in about system.

### INTRODUCTION

The operation of classical resonant circuit [1] developed for the pulse energizing is investigated. The HV pulse or generator is very compact by a soft switching circuit made up of IGBT working at over 30kHz. The frequencies of macro pulses and micro pulses can be arbitrarily tuned below resonant frequency to digitalize the HV pulse power. The micro pulses can also be connected by filter circuit to get the HVDC power. The circuit topology is given and its novel control logic is analyzed by flowchart. The circuit is part of a system consisting of an AC or DC LV power supply, a pulse transformer, the pulse generator implemented by LV capacitor and leakage inductance of the transformer, a HV DC or pulse power supply and the charged HV capacitor of the modulators.

The system is controlled by the required feedback signals of load and soft zero-current-switching. It uses feedback signal from the requirement of final load, which could be the signal of the probed high voltage on the charged HV capacitors or the current of the charged inductance. The preliminary experiments give us confidence to develop these compact HV source at power level of 112 KW with 3-phase input system.

The efficiency of above system is enhanced by working only at resonant mode with micro pulse, which decreases the turn-on and turn-off losses of IGBT devices significantly and differs it from more conventional

working logic. The novel concept for efficiency improvement is described in the paper, which may lead it to wide applications, for enhancement of efficiency is one of the most important aspects for the development of power electronics used in industry.

### BASIC CONFIGURATION

The available commercial M57962L is first selected as drivers to high power IGBT devices. Its turn-on and turn-off times are measured, which can not satisfy the needs of switching frequency over 30 kHz. Then a high speed driver is developed, whose turn-on and turn-off times is one order's below. Finally, the main design criteria for the high power high voltage charger are discussed.

### The Present Commercial Drivers for IGBT

The developed driver board with commercial M57962L is illustrated in Fig. 1, which is one driver means for high power IGBT. The measured turn-on and turn-off delays, which are about 1 $\mu$ s, are respectively shown in Fig. 2 and Fig. 3.

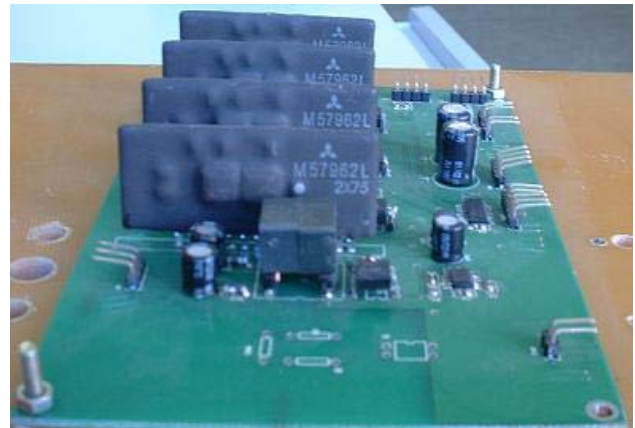


Figure 1: The driver board for high power IGBT.

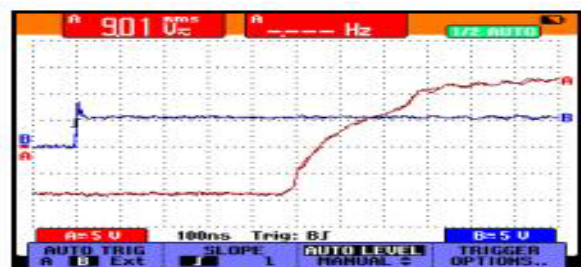


Figure 2: The turn-on delay of M57962L.

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# lige@sjtu.edu.cn

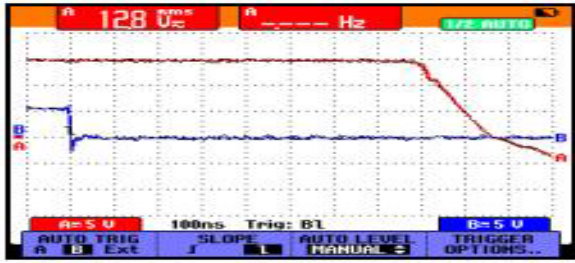


Figure 3: The turn-off delay of M57962L.

**The High Speed Driver System of IGBT**

As the available commercial M57962L can not work beyond the frequency of 30 kHz, the high speed driver for IGBT is developed as illustrated in Fig. 4. Its turn-on and turn-off times at the same condition of M57962L are respectively shown in Fig. 5 and Fig. 6. Both of its turn-on and turn-off times are within 100ns, which is one order ‘s below than general commercial driver. Therefore, it controls the switch-on and switch-off of IGBT very quickly and reliably, which significantly decrease the turn-on and turn-off losses in the IGBT’s transient period.

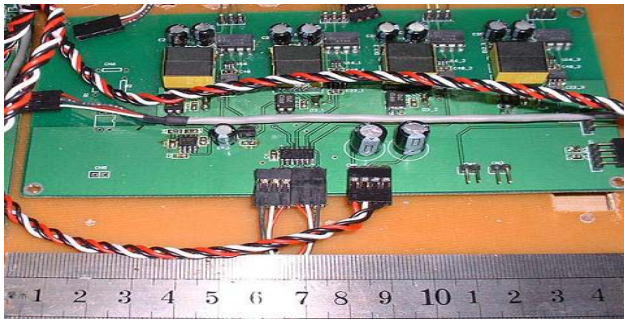


Figure 4: High speed driver for IGBT.

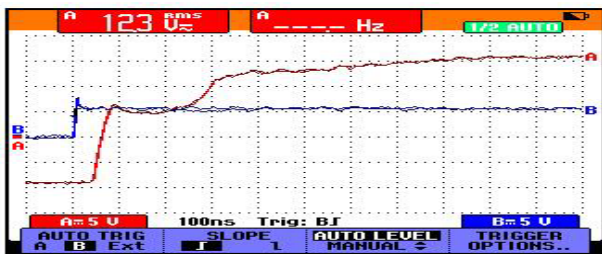


Figure 5: The turn-on delay of high speed driver.

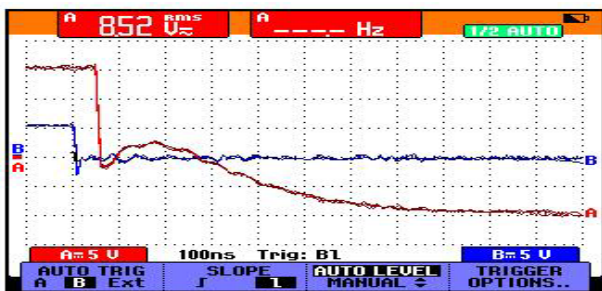


Figure 6: The turn-off delay of high speed driver.

**The Main Circuit Analysis**

The 50/60 Hz AC utility supply is first rectified to get the DC energy storage in capacitor, then the positive and negative half cycle of high frequency oscillations are got by switching IGBT1 IGBT4 and IGBT2 IGBT3 in turn with the leakage inductance of transformer and resonant capacitor Cr. The induced high voltage of second winding in the high frequency transformer is rectified again and filtered to charge the modulator capacitor. Typical parameters of the main circuit are listed in Table 1.

Table 1: Typical Parameters of the main circuit

Resonant Parameters	Case 1	Case 2
Leakage Inductance/ $\mu\text{H}$	7.11	7.11
Resonant Capacitor/ $\mu\text{F}$	0.75	1.88
Resonant Frequency/kHz	69	43.6
Impedance/ $\Omega$	3.079	1.945

Voltage steps are increased for the switching frequency could be as high as 69 kHz by selecting the leakage inductance of transformer and resonant capacitor Cr. The circuit impedance is determined by matching leakage inductance of transformer and resonant capacitor Cr. Roadmap of increase the charging accuracy of the modulator voltage is enhancing the frequency of coherent circuit in order that more voltage steps can be got in one charging cycle. The voltage steps are derived as:

$$N_v \leq 2f_r / f_m \quad (1)$$

Where  $f_r$  is the frequency of resonant circuit and  $f_m$  is the working frequency of charged modulator.

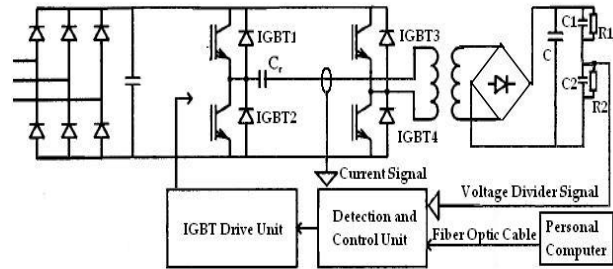


Figure 7: The main circuit of the compact HV charger.

**ZCS and Driving Auto Following**

The flow charter of the driving signal for one pulse, which is used to drive IGBT1 IGBT4 or IGBT2 IGBT3 in the main circuit to generate one micro current pulse, is shown in Figure 8. The minimum driving time of one IGBT bridge is defined as  $3\mu\text{s}$ , which can be changed and is automatically extended to the value when the detected current signal is not zero. The ZCS is realized by switching off the driving signal of the IGBT bridge when the detected current is zero. The bandwidth of the current detector is 200 kHz and the detected delay of the current signal is less than  $0.3\mu\text{s}$ . So, the maximum frequency of the driving system could be as high as 200 kHz by tuning down the minimum driving time from  $3\mu\text{s}$  to  $2\mu\text{s}$ . The

working logic is implemented in one logic chip, which can be changed from the PC through Fiber Optic Cable.

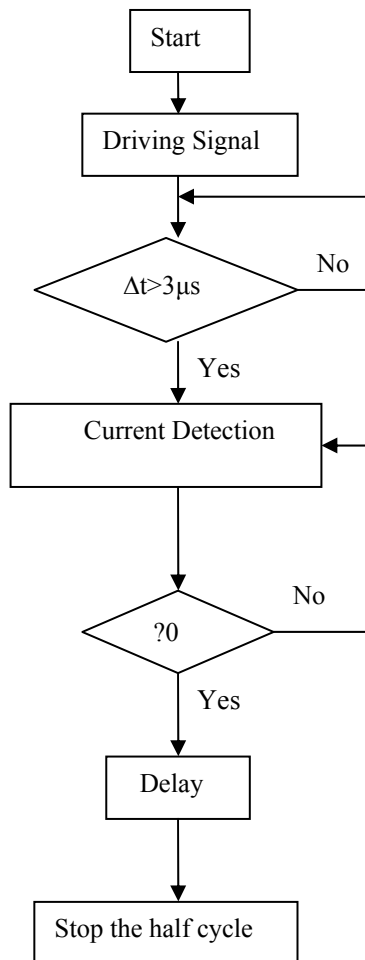


Figure 8: The flow charter of one pulse

### PRIMARY EXPERIMENTS

The power transfer capacity of the system is first tested by replacing the charged capacitor C in Fig. 7 with one resistance load. One current macro pulse in resonant capacitor Cr is measured by 40A/1V current probe. The macro pulse composed by 16 micro pulses is shown in Fig. 9. 400A peak current is excited by 620V DC rectified voltage. It states the pulse peak power reaches 248kW, which can be transferred to the second HV load by high frequency HV transformer.

In order to check the possibility of high voltage system driven by above high frequency resonant charger, the circuit illustrated as Fig. 7 is developed. The measured HV waveform is shown in Fig. 10. The output voltage is probed by one simple 1667:1 impedance matched voltage divider, which is composed by capacitors and resistances with the same time constant. The load is one 30mm ball air gap. The measured peak voltage reaches 56.68 kV.

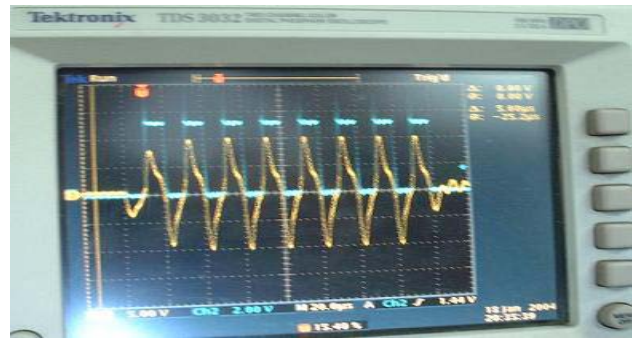


Figure 9: One current macro pulse.

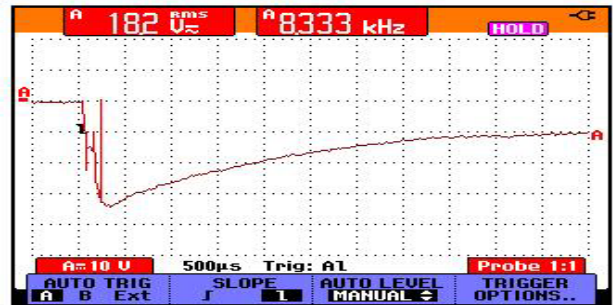


Figure 10: The HV waveform with voltage divider.

### SUMMARY

The PC controlled high voltage charger with high efficiency and high precision is designed, built and tested. The frequencies of macro pulses and micro pulses can be arbitrarily tuned below resonant frequency to digitalize the HV pulse power, which satisfies arbitrary needs of different loads. More voltage steps are created by the system working in high resonant frequency, which is as high as 69 kHz. The high voltage in load capacitor of modulator as well as other loads is precisely charged, the voltage droop with time could be recharged by one burst of micro pulses.

The turn-on and turn-off times of present commercial drivers, M57962L as well as EXB840 and EXB841, are generally from 1μs to 1.5μs, which limit the performance of power electronics, particularly in case of working over 20 kHz. The drivers in the experimental setup of this paper cut the turn-on and turn-off times to 0.1μs, which significantly decrease the turn-on and turn-off losses in the transient period of IGBT and increase the controllability and reliability of the power system composed by IGBT. The theory and primary experiments in the paper give us confidence about its applications as high voltage chargers for modulators and accelerators with high efficiency and high precision.

### REFERENCES

- [1] Nasser H. Kutkut, Divan\_DM, Novotny\_DW, Raymond HM: "Design Considerations and Topology Selection for a 120KW IGBT Converter for EV Fast Charging", IEEE Transactions on Power Electronics, Vol. 13, No.1, pp.27-36, January 1998