# Introduction of High Precision Charging Technique Applied in Pulsed Magnetron Modulator for Industrial Computerized Tomography System

ZHANG Yabin, REN Xianwen, TU Guofeng, LI Xiaojin
(Institute of Environmental Protection Engineering, PR China Academy of Engineering Physics
P.O.Box 919-826, Mianyang 621900, PR China. E-mail: zhangyb@entech.com.cn)

**Abstract:** In this paper the charging technique used in PMM (Pulsed Magnetron Modulator) of ICT (Industrial Computerized Tomography) system is introduced. This charging technique is based on the high frequency series resonant inverter technology, which is applied in many kinds of power supplies or modulators. For high spatial resolution and high density resolution in ICT, the required precision of output voltage between pulses of PMM is more than 99.9%. Based on the requirement of output parameters of PMM (shown in Table 1), a two-stage series resonant charging technique is adopted. First stage is fast-charging stage which lasts 2ms, and the PFN (Pulse Forming Line) could be charged to 97% of rating voltage in the end of the stage. Second stage is slow-charging stage which lasts 0.6ms and ensures the voltage of PFN varies less than 0.1% between pulses.

**Keywords:** ICT, inverter, pulsed power, magnetron

## 1 INTRODUCTION

In ICT system the resolution of the object is much related with the output power of X-ray source [1-4]. When the power of X-ray source varies little during the time of scanning, high spatial resolution and high density resolution could be gotten. The X-ray source power is determined by the power of microwave radiated by magnetron, and essentially is determined by the output power of PMM. If the output power of PMM is relatively stable, the microwave power is certainly keeping invariant and the X-ray source power is always the same when scanning. So the PMM is one of key devices in ICT system [5-8].

The required output parameters for a 6MeV ICT system are shown in Table 1. It's obvious that the precision of output voltage between pulses of PMM should be more than 99.9%. Due to the load character of magnetron close to pure resistor, the microwave power is much related to the output voltage of PMM. So the voltage stabilization technique is the key in PMM.

## 2 PRINCIPLE

The diagram of PMM is shown in Fig. 1. PMM is powered by three-phase AC380 V (50 Hz) electric grid. Eight IGBTs and two couples of resonant inductor and resonant capacitor form two H-bridge inverters, and each inverter is an independent stage charging the PFN through the boost transformer and high frequency rectifier. When the thyratron is triggered the PFN is discharging to the magnetron through the high voltage pulse transformer.

If a sole stage of H-bridge inverter charging is adopted in PMM, due to the required precision of voltage there should be 1000 times of charging in less than 4 ms. That means the charging frequency should be more than 250 kHz. But in such working statement the reasonable H-bridge switches and core material of transformer is hard to find and the control system is also complicate. By two-stage charging only 50 kHz is needed.

The difference between two stages is the resonant resistance in the circuit, which could be calculated by Formula-(1).

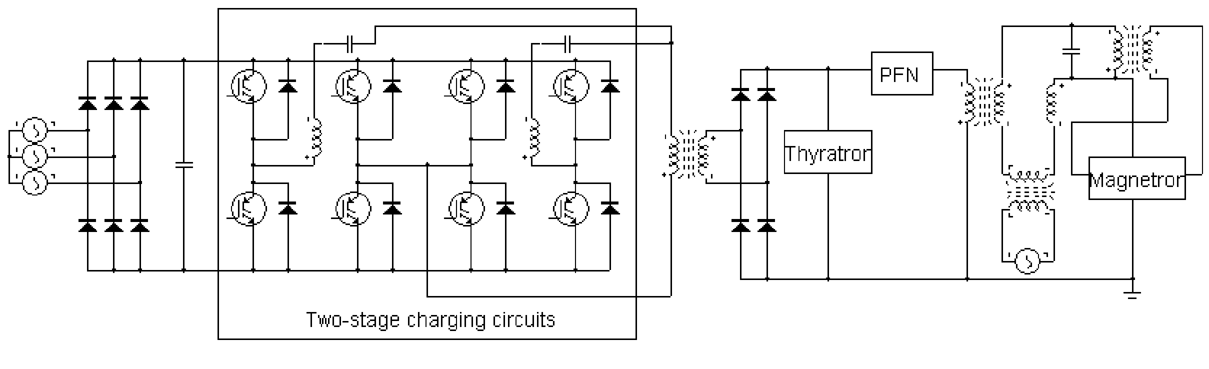


**Fig. 1** Brief diagram of PMM

$$R=\sqrt{\frac{L_r}{C_r}} \tag{1}$$

where: $R$: Resonant resistance;

$L_r$: Resonant inductance;

$C_r$: Resonant capacitor.

$R$ is much smaller in first charging stage than that in second charging stage. Low $R$ means high resonant current. And resonant current is the primary equivalent value of charging current. So by reasonable design of resonant parameters, the PFN could be quickly charged to nearly the rated value in 2 ms-3ms and then in left time PFN could be slowly charged to satisfy the precision requirement.

**Table 1** Brief Output parameters of PMM

| | |
|---|---|
| Output voltage (peak) | 48 kV |
| Output current (peak) | 110 A |
| Pulse repetition frequency | 250 Hz |
| Pulse Width | 5 μs |
| Stabilization precision of pulse top | ≮ 99% |
| Stabilization precision of output voltage between pulses | ≮ 99.9% |

## 3 EXPERIMENT RESULT

The voltage waveform of PFN is shown in Fig. 2. And Fig. 3 is the partial enlarged image of the turning point of two-stage charging. According to those waveforms, the procedure of charging is lasting less than 3 ms. First fast-charging stage lasts 2 ms, and the PFN is charged to 20.63 kV (nearly 97% of rating voltage). Second slow-charging stage lasts 0.6 ms, and PFN is charged to 21.23 kV in the end. And 0.8 ms later PFN starts discharging.

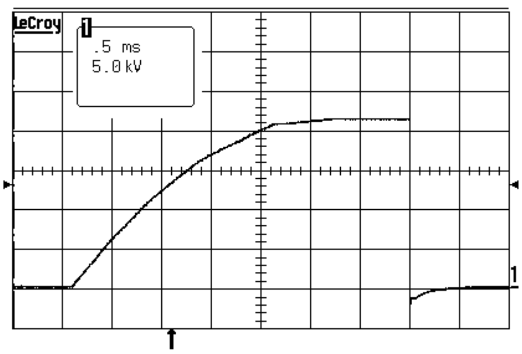


**Fig. 2** Voltage of PFN

The average charging current of each stage could be calculated by Formula-(2).

$$I\cdot\Delta t = C\cdot\Delta U \tag{2}$$

where: $I$: Average value of charging current;

$\Delta t$: Charging duration;

$C$: Equivalent capacitor of PFN;

$\Delta U$: Variable value of PFN voltage.

According to the data in Fig. 2 and Fig. 3, the average value of each stage charging current is calculated, 1 A in first stage and 0.1 A in second stage. Correspondingly the average value of two-stage resonant current is known due to the ratio 1:50 of the boost transformer. And the main charging parameters are shown in Table 2.

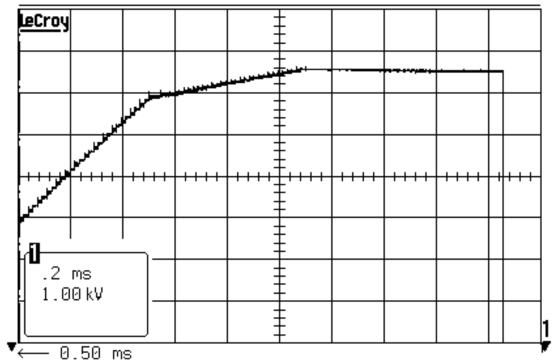


**Fig. 3** Turning point of charging

**Table 2** Brief charging parameters

| | |
|---|---|
| Charging frequency | 50 kHz |
| Fast-stage period and resonant current (average value) | 2 ms/50 A |
| Slow-stage period and resonant current (average value) | 0.6 ms/5 A |

The output pulse waveform of PMM is shown in Fig. 4 and the 255 Hz repetitive pulse output is shown Fig. 5. It's obvious that the output peak voltage is up to 50 kV. And according to the measured data the peak value varies less than 0.1% between pulses.

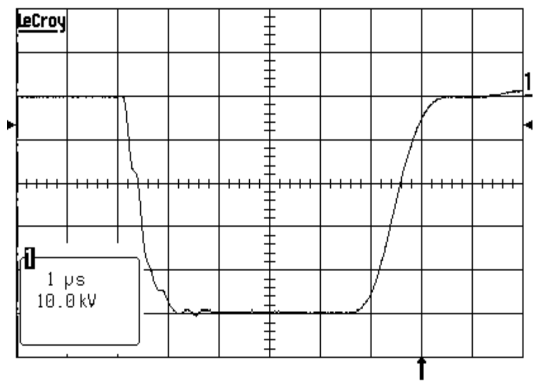


**Fig. 4** Output pulse of PMM

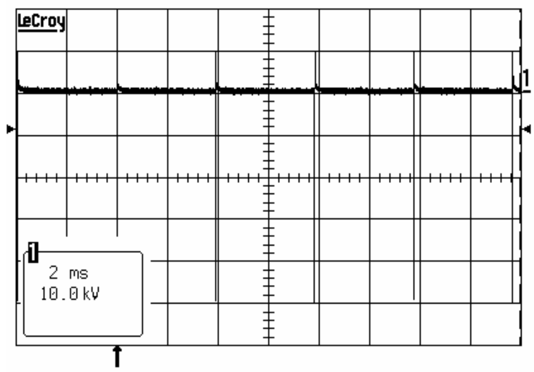

**Fig. 5** Repetitive Pulses of 255 Hz

## 4 CONCLUSIONS

Since the output precision of the PMM relates to the charging frequency and the charging current, a feasible two-stage series resonant charging technique is adopted in the PMM of ICT system. With two relatively independent charging circuits and varied charging current, the technique realizes the fast charging which satisfies the energy requirement and the slow charging which satisfies the precision requirement. And the output precision between pulses is up to more than 99.9%.


## ACKNOWLEDGEMENTS

We would like to give our heartfelt thanks to Technician Hu Xinkang, Professor Zhang Zhifu and Professor Zhao Junke who give great help and useful advises.


## REFERENCES


1. Izumi, S., Kamata, S., Satoh, K., Miyai, H. High energy X-ray computed tomography for industrial applications. Nuclear Science, IEEE Transactions on Volume 40, Issue 2, Apr 1993 Page(s): 158-161.
2. Y C, Xian W, Hall E L. Zero cylinder coordinate system approach to image reconstruction in fan beam ICT[C]. Proceedings of the SPIE-The International Society for Optical Engineering, vol. 1826, 486.
3. Wang Zhaoba, Jinyong. Research Progress on High Energy X-ray Industrial Computed Tomography. Journal of Test and Measurement Technology, 2002(2).
4. Ramakrishna G. S., Datta S. S., Datta S. S., et al. Design and Applications of Computed Industrial Tomograpic Imaging System (CTIS), New Delhi, India, 1996. 293-299.
5. Pahlevaninezhad, M. Motahari, R. et al. Analysis and Implementation of A LLC Resonant Converter for Magnetron Modulator, IEEE International Conference on Industrial Technology, 2006. ICIT 2006. 998-1003.
6. Vizir, V.A. Ivanov, S.N. Kovalchuk, B.M. et al. Solid state power supply modulator system for magnetron, Digest of Technical Papers. PPC-2003. 14th IEEE International Pulsed Power Conference. Vol.2: 1462-1464.
7. Bees, G.L. Huhn, B. Tydeman, A. et al. A 65 kV 15 kW switch mode power supply for a direct switched magnetron pulser. Pulsed Power 2000, IEE Symposium, Digest No. 2000/053.
8. Carleto, N. Motta, C.C. Design, construction and characterization of a line-type pulse modulator for driving high power magnetron. International Conference on Microwave and Optoelectronics, 2005 SBMO/IEEE MTT-S, 330-333.