CW-TYPE HV POWER SUPPLY OF 50 Hz AND ITS APPLICATIONS IN ACCELERATOR POWER SUPPLY*

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Abstract

The high-voltage power supply is an integral part of accelerator technology, as its stable and reliable output is an important guarantee for accelerator properly working. In a number of engineering practices of accelerator design and construction, we tried to use the Cockcroft-Walton (CW) type of power supply driven by 50 Hz and got success. It is of simple structure, low cost, easy maintenance and high efficiency. This report describes the technical difficulties and the solutions in the CW-type power supply driven by 50 Hz. It also gives an introduction of the latest design of 800 kV/30 mA electron accelerator, which is being assembled at SINAP. Recent work has shown that it is an option to choose 50 Hz driven power system when it is more lenient on the voltage ripple but needed to be as high as possible on the energy conversion efficiency.

INTRODUCTION

The application of electron accelerator in irradiation processing needs high power and high voltage generator. Therefore it is in the face of high demand that output of high-power with high energy conversion efficiency. If the traditional high voltage generator driven by line voltage, its total energy efficiency can be increased by cancel the intermediate frequency generator or the medium-frequency power supply. In the development of high power electron accelerator for the process of flue gas desulphuration, we have adopted the Cockcroft-Walton (CW) type circuit driven by the 50 Hz line voltage, with the SF_6 gas insulated. This kind of high voltage generator is simple structure, low cost, easy maintenance, while meets the requirements of high power output and high voltage conversion efficiency.

THE CIRCUIT DESIGN

The Steady-State Circuit Calculation

The steady-state calculation problems of symmetrical CW (SCW) type circuit can be solve following the Table 1[1-3], such as the voltage drop, voltage ripple, voltage efficiency, etc. In Table 1, N is the number of stages, I is the output current, f is the driven frequency, C_n and $C_{s(n)}$ are the capacitance value of each stage of the charge transporting columns and that of the filtering column respectively. The voltage ripple of the capacitive part δV_c equals to zero when the two transformers are symmetrical uniformity. The voltage efficiency F is approaches 1 relating to b, which is the ratio of the capacitance of each stage to the equivalent capacitance of each rectifier considering the stray capacitance.

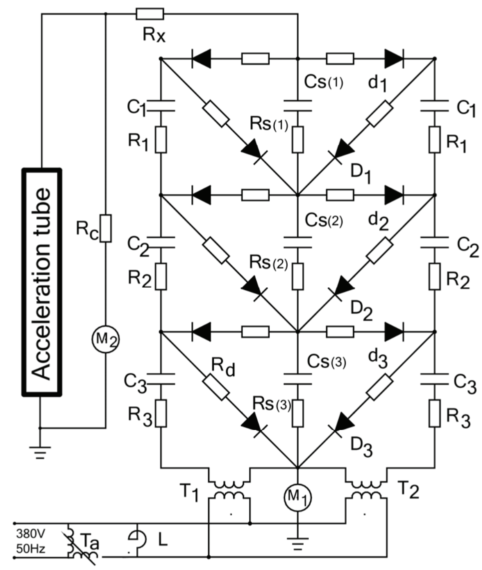

Figure 1: Block diagram of 1.2 MV/50 mA symmetrical C-W generator. C_1, C_2, and C_3: Coupling Capacitor; C_s: Smoothing Capacitor, $C_{s(1)}=C_{s(2)}=C_{s(3)}=C_s$; d_1, d_2 and d_3; D_1, D_2 and D_3: Rectifier; R_1, R_2 and R_3; $R_{s(1)}$, $R_{s(2)}$ and $R_{s(3)}$: Current-limiting Resistor; R_d: Current-limiting Resistor of Rectifier; R_c: Measuring Resistor; R_x: Damping Resistor; T_a: Regulating Transformer; L: Inductor; T_1 and T_2: Step-up Transformer; M_1: Amperemeter for Load current Measurement; M_2: Amperemeter for Output Voltage Measurement.

Table 1: The Steady-state SCW Circuit Calculation

Circuit Parameter		Equation
Output Voltage		$V=(2NV_0-\Delta V)F$
Voltage Drop	Total voltage drop	$\Delta V=\sqrt[m]{(\Delta V_C)^m+(\Delta V_R)^m+(\Delta V_{Ls})^m}$
	By capacitors	$\Delta V_C=\frac{I}{2f}\sum_{n=1}^{N}\left[\frac{n^2}{C_n}+\frac{1}{2C_{s(n)}}(1-\varepsilon)\right]$
	By the forward resistance of the rectifier branch	$\Delta V_R=(3\pi)^{2/3}NV_0\left(\frac{R_t+R_D}{V_0}\frac{I}{2}\right)^{2/3}$

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	By the transformer	$\Delta V_{Ls}=2.32NV_0\left(\frac{\omega L_s}{V_0}\frac{NI}{2}\right)^{1/2}$
Voltage Ripple	The load-dependent part	$\delta V=\frac{I}{2f}\sum_{n=1}^{N}\frac{1}{C_{s(n)}}(1-\varepsilon)$
	The capacitive part	$\delta V_c=\frac{\lvert V_L-V_R\rvert b^{-1/2}\sinh^2(Nb^{-1/2})}{\cosh(2Nb^{-1/2})\sinh(b^{-1/2})}$
Voltage Efficiency		$F=\frac{\sqrt{b/2}}{N}\tanh\left(\frac{N}{\sqrt{b/2}}\right)$

The Rectifier's Working Status and the Circuit's Capacitive Impedance

As show in the Fig. 1, there are two types of rectifiers. One is d class, i.e., d(n), and another is D class, i.e., D(n). The backward voltages of them, $V_{d(n)}$ and $V_{D(n)}$, are given by the following two functions,

$$V_{d(n)}(t)=V_a(1+\cos\omega t)-\frac{\Delta Q}{2}\sum_{i=n}^{N}\frac{i}{C_i}-(N-n+1)\frac{It}{C_s},\quad n=1,2,\ldots,N, \tag{1}$$

and

$$V_{D(n)}(t)=V_a(1+\cos\omega t)-\frac{\Delta Q}{2}\sum_{i=n}^{N}\frac{i}{C_i}+(N-n)\frac{It}{C_s},\quad n=1,2,\ldots,N, \tag{2}$$

where $\Delta Q = IT$, I is the load current[4]. It can get the operation section time $T_{d(n)}$ and $T_{D(n)}$ by $T_{d(n)} = T/2 - t_{d(n)}$ and $T_{D(n)} = T/2 - t_{D(n)}$, where $t_{d(n)}$ and $t_{D(n)}$ are the solutions the functions $V_{d(n)} = 0$ and $V_{D(n)} = 0$. Therefore, the duty ratios are determined by $\varepsilon_{d(n)} = 2T_{d(n)}/T$, $\varepsilon_{D(n)} = 2T_{D(n)}/T$. Then the circuit's capacitive impedance X_e can be calculated by equation (5), where $\omega = 2\pi/T$. So the equivalent capacitive reactance is related to the capacitance $C_{d(n)}$ and $C_{D(n)}$, which are determined by equation (3) and equation (4). It gives the results of the 800 kV/30 mA generator in Table 3.

$$\frac{1}{C_{d(n)}}=\sum_{i=n}^{N}\frac{1}{C_i}+\frac{N-n+1}{C_s},n=1,2,\ldots,N \tag{3}$$

$$\frac{1}{C_{D(n)}}=\sum_{i=n}^{N}\frac{1}{C_i}+\frac{N-n}{C_s},n=1,2,\ldots,N \tag{4}$$

$$X_e=\frac{1}{\omega}\left(\frac{1}{\sum_{n=1}^{N}\varepsilon_{d(n)}C_{d(n)}}+\frac{1}{\sum_{n=1}^{N}\varepsilon_{D(n)}C_{D(n)}}\right) \tag{5}$$

The Value of the Protection Resistance

The value of the protection resistance should be satisfied $R_0 = 2u_0(\tau/T_m)^{1/2}/I_m$, where I_m is the maximum working current of the rectifiers, u_0 is the total voltage of the capacitors in the short-circuited loop, τ is the duration in the short-circuit transition being in the range of 10 – 1000 s. In the latest generator of 800 kV/30 mA, the I_m = 500 mA, T_m = 20 ms, u_0 = 686.6 kV, then the protection resistance should not be less than 614 kΩ.

APPLICATIONS

We have constructed three electron accelerators adopting this kind of high voltage generator shown in Table 2. One is for the electron curtain accelerator EBS-300-15 in Suzhou used for rubber vulcanization, which is built by Suzhou University and Iwasaki Electric Company in Japan [5]. We provided the 300 kV power supply. Its set-up transformer is inside the steel vessel with high-pressed SF_6 gas, as shown in Fig. 2. One is for the flue gas desulphuration developed in the program of key technology of nuclear technique applications, with two large 250 kV transformers outside, as shown in Fig. 3 [4]. The other is for the 800 kV/30 mA electron accelerator, as shown in the Fig. 4. Its circuit parameters are calculated as shown in Table 3.

In these case, it is the same in the design of high voltage capacitor component[6]. The component is constructed by high-voltage and large capacity polyester film capacitors, which are non-sealed with aluminum layered in parallel and in series. It has good high-voltage capability in the SF_6 high press environment, and is easy to connect.

Table 2: The High Voltage Power Supplies of CW Type Driven by 50 Hz

Performance	Circuit Type	Voltage Ripple	Stage Number
1.2 MV/30 mA	Symmetrical	< 10%	3
300 kV/60 mA	Conventional	< 5%	1
800 kV/30 mA	Symmetrical	< 5%	3

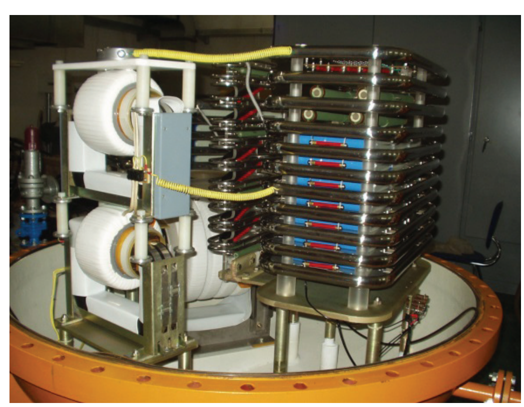


Figure 2: The 300 kV/60 mA power supply for electron curtain accelerator in Suzhou.

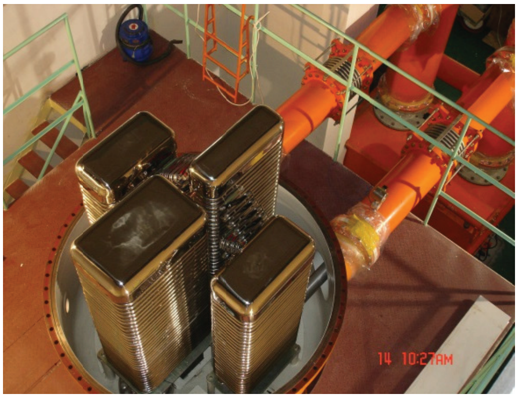
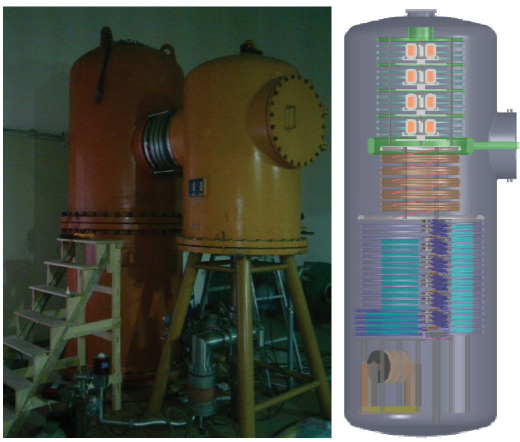


Figure 3: The 1.2 MV/50 mA power supply.



(a) (b)

Figure 4: The 800 kV/30 mA electron accelerator and its power supply structure. (a) The accelerator. (b) The profiles of the power supply.

Table 3: The Rectifier Working Parameters of 800 kV/300 mA CW Type of High-voltage Generator

Rectifier	d1	d2	d3	D1	D2	D3
Conduction Angle $T_{d(n)}$, $T_{D(n)}$ (ms)	5.80	6.39	7.62	6.75	7.04	7.96
Duty Ratio ε	0.42	0.36	0.24	0.35	0.30	0.20
Maximum Backward Voltage (kV)	250	274	321	250	274	303
Mean Operating Current (mA)	70	82	124	91	100	144
Peak Current (mA)	95	110	168	123	135	195

RESULT

In the development of such kind of high-voltage generator, it is indicated that the CW type of power supply driven by line-frequency is satisfied for the requirements of electron accelerator while in the condition of less demand for voltage ripple. It is an option for the range of 300 kV to 1.2 MV with simple structure, low cost, easy maintenance and high efficiency.

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