AN 800kV 30mA LINE-FREQUENCY COCKCROFT-WALTON DC GENERATOR USING GAS INSULATED TRANSFORMER FOR RADIATION APPLICATION

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Abstract

The design and construction of a line-frequency 800 kV Cockcroft-Walton DC generator using gas insulated transformers are described, as well as the motive to develop it into radiation application. Several features are underlined, preliminary test results of the prototype presented and some problems encountered discussed.

INTRODUCTION

The well-known Cockcroft-Walton generator has been widely adopted in various applied DC power supplies as well as HV DC generator for an accelerator (also known as Cockcroft-Walton accelerator) since its invention by Greinacher in the 1920s [1, 2]. At the early stage of its development, many high voltage generators of this type were made but normally air-insulated and thus very large [3]. Several versions of its improved cascade circuits, various insulation medium and different operating frequency of its driving ac power have been extensively reported to be used in various applied occasions during decades of its development since then [4-6]. Despite all these, Cockcroft-Walton electron accelerators for industrial applications have seldom been reported all along and remarkably less dominate nowadays. The most successful instance seems to be a series of Cockcroft-Walton electron accelerators developed by the Nissin-High Voltage Co., Ltd. in Japan, in which a similar cascade circuit to a symmetrical one was adopted but the middle capacitor column omitted, compressed gas used for insulation, and a medium frequency of 3 kHz of ac input power employed so as to reduce the generator size as far as possible and the internal impedance. The energy range from 1 to 5 MV and the maximum beam power up to 150 kW could be achieved in such Cockcroft-Walton systems [7, 8].

Inspired by a 1.2 MV 50mA line frequency (50Hz)-driven Cockcroft-Walton electron accelerator developed by us in 2007, in which two large oil-filled transformers were used as ac power input, an 800 kV 30 mA line frequency Cockcroft-Walton electron accelerator using gas insulated transformers was designed and constructed. The use of line frequency as driving source will greatly simplify jobs on driving ac power supply and suitable transformers (e.g. for a medium frequency of a few kHz) , therefore also be very cost-saving. The gas insulated transformers could be directly placed in the same pressure vessel as where the cascade generator was contained, which will greatly reduce the system size and costs further considering the total large size and/or complex structure of the oil-filled transformers and feedthrough electrical connections between the transformers and pressure vessel. In this paper, the design and construction of such a Cockcroft-Walton generator will be described, some features underlined and initial test results presented.

DESIGN DESCRIPTION

A conventional symmetrical Cockcroft-Walton cascade circuit (Fig. 1) with three stages was adopted to produce a high voltage of 800 kV except that the three stages in the two side columns are not identical. A higher capacitance value of 37.5 nF for the capacitor C3' in the lowest stages (the first stage) in the two 'side' columns was used to alleviate oscillating amplitudes on it considering relatively larger charging/discharging currents in the first stages, which was thought, primarily based on our past experiences, to be helpful in protecting the rectifiers at this stage from high voltage transients in the events of ground faults of the high voltage terminal caused by e.g. electrical breakdown in the accelerating tubes. All other capacitors including all the capacitors in the central column have an equal capacitance of 12.5 nF.

Each capacitor actually comprises of several basic capacitor elements being series or series-parallel connected and placed in the different layers of a stage. Each capacitor element has a capacitance of 75 nF and nominal withstanding voltage of 50 kV. Such capacitor elements fabricated of polyester films and aluminum foils have been used on various occasions here and proved to be suitable for being used in compressed SF_6 gas environment.

Each rectifier composes of three series-connected 200 kV/0.5A rectifier elements available from the market. Voltage dividing resistors and current limiting resistors were incorporated in each rectifier to equalize the reverse voltage drops among the rectifier elements and protect the rectifiers from overcurrent. Simple analysis could conclude that a maximum reverse voltage 367 V on the rectifiers happened in the first stage, which was a little more than one half of the nominal withstanding voltage of one rectifier.

A current limiting resistor of 720 kΩ was connected between the high voltage terminal and accelerating tube, which was used to protect the electrical components in the cascade column from high voltage transients and should withstand 800 kV voltage in the event of breakdown in the accelerating tubes.

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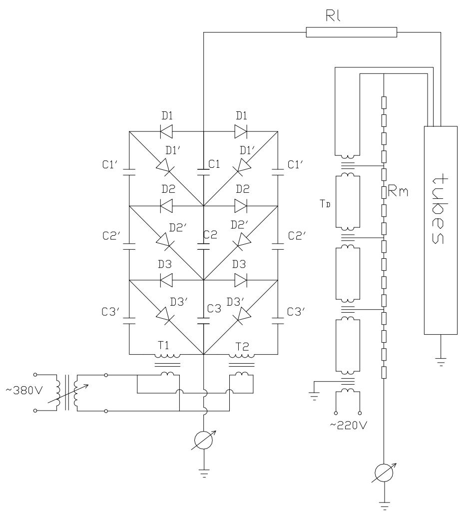

Figure 1: Circuit diagram of the 800kV 30mA Cockcroft-Walton electron accelerators.

Two identical gas insulated transformers of 130V(RMS)/300mA that will supply the two side columns with a balanced ac input voltage was designed specially to not only suffice for the cascade generator but also meet the requirement of its use in compressed SF_6 gas. Its capacity margin, size and structure had to be balanced carefully since a relatively compact structure of the whole system was also one of our goals. These two transformers were further supplied by a 400 V voltage regulator adjacent to the pressure vessel driven by a stepper motor which was remotely controlled by the computer to acquire regulated high voltage output of the cascade generator whenever non-loaded or beam-loaded.

Four isolation transformers with 220/220 turns ratio and 200 kV insulation voltage each were connected in series as ac power input to the filament of the electron gun, a separate transformer with turns ratio of 220:4 was used as an impedance match between the last isolation transformer and the filament. The heating power of the filament was regulated through a SCR(Silicon-controlled rectifier) circuit integrated in the control cabinet whose output was connected to the input of the first isolation transformer.

A chain of high voltage resistors was used not only to measure high voltage but also as voltage-dividing resistors to distribute uniformly 800 kV along the corona rings surrounding the isolation transformers from top to bottom. Currents passing through the rectifiers, an approximate indication of beam currents while beam-loading, were measured by an ammeter connected between the 'central point' of the cascade circuit and the ground.

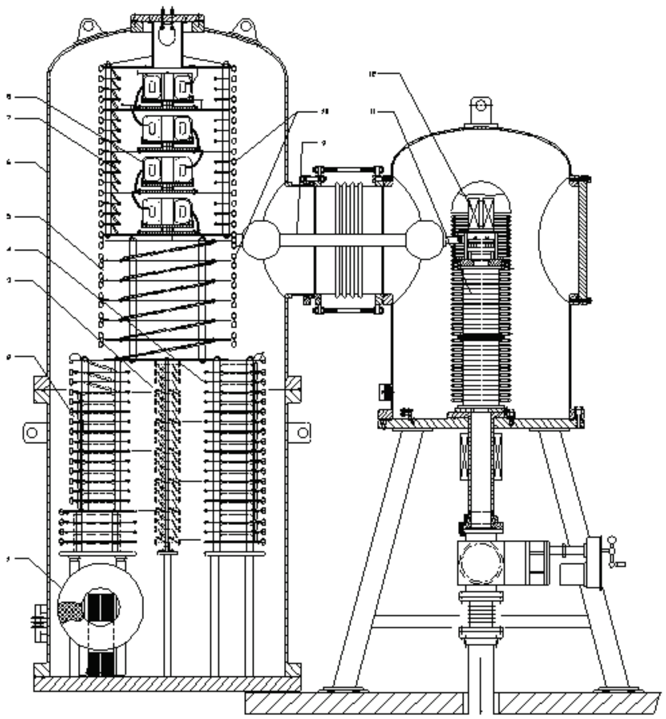

Figure 2: Diagram of the Cockroft-Walton electron accelerator (the scanning magnets and horn not shown): 1-tansformer; 2-side capacitor column; 3-rectifier column; 4-central capacitor column; 5-current-limiting resistor cage; 6-pressure vessel; 7-volatge measurement resistor string; 8-isolation transformer; 9-electrical conductor; 10-corona rings; 11-accelerating tubes; 12-filament transformer.

CONSTRUCTION DESCRIPTION

A diagram of this Cockroft-Walton accelerator is shown in Fig. 2. The cascade generator and the accelerating tubes are separately housed in the two pressure vessels connected by a corrugated pipe, through which a hollow conductor is used to transmit the high voltage to the top end of the accelerating tubes. A pair of electric wires in the conductor floating at 800 kV carries ac power from the last isolation transformer to the filament transformer in the dome of the accelerating tubes.

The two side capacitor columns, one central capacitor column and two rectifier columns constitute the main part of the cascade circuit (only parts of them shown in Fig. 2). The transverse dimension of the first stages of the two side capacitor columns has to be larger since each layer has to contain two capacitor elements. As a conventional practice in high voltage design, voltage-dividing resistors and corona rings are incorporated along the capacitor and rectifier columns.

The two heavy gas insulated transformers sit on the vessel floor and are placed just beneath the two side capacitor columns, which makes electrical connection an easy job. However, the support posts for the two side capacitor column made of insulation material have to be used since there usually exists a few hundreds of kilovolts potential difference between their metal base plates and the tank floor (the ground).

The cage containing the current limiting resistors sits on the 800 kV high voltage platform at the top of the cascade circuit columns. Because of its relatively high weight, the isolation transformer assembly has to be hung to the top flange of the pressure vessel, where the feedthrough terminals for voltage measurement and filament heating are also located.

The power supply vessel is 1.2 m in interior diameter and about 3.4 m in total height. The two vessels are filled with compressed SF_6 gas at 0.65 MPa. The electrostatic field calculations on the whole electrode system were carried out using the Poission Superfish package in the two orthogonal planes, in which an approximate maximum potential gradient was obtained so as to ensure an enough margin to the breakdown gradient in the SF_6 gas at 0.65 MPa.

TESTS

At the beginning of the tests, the terminal voltage with tubes could be conditioned to only 680 kV even after we opened the tank several times to correct a few incorrect connections in the circuit and reprocess the accelerating tubes, which had been proved to be contaminated and therefore hamper the voltage conditioning. Unfortunately, one of the transformers was damaged by discharge during this period, in which the starting part of its secondary windings appeared to be melted. To continue the tests, we could only use one side capacitor column so the circuit become an asymmetrical one. At this point, 15 mA beam current at 650 kV could be safely output continuously for about one hour.

To investigate the causes of the insufficient high voltage capability of the system, the SF6 gas was dried by regenerating alumina in the gas transfer system and putting some silica gel in the pressure vessel. After that, as high as 900 kV with non-load could be reached and most of conditioning time was silent nearly without sparks. Having validated the system in terms of high voltage, 800 kV/15mA (full load for the system since only one transformer left) was tested for an hour, during which a few breakdowns in the tubes occurred and the last one was proved to have damaged the cascade circuit, including the transformer.

DISCUSSIONS AND CONCLUSIONS

Because of its relatively high stored energy in the cascade circuit driven by line frequency, more useful or potent measures should be taken to protect electrical components in the circuit when the terminal discharges. It seems necessary and also feasible to improve the structure of the transformers since failure occurred at the same position of the two transformers. Furthermore, effective methods should be adopted to protect the transformers from high voltage transient impacts.

The transformers have been sent for repairing and the cascade circuit restored. More efforts are planned in near future.

The use of line frequency driving power eliminates costs spent on the custom-built medium-frequency driving power supply and transformers. Compared to dynamitron-like machines, it has a much higher electrical efficiency of around 90%. All these imply that it seems promising to develop it as a good alternative for industrial electron accelerators below 1 MV as long as the reliability could be guaranteed.

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