Advances in the Development of the Nested High Voltage Generator

R.J. Adler and R.J. Richter-Sand

North Star Research Corporation,
9931 Lomas, NE, Albuquerque, NM, 87108

I.Introduction

The Nested High Voltage Generator (NHVG) is a high voltage accelerator/power supply topology which can potentially satisfy a variety of requirements for a compact, reliable inexpensive DC accelerator in the 0.25 - 10 MeV range. Applications for this technology include the generation of high voltage, high current pulsed electron beams for microwave generation, the sterilization of medical products, the curing of polymers, and the sterilization of medical waste. This technology has recently been demonstrated in an accelerator which has operated at 500 kV with an electron beam in a 36 inch long, 17 inch diameter device.

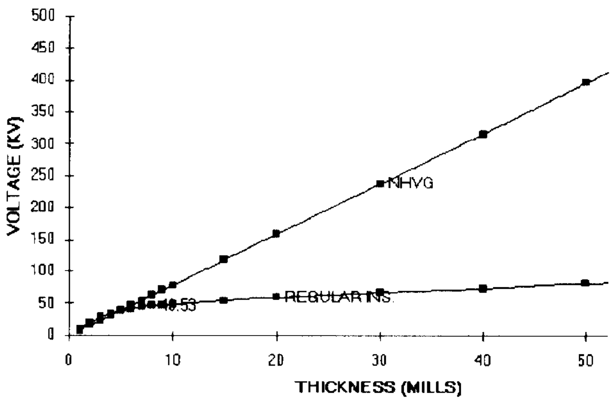

Figure 1. Maximum voltage as a function of insulation thickness from the Handbook for Electrical Engineers.

In this paper, we briefly describe the technology, and the operation of 3 machines built since the initial discussion of the technology in the 1991 Particle Accelerator Conference Proceedings[1]. The operation of a machine at up to 500 kV and 83 % efficiency has been demonstrated, and is particularly noteworthy.

II. Description of Nested High Voltage

There are two critical generic questions in the design of a high voltage, high power accelerator--how do you insulate the voltage ? and how do you get the power required into the high voltage system? Traditional DC systems include the Insulated Core Transformer (ICT), the Van de Graaf or Pelletron, the Cockroft Walton, and the Dynamitron. These systems all use gas (typically SF_6) insulation and they have varying power supply systems including electrostatic charge motion (Pelletrons/Van de Gaafs), capacitive coupling (Dynamitron), conventional transformer cores (Insulated core transformer), and voltage multipliers (Cockroft-Walton).

The primary motivation for the development of the NHVG was the requirement to significantly reduce the size of a DC accelerator, and the primary means of reducing the size was to use solid insulation in order to decrease the diameter of the machine. The fundamental problem of solid insulation is that as the voltage increases, the allowable electric field for insulation drops. This is illustrated by the standard data shown in Figure 1[2,3,4]. The straight line of Figure 1 shows the insulation trend if the voltage across a single insulator is rigidly subdivided.

The NHV concept is that the only way that the voltage can only be subdivided uniformly without voltage concentration in a fault mode is to split the high voltage structure into nested Faraday Cages in which each one has it's own power source. The power is supplied to the Faraday cages by allowing azimuthal electric fields (axial magnetic fields) into the individual cages. In this embodiment, the NHVG is a distributed air core switching transformer with each coil/power supply coupled to it's own insulation.

An intrinsic advantage of the NHVG relative to other DC generators is the way that the segmented voltage system affects the behavior of the system components in case of a fault mode as shown in Figure 3. Because each vacuum interface (hatched element in the figure) is associated with it's own capacitance, and there is no other total system capacitance, the voltage in a fault does not exceed the ambient voltage. In DC accelerators, spark gaps are placed along the

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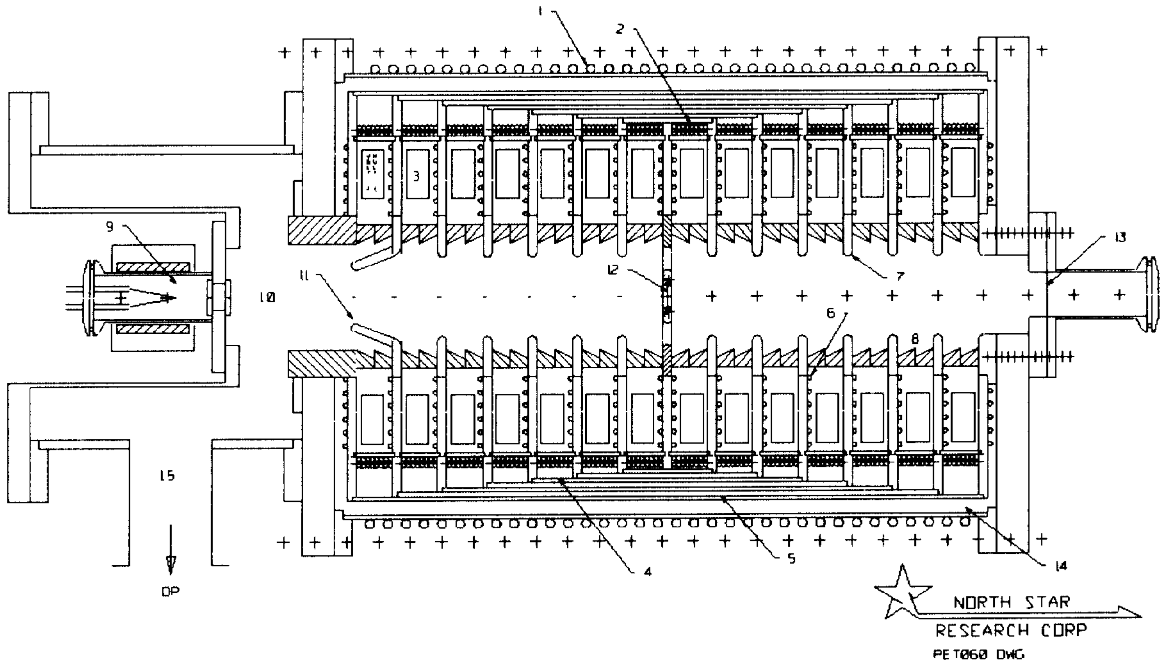

Figure 2.. Detailed schematic of the PET NHVG negative ions. 1)Primary winding 2)Secondary winding 3)Voltage multiplier 4)Conducting shell 4)Insulator 6)Conductor 7)Grading ring 8)Vacuum insulators 9)Ion Source 12)Stripping foil.

column to prevent voltage transients from building up, but even with spark gaps, components are subjected to 3 time the ambient voltage because the pulsed hold-off voltage of the spark gap is typically 3 times the DC hold-off voltage.

The most common machine fault modes involve flashover along the insulators, and we have designed the accelerator with resistance between the nested conductors and the associated vacuum electrode. This means that almost all of the stored energy is dissipated in resistors in the case of a fault.

A typical cross-section of an NHVG is shown in Figure 2. Insulation is provided in the radial direction by multiple layers of high dielectric strength film, and in the axial direction by a combination of plastic film or sheet, and dielectric fluid (oil). All films are impregnated with thin layers of this fluid. The potentials of each stage are defined by axial, cylindrical, conducting metal sheets which form the outer and inner boundary of each stage. These sheets are terminated on the ends by spiral conductors which are used to connect the grading rings on the insulator stack to the cylindrical metal sheets. No electrical connections are made between stages except by the conducting sheets.

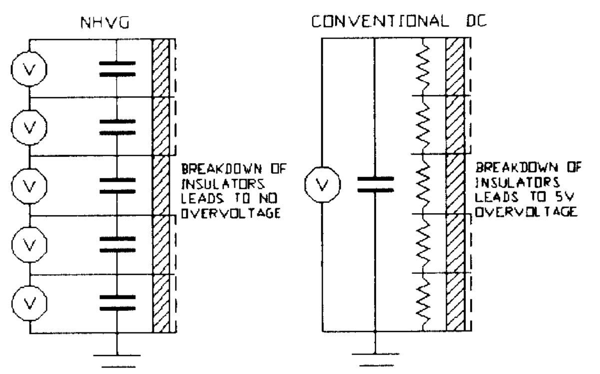

Figure 3.. Nested High Voltage and DC accelerators in a fault mode. The NHVG fault mode voltage does not exceed the operating voltage. The DC accelerators is subject to extreme over-voltage.

III. Existing Accelerators

Work on this concept has been supported by a number of agencies. In the work of reference 1, an 11 inch diameter, 30 inch long device with 1 cm. of total radial insulation was operated at 150 kV. Since the writing of that article, that device has been operated at up to 300 kV. Three other devices have also been operated.

500 kV Tandem Accelerator

A 500 kV tandem accelerator has been built and tested at full voltage (albeit with an electron rather than ion beam load). That device was designed for Positron Emission Tomography applications and has been operated successfully to test the sterilization of medical products under contract to a major medical manufacturer.

The efficiency of the 500 kV NHVG has been tested at low powers and is found to be as high as 83 % in operation at 60 kV. This level of efficiency is expected to scale to much higher powers. The distributed air core transformer can be very efficient. Both solid state and tube based power supplies have been used in testing this device.

A unique feature of the NHVG is the ease with which power can be supplied to the terminal of the device by providing primary/secondary combinations tuned to different frequencies. We demonstrated this on the 500 kV NHVG in electron beam mode.

200 kV Accelerator for Well Logging

A 200 kV device with a 4 inch diameter has been successfully tested at NSRC. This device accelerated electron beams up to 200 kV using a Cockroft-Walton type power system. We believe, based on the test data from this device, that MeV level accelerators can be built with diameters of 4 inches. This work was supported by the National Science Foundation.

300 kV Pulsed Beam Accelerator

A 300 kV device has been built to test operation of the NHVG in DC operation with grid controlled pulsed beam extraction. In operation with a ceramic accelerating column and a dispenser cathode, beams with currents of up to 80 amperes were accelerated for 200 ns. pulses at repetition rates of up to 200 Hz. This type of power system is capable of operation at repetition rates up to 10 kHz. depending on the details of grid dissipation and the prime power system.

Systems of this type have been designed to operate at 1 kA and 200 Hz. with 200 ns. pulses for applications to linear colliders, and at 100 amperes and 5 kHz. with application to high power microwave generation. Work in this area has been funded by the Department of Energy and the US Army Research Laboratory.

IV. Conclusions

The NHVG has been demonstrated to be both versatile and useful. To date, with 4 accelerators tested, we have experienced no problems with dielectric breakdown. The NHVG principle will allow a new class of inexpensive DC accelerators to be used in a variety of industrial and research applications.

References

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2. J.P. Shannon, S.F. Philip, J.G. Trump, "Insulation of high voltages across solid insulators in vacuum," Proc. First International Symposium on Insulation of High Voltages in vacuum, M.I.T., Cambridge, MA, October 1964.

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