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Design and Construction of a 1.2 kV, 2 Amp Van de Graaff Generator for X-ray and Medical/Nuclear Applications Using Locally Sourced Materials

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ABSTRACT
This article presents the design, construction, and practical applications of a 1.2 kV, 2 Amp Van de Graaff (VDG) generator tailored for use in X-ray generation and medical/nuclear research. Emphasis is placed on the utilization of locally sourced materials, ensuring affordability, sustainability, and ease of replication in resource-limited settings. The VDG was first developed by Robert Jemison Van de Graaff in 1929, in the United States which was why it conveys his name till date. The generator operates using electrostatic principles to produce high-voltage direct current (DC) power. Applications discussed include diagnostic radiography, material excitation for spectroscopy, and particle acceleration. Challenges such as corona discharge, charge leakage, and dielectric breakdown are addressed, and mitigation strategies are outlined. Diagrams and circuit schematics are included to guide replication. The work underscores the potential for low-cost yet effective high-voltage research tools in developing countries. Though the DC current is extremely low, and dissipation of its voltages is very fast which makes it safe to operate with minimal risks. The design and construction looks simpler, its operating principle is cumbersome as electric charges are generated without frictional forces between the belt and the rollers.

Keywords:
Van de Graaff high voltage,
X-ray generation,
Medical research,
Nuclear physics,
Locally sourced materials,
Particle accelerator.

INTRODUCTION

The VDG generator, first conceptualized by Robert J. Van de Graaff in 1929, remains an effective means of generating extremely high voltages (Van de Graaff, 1931). While widely utilized in particle physics and material research, its adaptation for medical and nuclear research in low-resource settings has been limited due to cost and material constraints. This article addresses these limitations by detailing a scalable 1.2 kV, 2 Amp model using readily available materials (Gallagher, and Nagle, 1960, Khan, 2014, Ogundipe, 2020, Saxena, and Sharma, 2023).

High-voltage generation plays a critical role in a wide range of scientific, industrial, and medical applications, from particle acceleration and material analysis to diagnostic imaging and radiation therapy. Among the most reliable and accessible tools for generating high voltages is the VDG generator, an electrostatic device first developed by Robert J. Van de Graaff in 1929 (Van de Graaff, 1931). This generator has since evolved from a physics demonstration tool to a powerful high-voltage source capable of producing potentials in the kilovolt to megavolt range (Van de Graaff, 1933, Okeke, E. C. 2019).

The VDG generator shown in Figure 1, operates by mechanically transporting electric charge via a moving belt to a high-voltage terminal, where the charge accumulates. Unlike transformers or inverters, it uses no magnetic fields or electromagnetic induction, making it inherently stable and capable of delivering pure DC. This quality is especially advantageous for applications like X-ray generation, radiation dosimetry, and nuclear experimentation where DC is preferred or required (Paetz gen. Schieck and Paetz gen. Schieck, 2014, William, 2015, Cassiday, 2022, VDG MagLab, 2022)

In developing countries, high-voltage equipment is often prohibitively expensive and dependent on imported components. However, the VDG generator's simple construction and reliance on basic mechanical and electrostatic principles make it highly adaptable to local fabrication. With proper design, locally available materials such as aluminum domes, rubber belts, PVC tubes, and DC motors can be used to construct an efficient, low-cost generator (Takacs, 1996, Hinterberger, 2022, Wilson, 2022).

This article focuses on the design and fabrication of a 1.2 kV, 2 Amp VDG generator using mostly locally sourced materials. The goal is to provide a functional, replicable device suitable for use in low-resource laboratories engaged in X-ray imaging, radiation research, and nuclear diagnostics. The design prioritizes cost-effectiveness, accessibility, and safety, with an emphasis on modular construction to allow easy maintenance and component replacement.

The 1.2 kV output, while relatively modest compared to large-scale accelerators, is sufficient for low-energy X-ray generation and soft radiographic applications. At 2 Amps, the current capacity allows for reliable excitation of X-ray tubes and basic ion beam experiments. Additionally, this voltage level is well-suited for instructional use in educational environments, offering students a safe yet powerful means to study high-voltage phenomena and instrumentation.

The introduction of such equipment into educational and research institutions can bridge the technological gap, foster scientific innovation, and build local capacity in fields such as medical physics, nuclear science, and electrical engineering. It also provides an important step toward self-reliant technology development in regions that often rely on expensive and unsustainable foreign imports.

Overall, the VDG generator stands as a compelling example of how foundational scientific concepts can be leveraged to create sophisticated tools from simple, locally obtainable components. The subsequent sections of this article will explore the theory, materials, construction process, applications, and safety considerations involved in building and utilizing a VDG generator tailored to the specific needs of low-resource settings.

Figure 1: The complete VDG Accelerator built from locally sourced materials

Working Principle of the VDG Generator

The generator operates on the principle of electrostatic charge accumulation via a moving insulating belt. The belt transfers charge to a high-potential terminal where it accumulates. A corona discharge or brush system facilitates charge transfer at both ends of the belt. Once accumulated, this potential can be harnessed for various high-voltage applications (García-León, 2022).

Charge Transport Mechanism

i. Lower Comb**:** Connected to a voltage source, it ionizes the air around the belt, charging it.
ii. Upper Comb**:** Discharges the belt to the dome, which stores the charge.
iii. Collector Dome**:** Functions as a high-capacity capacitor, accumulating charge to desired potential.

MATERIALS AND METHODS

Design Specifications for the VDG Accelerator System

Table 1: System Parameters and Specifications for the construction of the VDG accelerator

Parameter	Specification
Output Voltage	1.2 kV
Output Current	2 A
Belt Speed	3–5 m/s
Belt Material	Rubber or PVC

Electrode Material	Aluminum / Steel mesh
Dome Diameter	30–45 cm
Base Voltage Supply	12–24 V DC Motor
Insulation	Acrylic Tube / Polycarbonate

Locally Sourced Materials

Conductive Components

i. Electrodes**:** Locally sourced stainless steel rods and mesh.
ii. Dome**:** Recycled aluminum pressure cooker lid.

Non-conductive Parts

i. Belt**:** High-dielectric rubber or industrial conveyor belt from local factories.
ii. Rollers**:** Plastic (PVC) tubing or repurposed bicycle wheel bearings.
iii. Base Frame**:** Welded steel or aluminum from local fabricators.

Motor and Drive

i. DC Motor (12–24 V): Salvaged from electric fans motor.
ii. Pulley System: Adapted from motorcycle chain sprockets.

Insulation and Support

i. Acrylic/Perspex: Locally cut from used advertising signs.
ii. Mounts and Base: Bakelite for minimal dielectric interference.

Construction Process

The schematic diagram of VDG accelerator showing the construction as shown in Figure 2 below

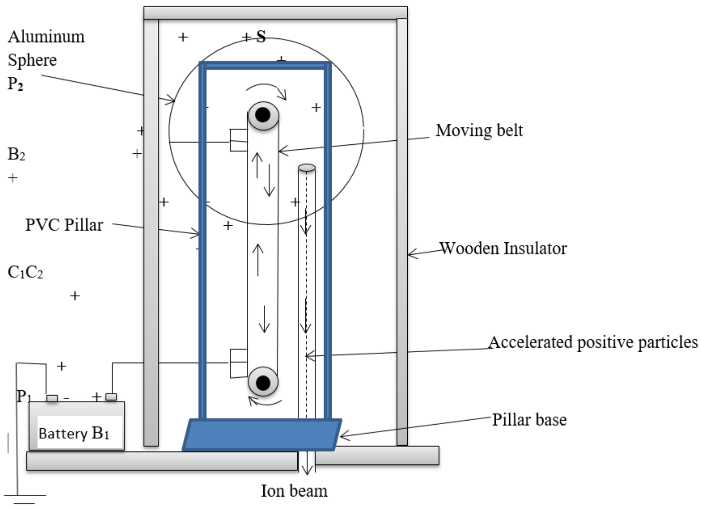

Figure 2: Schematic diagram of the VDG accelerator showing Cross-sectional Diagram Showing Charge Transfer

Mechanical Assembly

i. Frame Construction: Secure vertical supports for the roller system.
ii. Roller Integration: Install upper and lower rollers with belt tension control.
iii. Motor Attachment: Connect to lower roller with pulley and speed controller.
iv. Dome Installation: Ensure strong, smooth electrical contact with the upper brush.

Electrical System

i. Voltage Input: DC motor powered by 12 V battery.
ii. Comb Brushes: Thin copper wires or bristles from used brushes.
iii. Load Output: High-voltage output taken from dome with corona ring protection.

VDG accelerator Circuit Schematic

The VDG accelerator circuit schematic diagrams are as shown in the Figures 3, and 4 below.

Basic Generator Schematic

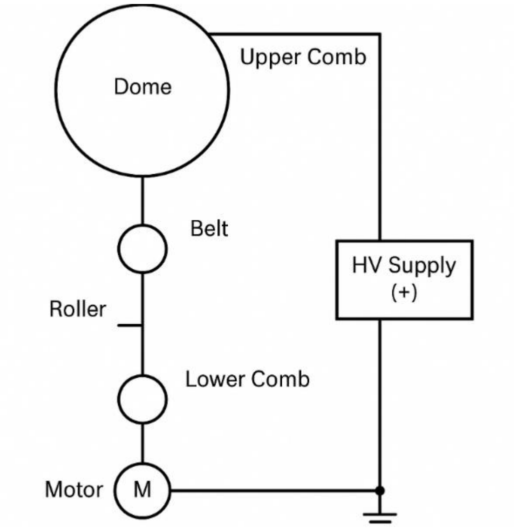

Figure 3: VDG accelerator Circuit Schematic Diagram

VDG Output Load Configuration

It is important to note that in this Design, e.g., Figure 4;

i. The **resistor (R1)** is critical to protect the generator and user.
ii. The **capacitor (C1)** is rated above the generator's maximum voltage (e.g., 1.5 kV for 1.2 kV output).
iii. Use **corona rings** or **Faraday cages** around HV areas to suppress corona discharge.
iv. For X-ray applications, it was ensured that the load impedance matches the characteristics of the tube.

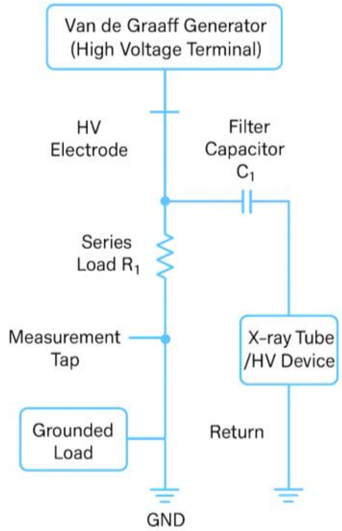

Figure 4: Schematic Diagram of the VDG Generator Output Load Configuration

The Schematic Diagram of VDG provides a clean schematic figure that showed:

i. The VDG dome outputting to:
 - An X-ray tube.
 - A capacitor bank.
ii. Proper ground paths.

Application in X-ray Generation

X-ray Tube Coupling

The 1.2 kV output is sufficient for soft X-ray generation using a cold cathode or vacuum diode tube. These tubes emit X-rays when high-energy electrons strike an anode (usually tungsten or molybdenum). The VDG is capable of being applied in the following medical usages:

Medical Imaging Potential

i. Dental Imaging: Limited depth penetration suitable for teeth and soft tissue.
ii. Bone Density Checks: With shielding and precision tuning.

Safety Considerations

i. Lead shielding mandatory.
ii. Distance >1 m during operation.
iii. Time exposure <10 seconds.

Nuclear and Research Applications

The VDG was designed and constructed to be used for the nuclear and research applications, e.g.

i. Particle Acceleration: Protons or deuterons can be accelerated for neutron generation.
ii. Material Testing: Induced X-ray fluorescence (XRF) and spectroscopy.
iii. Radiation Dosimetry: Calibration of Geiger counters and scintillation detectors.

Safety Protocols

i. Enclosure with acrylic shields.
ii. Ground fault detectors.
iii. Emergency kill switch.
iv. Use of Faraday cage for sensitive equipment.
v. Proper PPE for operators.

Performance Testing and Calibration

i. Voltage Measurement: Via electrostatic voltmeter or spark gap calibration.
ii. Current Limiting: Resistors and capacitors in series to avoid surge.
iii. Leakage Check: IR thermometer and digital multi-meter.
iv. Corona Discharge Control: Use of rounded corona rings and smooth surfaces.

Challenges and Solutions

Apart from the scarcity of funds, there are other challenges we faced in the cause of the construction which the table below explicitly explained together with the solutions.

Table 2: Some Challenges Faced and the Solutions

Challenge	Solution
Humidity and Charge Leakage	Use silica gel packs and plastic insulation
Corona Discharge Losses	Corona rings and smooth domes
Motor Heating	Aluminum heatsinks and ventilation slots
Belt Tracking Problems	Adjustable rollers and tension springs

Economic Consideration

The total cost of construction was well above ₦4,500,000:00 compared to the commercial priced above United States $5,000:00, equivalent of the Nigerian Naira of ₦7,693,153.60, using the prevalent exchange rate. The idea to use local materials could be supported for mass production that would bring relieved to the country's institutions of higher learning and the health sector.

CONCLUSION

This article demonstrates that a functioning 1.2 kV, 2 Amp VDG generator can be constructed using locally available materials at minimal cost. Such a generator is viable for controlled X-ray generation and basic nuclear physics experiments. With further optimization and shielding, it can support academic and diagnostic use in remote or resource-limited settings. The difficulty encountered in the construction is in the smoothening of the metal sphere because it improves the maximum charge generated. A well-polished surface gives high electrostatic induction. Secondly, the entire device was not contained in a steel chamber in which nitrogen or methane gas is kept at high pressure. A maximum induction and hence a high electric field is obtained in the presence of the gas at high pressure. A well-polished surface gives high electrostatic induction. The measured PD and the current could have been more than 1.2kV and 2 A respectively, if the metal sphere was polished and the steel containment with the gas were available. The belt is also an essential part of the generator which have to be improved. The VDG is capable of generating a very high PD and a high current that was used for X-ray generation and other purposes. The constructed prototype electrostatic VDG accelerator could be improved by investing more fund for a compressive design and construction. This will enable a complete, smooth and shiny conducting metallic sphere to be obtained. Improving on this construction will make the VDG accelerator be used for accelerating electrons to sterilize food and process materials, accelerating protons for Nuclear Physics Experiments, producing energetic X-ray beams in Nuclear Medicine, Physics Education and Entertainment.

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