Mid-Semester (UG) Examinations, 2018
Answer sheet

Subject Code-031736   **Subject: High Voltage Engineering**
Semester: 7th   **Department: EE**
Duration: 2 Hrs.   **Total marks: 20**

Instructions:
(i)   The marks are indicated in the right-hand margin.
(ii)   There are **Six** questions in this paper.
(iii)   Attempt **Four** questions in all.

Answer the following questions

1. With neat sketch explain the working principle of a Cockcroft-Walton Voltage Multiplier Circuit.

Answer:

Cascaded voltage multiplier circuits for higher voltages are cumbersome and require too many supply and isolating transformers. İt is possible to generate very high d.c. voltages from single supply transformers by extending the simple voltage dobler circuits. This is simple and compact when the load current requirement is less than one milliampere, such as for cathode ray tubes, etc. Valve type pulse generators may be used instead of conventional a.c. supply and the circuit becomes compact. A typical circuit of this form is shown in Fig. 1.
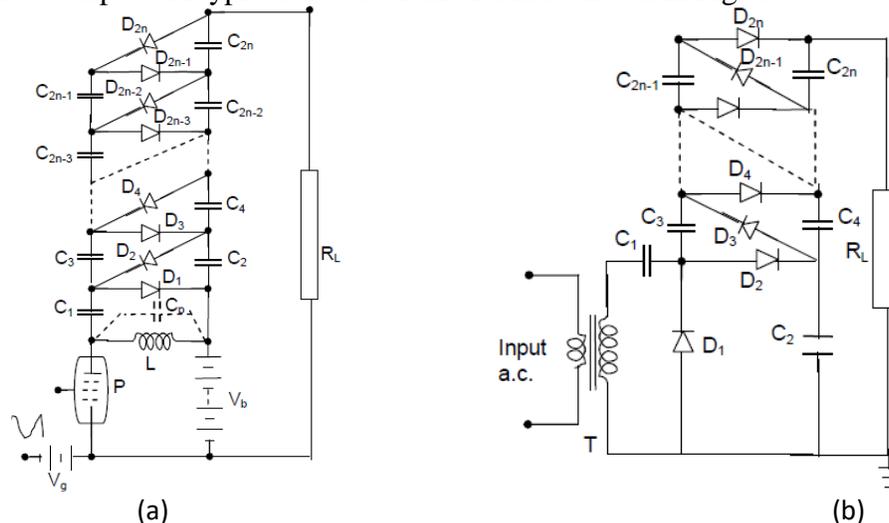

Figure: 1 (a) Cascade rectifier unit with pulse generator, (b) Cockcroft-Walton voltage multiplier circuit. P – Pulse generator, V_b – D.C. supply to pulse generator, V_g – Bias voltage

The pulses generated in the anode circuit of the valve P are rectified and the voltage is cascaded to give an output of $2nV_{max}$ across the load RL. A trigger voltage pulse of triangular waveform (ramp) is given to make the valve switched on and off. Thus, a voltage across the coil L is

produced and is equal to Vmax = Imax $(L/C_p)^{1/2}$, where C_p is the stray capacitance across the coil of inductance L. A d.c. power supply of about 500 V applied to the pulse generator, is sufficient to generate a high voltage d.c. of 50 to 100 kV with suitable number of stages. The pulse frequency is high (about 500 to 1000 Hz) and the ripple is quite low (<1%). The voltage drop on load is about 5% for load currents of about 150μA. The voltage drops rapidly at high load currents.

Voltage multiplier circuit using the Cockcroft-Walton principle is shown in Fig. 1b. The first stage, i.e. D1, D2, C1, C2, and the transformer T are identical, as in the voltage doubler shown in Fig. 4.3a. For higher output voltage of 4, 6, … 2n of the input voltage V, the circuit is repeated with cascade or series connection. Thus, the condenser C4 is charged to 4Vmax and C2n to 2nVmax above the earth potential. But voltage across and individual condenser or rectifier is only 2Vmax.

2. Explain with diagrams, different types of rectifier circuits for producing high DC voltages.
    Answer:

    Rectifier circuits for producing high d.c. voltages from a.c. sources may be
    (a) halfwave,
    (b) full wave, or
    (c) voltage doubler type rectifiers.

    The rectifier may be an electron tube or a solid state device. Nowadays single electron tubes are available for peak inverse voltages up to 250 kV, and semiconductor or solid state diodes up to 20 kV. For higher voltages, several units are to be used in series. When a number of units are used in series, transient voltage distribution along each unit becomes non-uniform and special care should be taken to make the distribution uniform. Commonly used half wave and full wave rectifiers are shown in Fig 1.
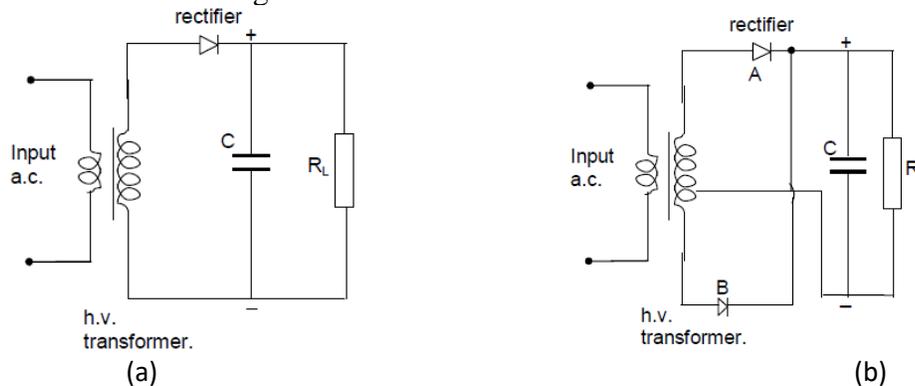

Figure 1: Half and Full Wave rectifier

In the half wave rectifier (Fig. 1a) the capacitor is charged to V_{max}, the maximum a.c. voltage of the secondary of the high voltage transformer in the conducting half cycle. In the other half cycle, the capacitor is discharged into the load. The value of the capacitor C is chosen such that the time constant CRL is at least 10 times that of the period of the a.c. supply. The rectifier valve must have a peak inverse rating of at least 2Vmax. To limit the charging current, an additional resistance R is provided in series with the secondary of the transformer.

A full wave rectifier circuit is shown in Fig. 1b. In the positive half cycle, the rectifier A conducts and charges the capacitors Vmax, while in the negative half cycle the rectifier B conducts and charges the capacitor. The source transformer requires a centre tapped secondary with a rating of 2 V.

For application at high voltages of 50 kV and above, the rectifier valves used are of special construction. Apart from the filament, the cathode and the anode, they contain a protective shield or grid around the filament and the cathode. The anode will be usually a circular plate. Since the electrostatic field gradient are quiet large, the heater and the cathode experience large electrostatic forces during the non-conduction periods. To protect the various elements from these forces, the anode is firmly fixed to the valve cover on one side. On the other side, where the cathode and filament are located, a steel mesh structure or a projective grid kept at the cathode potential surrounds them so that the mechanical forces between the anode and the cathode are reflected on the grid structure only.

Both full wave and half wave rectifiers produce d.c. voltages less than the a.c. maximum voltage. Also, ripple or the voltage fluctuation will be present, and this has to be kept within a resonable limit by means of filters.

3. An impulse generator has eight stages with each condenser rated for 0.16µF and 125kV. The load capacitor available is 1000pF. Find the series resistance and the damping resistance needed to produce 1.2/50 µs impulse wave. What is the maximum output voltage of the generator, if the charging voltages is 120 kV?

Answer:

C_1, the generator capacitance $= \dfrac{0.16}{8}$ 0.02 μF

C_2, the load capacitance $= 0.001$ μF

t_1, the time to front $= 1.2$ μs

$$= 3.0\, R_1 \frac{C_1 C_2}{C_1 + C_2}$$

$\therefore$

$$R_1 = 1.2 \times 10^{-6} \frac{C_1 + C_2}{C_1 C_2} \times \frac{1}{3}$$

$$= 1.2 \times 10^{-6} \frac{0.021 \times 10^{-6}}{0.02 \times 0.001 \times 10^{-12}} \times \frac{1}{3} = 420\ \Omega$$

t_2, time to tail $= 0.7\,(R_1 + R_2)\,(C_1 + C_2)$
$$= 50 \times 10^{-6}$$

or $\quad 0.7\,(420 + R_2)\,(0.021 \times 10^{-6}) = 50 \times 10^{-6}$

or $\qquad\qquad R_2 = 2981\ \Omega$

The dc charging voltage for eight stages is
$$V = 8 \times 120 = 960\ \text{kV}$$

The maximum output voltage is

$$\frac{V}{R_1 C_2 (\alpha - \beta)}\,(e^{-\alpha_1} - e^{-\beta_1})$$

where $\alpha = \dfrac{1}{R_1 C_2}$, $\beta = \dfrac{1}{R_2 C_1}$ and V is the dc charging voltage.

Substituting for R_1, C_1 and R_2, C_2,

$$\alpha = 0.7936 \times 10^{+6}$$
$$\beta = 0.02335 \times 10^{+6}$$

$\therefore \qquad$ maximum output voltage $= 932.6$ kV.

4. What is the principle of operation of a resonant transformer? How is it advantageous over the cascade connected transformers?

Answer:

The equivalent circuit of a high voltage testing transformer consist of the leakage reactances of the windings, the windings resistances, the magnetizing reactance, and the shunt capacitance across the output terminal due to the bushing of the high voltage terminal and also that of the test object. This is shown in Fig. 1.
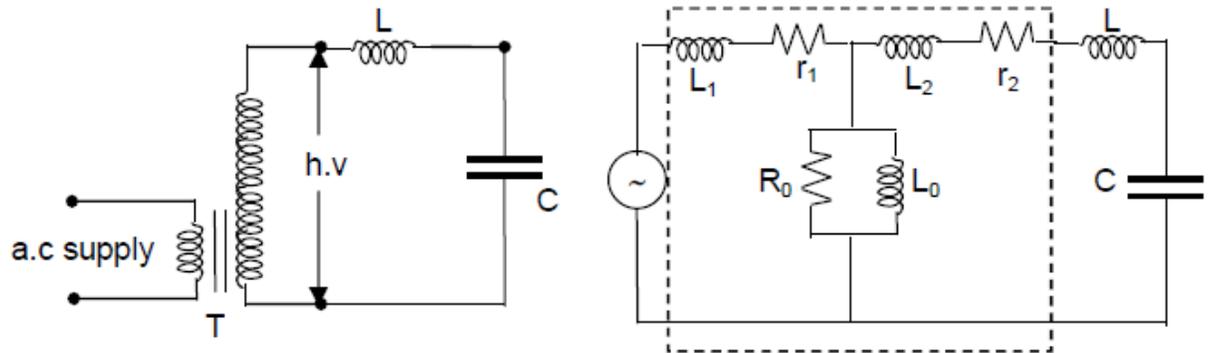

Figure 1: Resonant transformer and equivalent circuit. T – Testing transformer; L – choke; C – Capacitance of a h.v. terminal and test object; L_0 – Magnetizing inductance; L_1, L_2 – Leakage inductance of the transformer; r_1, r_2 – resistance of the windings; R_0 – Resistance due to core loss

It may be seen that it is possible to have series resonance at power frequency ω, $(L_1 + L_2) = 1/\omega C$. With this condition, the current in the tests object is very large and is limited only by the resistance of the circuit. The waveform of the voltage across the test object will be purely sinusoidal. The magnitude of the voltage across the capacitance C of the test object will be

$$V_c = \left| \frac{-jVX_c}{R + j(X_L - X_c)} \right| = \frac{V}{R} X_c = \frac{V}{\omega c R}$$

where R is the total series resistances of the circuit.

The factor $_c X /R$ is the Q factor of the circuit and gives the magnitude of the voltage multiplication across the test object under resonance conditions. Therefore, the input voltage required for excitation is reduced by a factor 1/Q, and the output kVA required is also reduced by a factor 1/Q. the secondary power factor of the circuit is unity. This principle is utilized in testing at very high voltage and on occasions requiring large current outputs such as cable testing, dielectric loss measurements, partial discharge measurements, etc. a transformer with 50 to 100 kV voltage rating and a relatively large current rating is connected together with an additional choke, if necessary. The test condition is set such that $\omega(L_e+L)=1/\omega c$ where L_e is the total equivalent leakage inductance of the transformer including its regulating transformer.

The chief advantages of this principle are:
a) it gives an output of pure sine wave,
b) power requirements are less (5 to 10% of total kVA required),
c) no high-power arcing and heavy current surges occur if the test object failed, as resonance ceases at the failure of the test object,
d) cascading is also possible for very high voltage,
e) simple and compact test arrangement, and
f) no repeated flashovers occur in case of partial failures of the test object and insulation

recovery. It can be shown that the supply source takes Q number of cycles at least to charge the test specimen to the full voltage.

The disadvantages are the requirements of additional variable chokes capable of withstanding the full test voltage and the full current rating.

5. Give the Marx circuit arrangement for multistage impulse generator.

Answer:

The schematic diagram of Marx circuit and its modification are shown in Figs 1 and 2, respectively. Usually the charging resistance Rs is chosen to limit the charging current to about 50 to 100 mA, and the generator capacitance C is chosen such that the product CRs is about 10 s to 1 min. The gap spacing is chosen such that the breakdown voltage of the gap G is greater than the charging voltage V. Thus, all the capacitances are charged to the voltage V in about 1 minute. When the impulse generator is to be discharged, the gaps G are made to spark over simultaneously by some external means. Thus, all the capacitors C get connected in series and discharge into the load capacitance or the test object. The discharge time constant CR_1/n (for n stages) will be very very small (microseconds), compared to the charging time constant CRs which will be few seconds. Hence, no discharge takes place through the charging resistors Rs. In the Marx circuit is of Fig. 1 the impulse wave-shaping circuit is connected externally to the capacitor unit. In Fig. 2, the modified Marx circuit is shown, wherein the resistances R_1 and R_2 are incorporated inside the unit. R_1 is divided into n parts equal to R_1/n and put in series with the gap G. R_2 is also divided into n parts and arranged across each capacitor unit after the gap G. This arrangement saves space, and also the cost is reduced. But, in case the waveshape is to be varied widely, the variation becomes difficult. The additional advantages gained by distributing R_1 and R_2 inside the unit are that the control resistors are smaller in size and the efficiency (V_0/nV) is high.
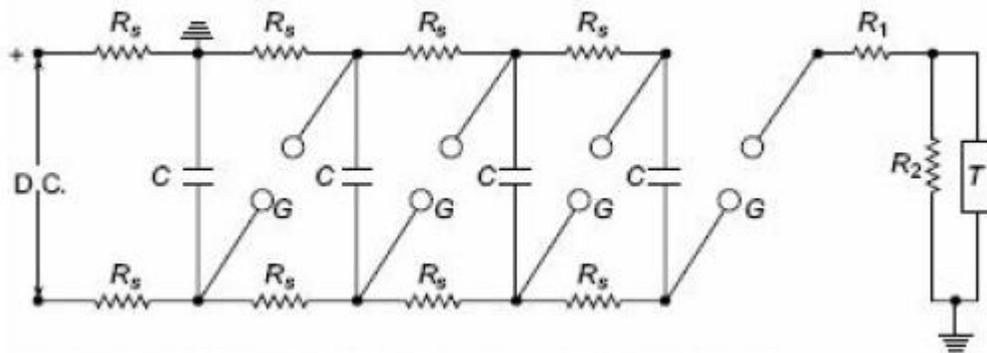

Figure 1: Schematic diagram of Marx circuit arrangement for multistage impulse generator
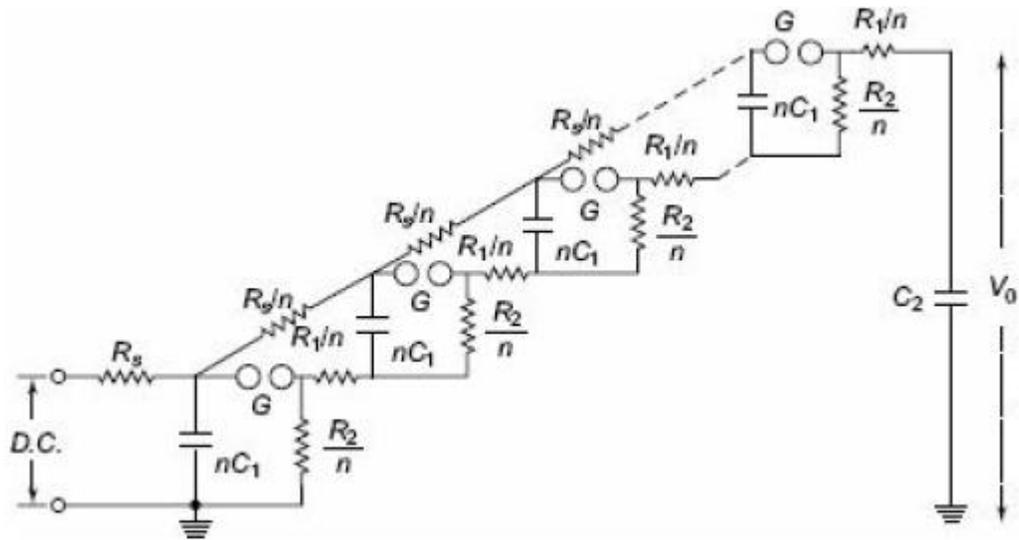
Figure 2: Multistage impulse generator incorporating the series and wave tail resistances with in the generator

Impulse generators are nominally rated by the total voltage (nominal), the number of stages, and the gross energy stored. The nominal output voltage is the number of stages multiplied by the charging voltage. The nominal energy stored is given by $C_1 V^2$ where $C1 = C/n$ (the discharge capacitance) and V is the nominal maximum voltage (n times charging voltage). A 16-stage impulse generator having a stage capacitance of 0.280μF and a maximum charging voltage of 300 kV will have an energy rating of 192 kWs. The height of the generator will be about 15 m and will occupy a floor area of about 3.25 × 3.00 m. The waveform of either polarity can be obtained by suitably changing the charging unit polarity.

6   Describe, with a neat sketch, the working of a Van de Graff generator.
Answer:

Working of the generator is based on two principles:
(a)Discharging action of sharp points, ie., electric discharge takes place in air or gases readily, at pointed conductors.
(b)If the charged conductor is brought in to internal contact with a hollow conductor, all of its charge transfers to the surface of the hollow conductor no matter how high the potential of the latter may be.
The generator is usually enclosed in an earthed metallic cylindrical vessel and is operated under pressure or in vacuum. Charge is sprayed onto an insulating moving belt from corona points at a potential of 10 to 100 kV above earth and is removed and collected from the belt connected to the inside of an insulated metal electrode through which the belt moves. The belt is driven by an electric motor at a speed of 1000 to 2000 metres per minute. The potential of the high voltage electrode above the earth at any instant is V = Q/C, where Q is the charge stored and C is the capacitance of the highvoltage electrode to earth. The potential of the high-voltage electrode rises at a rate

$$\frac{dV}{dt} = \frac{1}{C}\frac{dQ}{dt} = \frac{I}{C} \quad \text{where I is the net charging current.}$$

High-voltage terminal

Upper spray point

Upper pulley insulated from the terminal

Collector

Earthed enclosure

Insulated belt
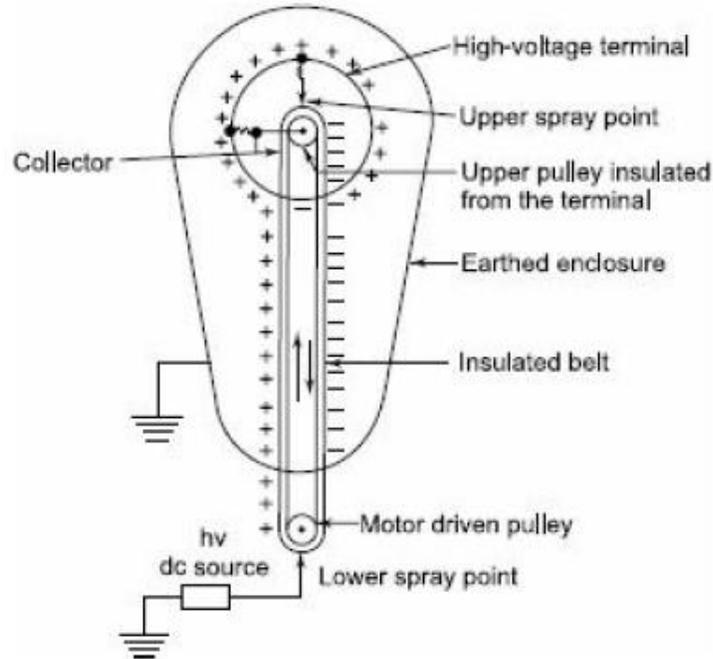
Motor driven pulley

hv
dc source

Lower spray point

Figure: Van de Graff generator

A steady potential will be attained by the high-voltage electrode when the leakage currents and the load current are equal to the charging current. The shape of the high-voltage electrode is so made with re-entrant edges as to avoid high surface field gradients, corona and other local discharges. The shape of the electrode is nearly spherical.

The charging of the belt is done by the lower spray points which are sharp needles and connected to a dc source of about 10 to 100 kV, so that the corona is maintained between the moving belt and the needles. The charge from the corona points is collected by the collecting needles from the belt and is transferred on to the high-voltage electrode as the belt enters into the high-voltage electrode. The belt returns with the charge dropped, and fresh charge is sprayed onto it as it passes through the lower corona point. Usually, in order to make the charging more effective and to utilize the return path of the belt for charging purposes, a self-inducing arrangement or a second corona-point system excited by a rectifier inside the high-voltage terminal is employed. To obtain a self-charging system, the upper pulley is connected to the collector needle and is therefore maintained at a potential higher than that of the high-voltage terminal. Thus, a second row of corona points connected to the inside of the highvoltage terminal and directed towards the pulley above its point of entry into the terminal gives a corona discharge to the belt. This neutralizes any charge on the belt and leaves an excess of opposite polarity to the terminal to travel down with the belt to the bottom charging point. Thus, for a given belt speed the rate of charging is doubled.

The charging current for unit surface area of the belt is given by $I = bv\,\delta$, where b is the breadth of the belt in metres, v is the velocity of the belt in m/sec, and δ is the surface charge density in coulombs/m2. It is found that δ is $\leq 1.4 \times 10{-5}$ C/m2 to have a safe electric field intensity normal to the surface. With b = 3 m and v = 3 m/s, the charging current will be approximately 125 µA. The generator is normally worked in a high-pressure gaseous medium, the pressure ranging from 5 to 15 atm. The gas may be nitrogen, air, air-freon (CCl_2F_2) mixture, or sulphur hexafluoride (SF_6).

Van de Graaff generators are useful for very high-voltage and low-current applications. The output voltage is easily controlled by controlling the corona source voltage and the rate of charging. The voltage can be stabilized to 0.01%. These are extremely flexible and precise machines for voltage control.