Example 6.1: A Cockcroft-Walton type voltage multiplier has eight stages with capacitances, all equal to 0.05 μF. The supply transformer secondary voltage is 125 kV at a frequency of 150 Hz. If the load current to be supplied is 5 mA, find (*a*) the percentage ripple, (*b*) the regulation, and (*c*) the optimum number of stages for minimum regulation or voltage drop.

Solution: (*a*) *Calculation of Percentage Ripple*

$$\text{The ripple voltage } \delta V = \frac{I}{fC}\frac{(n)(n+1)}{2}$$

$$I = 5 \text{ mA}, f = 150 \text{ Hz}, C = 0.05\ \mu\text{F}, \text{ and } n = 8,$$

$$\therefore \quad \delta V = \frac{5\times 10^{-3}}{150\times 0.05\times 10^{-6}}\times\frac{8\times 9}{2}$$

$$= 24 \text{ kV}$$

$$\%\text{ ripple} = \frac{\delta V\times 100}{2nV_{max}} = \frac{24\times 100}{2\times 125\times 8}$$

$$= 1.2\%$$

(*b*) *Calculation of Regulation*

$$\text{Voltage drop, } \Delta V = \frac{I}{fC}\left(\frac{2}{3}n^3 + \frac{n^2}{2} - \frac{n}{6}\right)$$

$$= \frac{5\times 10^{-3}}{150\times 0.05\times 10^{-6}}\left[\left(\frac{2}{3}\times 8^3\right)+\left(\frac{1}{2}\times 8^2\right)-\frac{8}{6}\right]$$

$$= 248 \text{ kV}$$

$$\therefore \quad \text{regulation}\left(\frac{V}{2nV_{max}}\right) = \frac{248}{2\times 8\times 125} = \frac{124}{1000}$$

$$= 12.4\%$$

(*c*) *Calculation of Optimum Number of Stages* ($n_{optimum}$)

Since $n > 5$,

$$n_{optimum} = \sqrt{V_{max} fC/I}$$

$$= \sqrt{\frac{125\times 150\times 0.05\times 10^{-6}\times 10^{+3}}{5\times 10^{-3}}}$$

$$= \sqrt{125\times 1.5}$$

$$= 13.69$$

$$= 14 \text{ stages}$$

Example 6.2: A 100 kVA, 400 V/250 kV testing transformer has 8% leakage reactance and 2% resistance on 100 kVA base. A cable has to be tested at 500 kV using the above transformer as a resonant transformer at 50 Hz. If the charging current of the cable at 500 kV is 0.4 A, find the series inductance required. Assume 2% resistance for the inductor to be used and the connecting leads. Neglect dielectric loss of the cable. What will be the input voltage to the transformer ?

Solution : The maximum current that can be supplied by the testing transformer is

$$\frac{100\times 10^3}{250\times 10^3} 0.4 \text{ A}$$

$X_C =$ Reactance of the cable is

$$\frac{V_C}{I} = \frac{500\times 10^3}{0.4} = 1250 \text{ k}\Omega$$

$X_L =$ Leakage reactance of the transformer is

$$\frac{\%X}{100}\times\frac{V}{I} = \frac{8}{100}\times\frac{250\times 10^3}{0.4} = 50 \text{ k}\Omega$$

At resonance, $X_C = X_L$.

Hence, additional reactance needed

$$= 1250 - 50 = 1200 \text{ k}\Omega$$

Inductance of additional reactance (at 50 Hz frequency)

$$\frac{1200\times 10^3}{2\pi\times 50} = 3820 \text{ H}$$

$R =$ Total resistance in the circuit on 100 kVA base is 2% + 2% = 4%.

Hence, the ohmic value of the resistance

$$= \frac{4}{100}\times\frac{250\times 10^3}{0.4} = 25 \text{ k}\Omega$$

Therefore, the excitation voltage E_2 on the secondary of the transformer

$$= I\times R$$

$$= 0.4\times 25\times 10^3$$

$$= 10\times 10^3 \text{ V or } 10 \text{ kV}$$

The primary voltage or the supply voltage, E_1

$$= \frac{10\times 10^3\times 400}{250\times 10^3}$$

$$= 16 \text{ V}$$

$$\text{Input kW} = \frac{16}{400}\times 100 = 4.0 \text{ kW}$$

Example 6.3: An impulse generator has eight stages with each condenser rated for 0.16 μF and 125 kV. The load capacitor available is 1000 pF. 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 voltage is 120 kV ?

Solution : Assume the equivalent circuit of the impulse generator to be as shown in Fig. 6.15b.

$$C_1\text{, the generator capacitance} = \frac{0.16}{8} = 0.02\ \mu\text{F}$$

$$C_2\text{, the load capacitance} = 0.001\ \mu\text{F}$$

$$t_1\text{, the time to front} = 1.2\ \mu\text{s}$$

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

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

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

$$= 420\ \Omega$$

$$t_2\text{, time to tail} = 0.7(R_1 + R_2)(C_1 + C_2)$$

$$= 50 \times 10^{-6}\ \text{s}$$

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

or, $\quad R_2 = 2981\ \Omega$

The d.c. charging voltage for eight stages is

$$V = 8 \times 120 = 960\ \text{kV}$$

The maximum output voltage is

$$\frac{V}{R_1 C_2 (\alpha - \beta)} (e^{-\alpha t_1} - e^{-\beta t_1})$$

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

Substituting for R_1, C_1 and R_2, C_2,

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

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

$\therefore$ maximum output voltage = 932.6 kV.

Example 6.6: A 12-stage impulse generator has 0.126 μF condensers. The wave front and the wave tail resistances connected are 800 ohms and 5000 ohms respectively. If the load condenser is 1000 pF, find the front and tail times of the impulse wave produced.

Solution: The generator capacitance $C_1 = \frac{0.126}{12} = 0.0105\ \mu F$

The load capacitance $C_2 = 0.001\ \mu F$

Resistances, $R_1 = 800$ ohms and $R_2 = 5000$ ohms

$$\therefore \quad \text{time to front, } t_1 = 3(R_1)\left(\frac{C_1 C_2}{C_1 + C_2}\right)$$

$$= 3 \times 800 \times \frac{(0.0105 \times 10^{-6} \times 0.001 \times 10^{-6})}{(0.0105 + 0.001) \times 10^{-6}}$$

$$= 2.19\ \mu s$$

$$\text{time to tail, } t_2 = 0.7(R_1 + R_2)(C_1 + C_2)$$

$$= 0.7(800 + 5000) \times (0.0105 + 0.001) \times 10^{-6}$$

$$= 46.7\ \mu s$$