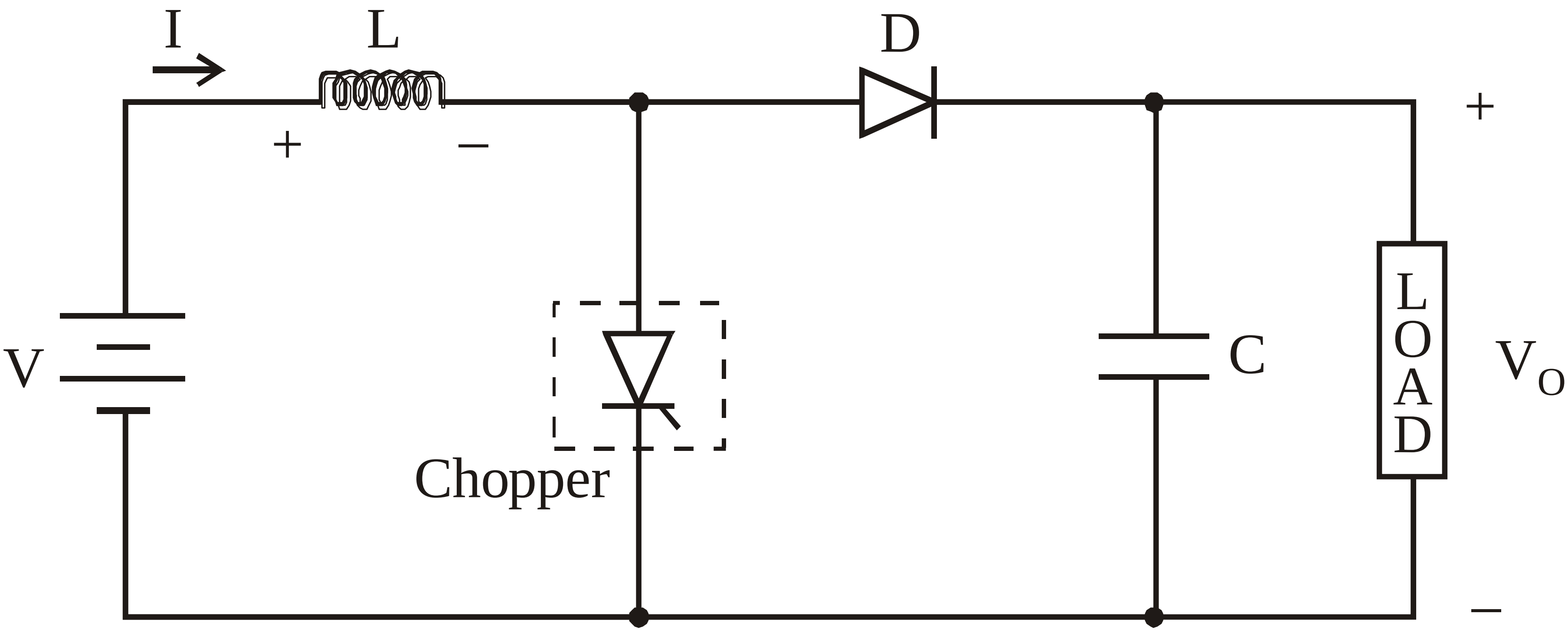
Principle Of Step-up Chopper



- Step-up chopper is used to obtain a load voltage higher than the input voltage *V*.
- The values of *L* and *C* are chosen depending upon the requirement of output voltage and current.
- When the chopper is *ON,* the inductor *L* is connected across the supply.
- The inductor current *'I'* rises and the inductor stores energy during the *ON* time of the chopper, t_{ON}.

- When the chopper is off, the inductor current *I* is forced to flow through the diode *D* and load for a period, t_{OFF}.
- The current tends to decrease resulting in reversing the polarity of induced EMF in *L*.
- Therefore voltage across load is given by

$$V_O = V + L\frac{dI}{dt} \quad i.e., \quad V_O > V$$

- A large capacitor ‘C’ connected across the load, will provide a continuous output voltage .
- Diode *D* prevents any current flow from capacitor to the source.
- Step up choppers are used for regenerative braking of dc motors.

Expression For Output Voltage

Assume the average inductor current to be I during ON and OFF time of Chopper.

When Chopper is ON

Voltage across inductor $L = V$

Therefore energy stored in inductor

$$= V.I.t_{ON}$$

Where $t_{ON} = ON$ period of chopper.

When Chopper is OFF

(energy is supplied by inductor to load)

Voltage across $L = V_O - V$

Energy supplied by inductor $L = (V_O - V) I t_{OFF}$

where $t_{OFF} = OFF$ period of Chopper.

Neglecting losses, energy stored in inductor

L = energy supplied by inductor L

$$\therefore \quad VIt_{ON} = \left(V_O - V\right) It_{OFF}$$

$$V_O = \frac{V\left[t_{ON} + t_{OFF}\right]}{t_{OFF}}$$

$$V_O = V\left(\frac{T}{T - t_{ON}}\right)$$

Where

T = Chopping period or period

of switching.

$$T = t_{ON} + t_{OFF}$$

$$V_O = V\left(\frac{1}{1-\frac{t_{ON}}{T}}\right)$$

$$\therefore \qquad V_O = V\left(\frac{1}{1-d}\right)$$

$$\text{Where } d = \frac{t_{ON}}{T} = \text{ duty cyle}$$

For variation of duty cycle $'d'$ in the range of $0 < d < 1$ the output voltage V_O will vary in the range $V < V_O < \infty$

Performance Parameters

- The thyristor requires a certain minimum time to turn *ON* and turn *OFF*.
- Duty cycle *d* can be varied only between a min. & max. value, limiting the min. and max. value of the output voltage.
- Ripple in the load current depends inversely on the chopping frequency, *f*.
- To reduce the load ripple current, frequency should be as high as possible.

Problem

- *A Chopper circuit is operating on TRC at a frequency of 2 kHz on a 460 V supply. If the load voltage is 350 volts, calculate the conduction period of the thyristor in each cycle.*

$V = 460$ V, $V_{dc} = 350$ V, f = 2 kHz

Chopping period $$T = \frac{1}{f}$$

$$T = \frac{1}{2 \times 10^{-3}} = 0.5\ m\sec$$

Output voltage $$V_{dc} = \left(\frac{t_{ON}}{T} \right) V$$

Conduction period of thyristor

$$t_{ON} = \frac{T \times V_{dc}}{V}$$

$$t_{ON} = \frac{0.5 \times 10^{-3} \times 350}{460}$$

$$t_{ON} = 0.38 \text{ msec}$$

Problem

- *Input to the step up chopper is 200 V. The output required is 600 V. If the conducting time of thyristor is 200 μsec. Compute*
  - *Chopping frequency,*
  - *If the pulse width is halved for constant frequency of operation, find the new output voltage.*

$$V = 200\ V, \quad t_{ON} = 200\mu s, \quad V_{dc} = 600V$$

$$V_{dc} = V\left(\frac{T}{T - t_{ON}}\right)$$

$$600 = 200\left(\frac{T}{T - 200\times10^{-6}}\right)$$

Solving for T

$$T = 300\mu s$$

Chopping frequency

$$f = \frac{1}{T}$$

$$f = \frac{1}{300 \times 10^{-6}} = 3.33 KHz$$

Pulse width is halved

$$\therefore \qquad t_{ON} = \frac{200 \times 10^{-6}}{2} = 100 \mu s$$

Frequency is constant

$$\therefore \qquad f = 3.33KHz$$

$$T = \frac{1}{f} = 300\mu s$$

$$\therefore \text{Output voltage} = V\left(\frac{T}{T - t_{ON}}\right)$$

$$= 200\left(\frac{300 \times 10^{-6}}{(300 - 100)10^{-6}}\right) = 300 \text{ Volts}$$

Problem

- *A dc chopper has a resistive load of 20Ω and input voltage V_S = 220V. When chopper is ON, its voltage drop is 1.5 volts and chopping frequency is 10 kHz. If the duty cycle is 80%, determine the average output voltage and the chopper on time.*

$$V_S = 220V,\ R = 20\Omega,\quad f = 10\ kHz$$

$$d = \frac{t_{ON}}{T} = 0.80$$

V_{ch} = Voltage drop across chopper = 1.5 volts

Average output voltage

$$V_{dc} = \left(\frac{t_{ON}}{T}\right)\left(V_S - V_{ch}\right)$$

$$V_{dc} = 0.80\left(220 - 1.5\right) = 174.8 \text{ Volts}$$

Chopper ON time, $t_{ON} = dT$

Chopping period, $T = \dfrac{1}{f}$

$$T = \frac{1}{10 \times 10^{3}} = 0.1 \times 10^{-3} \text{ secs} = 100 \ \mu\text{secs}$$

Chopper ON time,

$$t_{ON} = dT$$

$$t_{ON} = 0.80 \times 0.1 \times 10^{-3}$$

$$t_{ON} = 0.08 \times 10^{-3} = 80 \ \mu\text{secs}$$

Problem

- *In a dc chopper, the average load current is 30 Amps, chopping frequency is 250 Hz, supply voltage is 110 volts. Calculate the ON and OFF periods of the chopper if the load resistance is 2 ohms.*

$$I_{dc} = 30\ Amps,\quad f = 250\ Hz,\quad V = 110\ V,\quad R = 2\Omega$$

Chopping period, $T = \dfrac{1}{f} = \dfrac{1}{250} = 4 \times 10^{-3} = 4 \text{ msecs}$

$$I_{dc} = \frac{V_{dc}}{R}\ \&\ V_{dc} = dV$$

$$\therefore \qquad I_{dc} = \frac{dV}{R}$$

$$d = \frac{I_{dc}R}{V} = \frac{30 \times 2}{110} = 0.545$$

Chopper ON period,

$$t_{ON} = dT = 0.545 \times 4 \times 10^{-3} = 2.18 \text{ msecs}$$

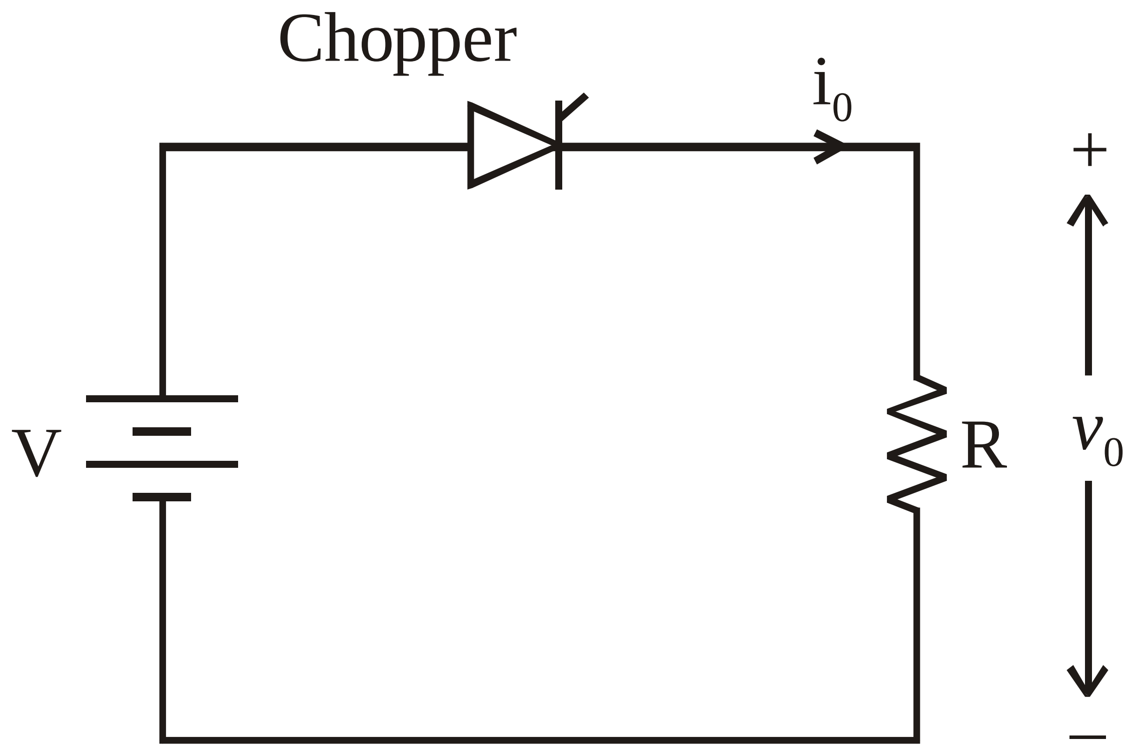
Chopper OFF period,

$$t_{OFF} = T - t_{ON}$$

$$t_{OFF} = 4 \times 10^{-3} - 2.18 \times 10^{-3}$$

$$t_{OFF} = 1.82 \times 10^{-3} = 1.82 \text{ msec}$$

- *A dc chopper in figure has a resistive load of R = 10Ω and input voltage of V = 200 V. When chopper is ON, its voltage drop is 2 V and the chopping frequency is 1 kHz. If the duty cycle is 60%, determine*
  - *Average output voltage*
  - *RMS value of output voltage*
  - *Effective input resistance of chopper*
  - *Chopper efficiency.*



$$V = 200\ V,\ R = 10\Omega,\ Chopper\ voltage\ drop\ V_{ch} = 2V$$

$$d = 0.60,\ f = 1\,kHz.$$

Average output voltage

$$V_{dc} = d\left(V - V_{ch}\right)$$

$$V_{dc} = 0.60\left[200 - 2\right] = 118.8 \text{ Volts}$$

RMS value of output voltage

$$V_O = \sqrt{d}\left(V - V_{ch}\right)$$

$$V_O = \sqrt{0.6}\left(200 - 2\right) = 153.37 \text{ Volts}$$

Effective input resistance of chopper is

$$R_i = \frac{V}{I_S} = \frac{V}{I_{dc}}$$

$$I_{dc} = \frac{V_{dc}}{R} = \frac{118.8}{10} = 11.88 \text{ Amps}$$

$$R_i = \frac{V}{I_S} = \frac{V}{I_{dc}} = \frac{200}{11.88} = 16.83\Omega$$

Output power is

$$P_O = \frac{1}{T}\int_0^{dT} \frac{v_0^2}{R} dt = \frac{1}{T}\int_0^{dT} \frac{\left(V - V_{ch}\right)^2}{R} dt$$

$$P_O = \frac{d\left(V - V_{ch}\right)^2}{R}$$

$$P_O = \frac{0.6\left[200 - 2\right]^2}{10} = 2352.24 \text{ watts}$$

Input power,

$$P_i = \frac{1}{T}\int_0^{dT} V i_O \, dt$$

$$P_O = \frac{1}{T}\int_0^{dT} \frac{V\left(V - V_{ch}\right)}{R} dt$$

$$P_O = \frac{dV\left(V - V_{ch}\right)}{R}$$

$$P_O = \frac{0.6 \times 200\left[200 - 2\right]}{10} = 2376 \text{ watts}$$

Chopper efficiency,

$$\eta = \frac{P_O}{P_i} \times 100$$

$$\eta = \frac{2352.24}{2376} \times 100 = 99\%$$

Problem

- *A chopper is supplying an inductive load with a free-wheeling diode. The load inductance is 5 H and resistance is 10Ω.. The input voltage to the chopper is 200 volts and the chopper is operating at a frequency of 1000 Hz. If the ON/OFF time ratio is 2:3. Calculate*
  - *Maximum and minimum values of load current in one cycle of chopper operation.*
  - *Average load current*

$$L = 5\ H, \quad R = 10\Omega, \quad f = 1000\ Hz,$$

$$V = 200\ V, \quad t_{ON} : t_{OFF} = 2:3$$

Chopping period,

$$T = \frac{1}{f} = \frac{1}{1000} = 1\ \text{msecs}$$

$$\frac{t_{ON}}{t_{OFF}} = \frac{2}{3}$$

$$t_{ON} = \frac{2}{3} t_{OFF}$$

$$T = t_{ON} + t_{OFF}$$

$$T = \frac{2}{3} t_{OFF} + t_{OFF}$$

$$T = \frac{5}{3} t_{OFF}$$

$$t_{OFF} = \frac{3}{5} T$$

$$T = \frac{3}{5} \times 1 \times 10^{-3} = 0.6 \text{ msec}$$

$$t_{ON} = T - t_{OFF}$$

$$t_{ON} = \left(1 - 0.6\right) \times 10^{-3} = 0.4 \text{ msec}$$

Duty cycle,

$$d = \frac{t_{ON}}{T} = \frac{0.4 \times 10^{-3}}{1 \times 10^{-3}} = 0.4$$

Maximum value of load current is given by

$$I_{\max} = \frac{V}{R}\left[\frac{1 - e^{-\frac{dRT}{L}}}{1 - e^{-\frac{RT}{L}}}\right] - \frac{E}{R}$$

Since there is no voltage source in the load circuit, E = 0

$$\therefore \qquad I_{\max} = \frac{V}{R}\left[\frac{1-e^{-\frac{dRT}{L}}}{1-e^{-\frac{RT}{L}}}\right]$$

$$I_{\max} = \frac{200}{10}\left[\frac{1-e^{-\frac{0.4\times10\times1\times10^{-3}}{5}}}{1-e^{-\frac{10\times1\times10^{-3}}{5}}}\right]$$

$$I_{\max} = 20\left[\frac{1-e^{-0.8\times10^{-3}}}{1-e^{-2\times10^{-3}}}\right]$$

$$I_{\max} = 8.0047\,\text{A}$$

Minimum value of load current with E = 0 is given by

$$I_{\min} = \frac{V}{R}\left[\frac{e^{\frac{dRT}{L}}-1}{e^{\frac{RT}{L}}-1}\right]$$

$$I_{min} = \frac{200}{10}\left[\frac{e^{\frac{0.4\times10\times1\times10^{-3}}{5}}-1}{e^{\frac{10\times1\times10^{-3}}{5}}-1}\right] = 7.995\ \text{A}$$

Average load current

$$I_{dc} = \frac{I_{max}+I_{min}}{2}$$

$$I_{dc} = \frac{8.0047+7.995}{2} \approx 8\ \text{A}$$

Problem

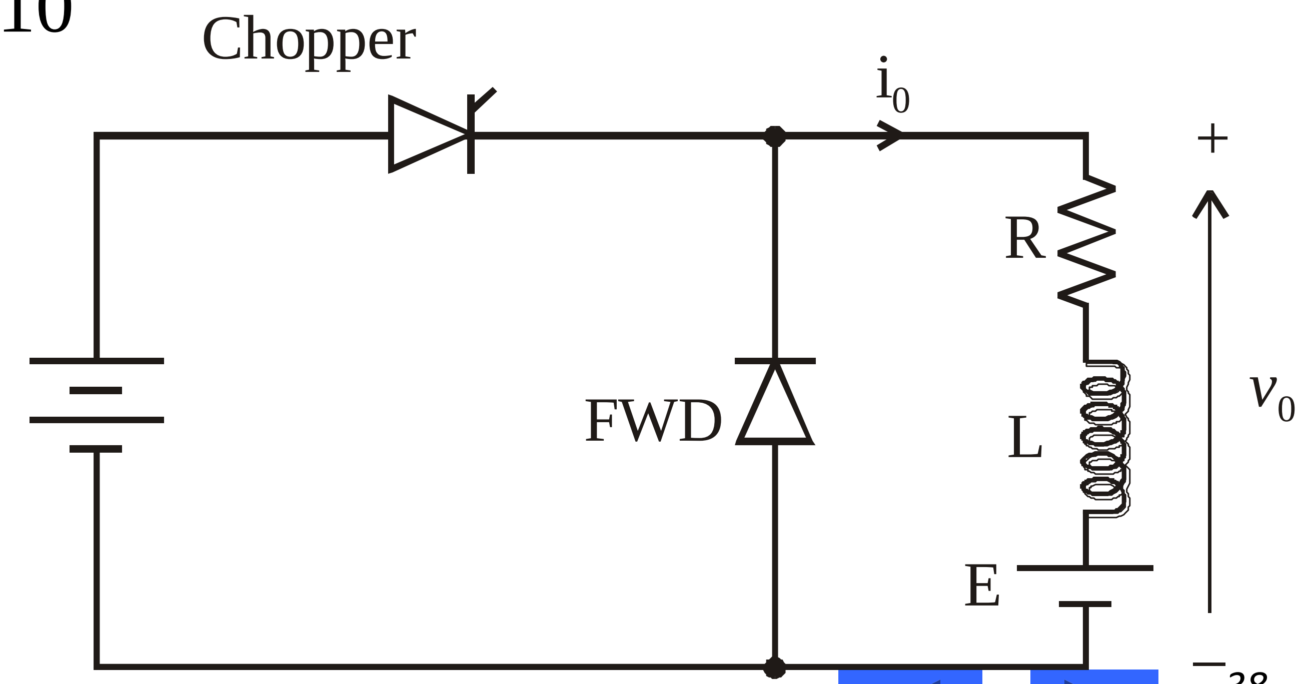
- *A chopper feeding on RL load is shown in figure, with V = 200 V, R = 5Ω, L = 5 mH, f = 1 kHz, d = 0.5 and E = 0 V. Calculate*
  - *Maximum and minimum values of load current.*
  - *Average value of load current.*
  - *RMS load current.*
  - *Effective input resistance as seen by source.*
  - *RMS chopper current.*

V = 200 V, R = 5Ω , L = 5 mH,

f = 1kHz, d = 0.5, E = 0

Chopping period is

$$T = \frac{1}{f} = \frac{1}{1\times10^3} = 1\times10^{-3} \text{ secs}$$



Maximum value of load current is given by

$$I_{\max} = \frac{V}{R}\left[\frac{1-e^{-\frac{dRT}{L}}}{1-e^{-\frac{RT}{L}}}\right] - \frac{E}{R}$$

$$I_{\max} = \frac{200}{5}\left[\frac{1-e^{-\frac{0.5\times5\times1\times10^{3}}{5\times10^{-3}}}}{1-e^{-\frac{5\times1\times10^{-3}}{5\times10^{-3}}}}\right] - 0$$

$$I_{\max} = 40\left[\frac{1-e^{-0.5}}{1-e^{-1}}\right] = 24.9\text{ A}$$

Minimum value of load current is given by

$$I_{\min} = \frac{V}{R}\left[\frac{e^{\frac{dRT}{L}}-1}{e^{\frac{RT}{L}}-1}\right]-\frac{E}{R}$$

$$I_{\min} = \frac{200}{5}\left[\frac{e^{\frac{0.5\times5\times1\times10^{-3}}{5\times10^{-3}}}-1}{e^{\frac{5\times1\times10^{-3}}{5\times10^{-3}}}-1}\right]-0$$

$$I_{\min} = 40\left[\frac{e^{0.5}-1}{e^{1}-1}\right] = 15.1\text{ A}$$

Average value of load current is

$$I_{dc} = \frac{I_1 + I_2}{2}$$

for linear variation of currents

$$\therefore \qquad I_{dc} = \frac{24.9 + 15.1}{2} = 20 \text{ A}$$

RMS load current is given by

$$I_{O(RMS)} = \left[I_{\min}^2 + \frac{\left(I_{\max} - I_{\min}\right)^2}{3} + I_{\min}\left(I_{\max} - I_{\min}\right) \right]^{\frac{1}{2}}$$

$$I_{O(RMS)} = \left[15.1^2 + \frac{(24.9 - 15.1)^2}{3} + 15.1(24.9 - 15.1) \right]^{\frac{1}{2}}$$

$$I_{O(RMS)} = \left[228.01 + \frac{96.04}{3} + 147.98 \right]^{\frac{1}{2}} = 20.2 \text{ A}$$

RMS chopper current is given by

$$I_{ch} = \sqrt{d}\, I_{O(RMS)} = \sqrt{0.5} \times 20.2 = 14.28 \text{ A}$$

Effective input resistance is

$$R_i = \frac{V}{I_S}$$

I_S = Average source current

$$I_S = dI_{dc}$$

$$I_S = 0.5 \times 20 = 10 \text{ A}$$

Therefore effective input resistance is

$$R_i = \frac{V}{I_S} = \frac{200}{10} = 20\Omega$$