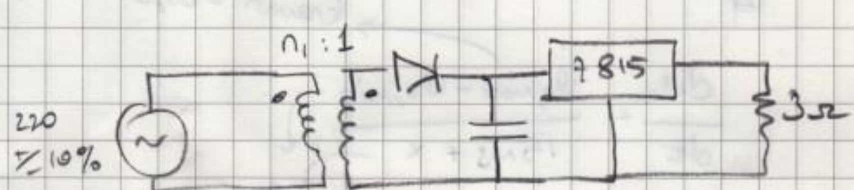
① Single Phase half-wave uncontrolled rectifier with cap. filter

An electronic load operates from a linear regulator with 15V. Load resister value is 3Ω. Linear regulator must be supplied by a 1Φ half-wave uncontrolled rectifier with cap. filter and output voltage of the rectifier must have a minimum average value of 20V with $\Delta v_{pp} = 2V$. Utility voltage is 220V +/- 5%.

① * Sketch the complete circuit diagram.



② suggest a transformer ratio? for the worst case of utility voltage?

$220 \cdot (0{,}95) = 209V$

$v_{o,max} = 21V.$

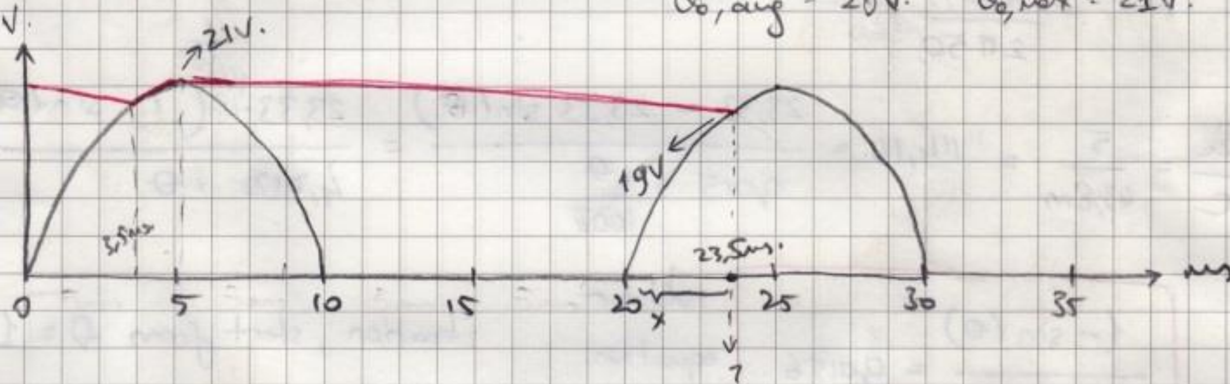
$v_{ac,max} = 209 \cdot \sqrt{2} = 295V.$

$\frac{v_{ac,max}}{v_{o,max}} = \frac{n_1}{1} = \frac{295}{21} \approx 14$

* For the minimum utility voltage, calculate the required cap. value.

output voltage → $v_{o,min} = 19V$. $\Delta v_{pp} = 2V$.

$v_{o,avg} = 20V$. $v_{o,max} = 21V$.



$$v_s = v_{ac,peak} \cdot \sin(\omega t) \cdot \frac{1}{14} = \frac{220 \cdot 0{,}95 \cdot \sqrt{2} \cdot \sin(\omega t)}{14} = 21{,}11 \sin(\omega t)$$

$$21{,}11 \sin(\omega t) = 19 \qquad \sin(\omega t) = 0{,}89$$

$$\omega t \cong 63° \cong 3{,}5\ ms \cong 1{,}1\ rad$$

capacitor voltage decreases linearly and supplies output current itself.

$i_o = 15/3 = 5A.$

(21,11-19)

capacitor eq. $i_c = C \cdot \frac{dv_c}{dt}$ $\qquad i_c \to 5A \qquad dt \to (0{,}015+0{,}0035)$

$$C = \frac{5 \cdot (0{,}0185)}{2{,}11} = 43{,}8\,mF.$$

* diode conduction angle / time → 1,5ms / 27°

cap. " " / " → 18,5ms / 333°

* calculate and sketch output voltage for 220V +5%.

$$v_{o,max} = v_{ac,max} \cdot \frac{1}{14} = \frac{220 \cdot 1{,}05 \cdot \sqrt{2}}{14} = 23{,}33V.$$

$i_c = C \cdot \frac{dv_c}{dt}$ — i_c known, dv_c, dt unknowns

$$\frac{dv_c}{dt} = \frac{v_{o,max} - v_{o,min}}{15ms + x}$$

$v_{o,max}$ known $= 23{,}33V$.

these two are related!

$$23{,}33 \sin(\omega t) = v_{o,min} \qquad \omega t = \theta$$

$$x = \frac{\theta \to rad}{2\pi 50}$$

$$\frac{i_c}{C} = \frac{5}{43{,}8m} = 114{,}16 = \frac{23{,}33 - 23{,}33\sin(\theta)}{0{,}015 + \frac{\theta}{100\pi}} = \frac{23{,}33 \cdot 100\pi \cdot (1-\sin(\theta))}{4{,}712 + \theta}$$

$$\boxed{\frac{1-\sin(\theta)}{4{,}712+\theta} = 0{,}0156.}$$ nonlinear equation.

iteration, start from $\theta = 1{,}1$ rad

first $\frac{1-\sin(1{,}1\,rad)}{4{,}712+1{,}1} = 0{,}0187$ $\qquad 0{,}0187 > 0{,}0156 \to \theta = 1{,}2$ rad

second $\frac{1-\sin(1{,}2)}{4{,}712+1{,}2} = 0{,}0115$ $\qquad 0{,}0115 < 0{,}0156 \to \theta = 1{,}15$ rad.

third $\frac{1-\sin(1{,}15)}{4{,}712+1{,}15} = 0{,}0149$ $\qquad 0{,}0149 < 0{,}0156 \to \theta = 1{,}14$ rad.

last → 0,0156 $\theta = 1{,}14$ rad.

$\theta = 1{,}14 \text{ rad} = 65{,}32^\circ = 3{,}63 \text{ ms.}$

$v_{o,min} = 23{,}33 \sin(1{,}14 \text{ rad}) = 21{,}19 \text{ V.}$

$\Delta v_o = 23{,}33 - 21{,}19 = 2{,}14 \text{ V.}$

$$v_{o,avg} = \frac{23{,}33 + 21{,}19}{2} = 22{,}26 \text{ V.}$$

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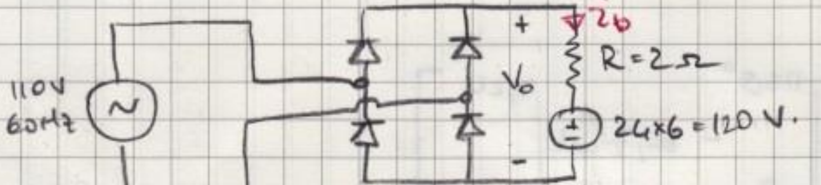
* Single Phase full-wave uncontrolled rectifier w/out cap. filler

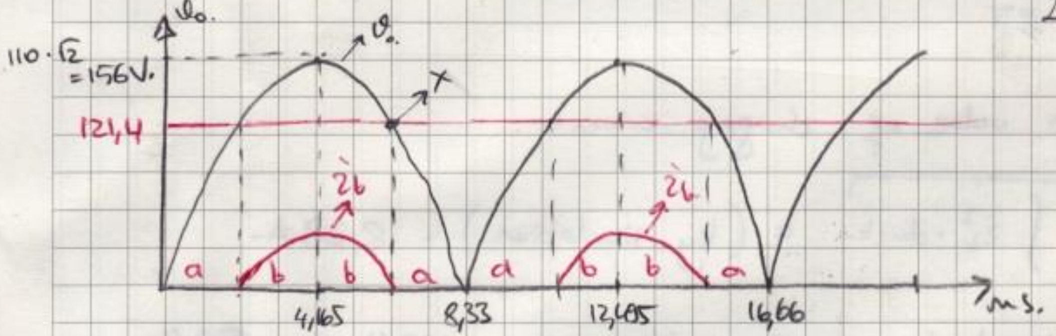
A utility voltage of 110 V_{ac} /60Hz. supplies and charges a battery group (24V × 5 series) through a full wave rectifier w/out cap. filter and 2 Ω current limiting resistor.



* if all diodes have 0,7V threshold voltages find the conduction angles.

2 diodes conducting

120 + 2·0,7 = 121,4 V.



$v_o = 156 \cdot \sin(\omega t) = 121{,}4\text{V} \Rightarrow \omega t = 51{,}1^\circ = 0{,}89 \text{ rad.} = 2{,}37 \text{ ms.}$

$a = 2{,}37 \text{ms}$

$b = 1{,}795 \text{ ms.}$

$x = 2b + a = 5{,}96 \text{ ms.}$

charging occurs → 2,37 ms to 5,96 ms

51,1° to 128,9°

0,89 rad to 2,24 rad.

GIPTA

* plot the charging current and calculate the average value.

$$i_b = \frac{156 \sin(\omega t) - 121{,}4}{2} = 78 \sin(\omega t) - 60{,}7$$

conducts from $51{,}1°$ to $128{,}9°$.

$$\langle i_b \rangle = \frac{2}{T} \int (78 \sin(\omega t) - 60{,}7)\, d\omega t$$

$$= \frac{1}{\pi} \int_{51{,}1°\,(0{,}89\text{ rad})}^{128{,}9°\,(2{,}24\text{ rad})} \left(78 \sin(\omega t) \cdot d\omega t - 60{,}7 \cdot d\omega t\right)$$

$$= \frac{1}{\pi} \left[(78\,(-\cos \omega t)) \Big|_{51{,}1°}^{128{,}9°} - 60{,}7\, \omega t \Big|_{0{,}89}^{2{,}24} \right]$$

$$= \frac{48{,}98 + 48{,}98 - 135{,}97 + 54{,}02}{\pi} = 5{,}1 \text{ A}.$$

* calculate the rms value of charging current.

$$i_{b,rms} = \sqrt{\frac{1}{T} \int i_b^2 \cdot d\omega t} = (\text{by simulation}) = 8{,}29 \text{ A}.$$

* find the time required to charge battery from 100Ah to 160Ah.

$160 - 100 = 60$ Ah.

$\langle i_b \rangle = I_b$ into battery

$$\frac{60 \text{ Ah}}{5{,}1 \text{ A}} = 11{,}76 \text{ h} = 11 \text{ hours } 45 \text{ minutes}.$$

* calculate the charging resistor loss, diode losses and complete efficiency?

$P_{diode} = 2{,}55 \cdot 0{,}7 \cdot 4 = 7{,}14W$

for one diode $\frac{\langle i_L \rangle}{2}$ is flowing $= 2{,}55A$.

$P_R = i_{b,rms}^2 \cdot R = 8{,}29^2 \cdot 2 = 137{,}45W$

$P_{batt} = 120 \cdot 5{,}1 = 612W$.

$$\text{efficiency} = \frac{P_{batt}}{P_{batt} + P_D + P_R} = \frac{612}{612 + 137{,}45 + 7{,}14} = 80{,}89\%.$$