1. a. \[ |V_{out}| = \frac{V_{inv, RMS} \cdot \sqrt{2}}{\text{Turns}} = \frac{|V_{inv}|}{20/1} = 8.5 \text{ V} \]

\[ |I_{out}| = \frac{|I_{inv}|}{\text{Turns}} \text{ from power conservation} \]

\[ = \frac{|I_{inv}|}{R} = 1.7 \text{ A} \]

\[ \Rightarrow |I_{in}| = 0.085 \text{ A} \]

b. \[ \langle P_{out} \rangle = \frac{1}{2} \int_{0}^{2\pi} V_{out} I_{out} \, dt = \frac{1}{2} \int_{0}^{2\pi} 8.5 \cdot 1.7 \sin^2(\omega t) \, dt \]

\[ = \frac{14.45}{2} \int_{0}^{2\pi} \frac{1 - \cos(2\omega t)}{2} \, dt \]

\[ \approx 7.2 \text{ W} \]

c. \[ PF = \frac{\langle P_{in} \rangle}{V_{inv, RMS} \cdot I_{inv, RMS}} \]

\[ \langle P_{in} \rangle = \langle P_{out} \rangle \text{ from conservation} \]

\[ V_{inv, RMS} = \frac{|I_{inv}|}{0.2} = 0.0601 \]

\[ \Rightarrow \frac{7.2}{120 \cdot 0.0601} = 1 \]

Note that the PF should be strictly one due to the waves being sinusoidal.

d. Ripple factor = \[ \sqrt{\frac{V_{\text{var}}}{V_{\text{avg}}}} \]

\[ V_{\text{avg}} = \frac{V_{\text{inv}}}{T} = 8.5 \text{ V} \text{ from a.} \]

\[ V_{\text{var}} = V_{\text{inv}} + \int_{0}^{T} \sin(\omega t) \, dt = 8.5 \cdot 0.75 \]

\[ \Rightarrow \text{Ripple factor} = \sqrt{\left(\frac{3.5}{8.5}\right)^2} = 0.483 \]
(a) \[ V_{\text{out}} (V) \]

\[ 4.25V = V_{\text{out, max}} \]

\[ 0.85A = i_{\text{in, max}} \]

\[ 0.85A = i_{\text{D1, max}} \]

\[ 0.85A = i_{D2, max} \]

\[ V_{\text{out, max}} = \frac{120 \times \sqrt{2}}{40} \]

\[ = 4.25V \]

\[ i_{\text{D1, max}} = i_{\text{D2, max}} \]

\[ = \frac{V_{\text{out, max}}}{R} = 0.85A \]

(b) \[ \langle P_{\text{out}} \rangle = \frac{V_{\text{out, rms}}^2}{R} = \frac{(120 \times \frac{1}{40})^2}{5} = 1.8W \]

(c) \[ PF = \frac{\langle P_{\text{in}} \rangle}{V_{\text{in, rms}} \cdot I_{\text{in, rms}}} \]

\[ \langle P_{\text{in}} \rangle = \langle P_{\text{out}} \rangle = \frac{V_{\text{out, rms}}^2}{R} = \frac{(V_{\text{out, max}} / \sqrt{2})^2}{R} \]

\[ PF = \frac{1}{40} \frac{V_{\text{out, max}}}{\sqrt{2} R} \times \frac{40 \cdot V_{\text{out, max}}}{\sqrt{2}} = 1 \]
(d) \[ \text{ripple factor} = \sqrt{\left( \frac{V_{\text{out, rms}}}{V_{\text{out, avg}}} \right)^2 - 1} \]

\[ \frac{V_{\text{out, rms}}}{V_{\text{out, avg}}} = \frac{V_{\text{out, max}} / \sqrt{2}}{V_{\text{out, max}} \cdot \frac{\pi}{4}} = \frac{\pi}{2 \sqrt{2}} \]

\[ \text{ripple factor} = \sqrt{\left( \frac{\pi}{2 \sqrt{2}} \right)^2 - 1} = 0.483 \]

(e) \( V_{\text{out, max}} \) is half that of problem 1.1 and \( <\text{Pout}> \) is \( \frac{1}{4} \) that of problem 1.1.

To deliver the same amount of power, the transformer step-down ratio should be \( 10:1 \), so that \( V_{\text{out, max}} \) is doubled.
1.3

(a) Half-wave rectifier

1 diode

(b) Full-wave bridge rectifier

4 diodes

(c) Center-tapped transformer rectifier

2 diodes
1 transformer (center-tapped)

\[ V_{pk}, \text{secondary} \]

\[ \frac{V_{pk}}{2 R_L} \]

\[ \frac{V_{pk, \text{secondary}}}{2} \]

\[ 1 \]

\[ 0.483 \]

Power factor

\[ 1.211 \]

Ripple factor

PF = \[ \frac{< P_{in} >}{V_{in, \text{rms}} \cdot I_{in, \text{rms}}} \]

\[ \sin \theta \]

\[ \sin \theta \]

\[ \frac{\pi}{2} \]

\[ 2\pi \]

\[ 0 \]

\[ V_{in} \]

\[ I_{in} \]
1.4 Assuming $V_1$ and $D_2$ are on, the results in the following:

\[ KVL: V_{ssin(\omega t)} + V_{D2} - V_{D1} = 0 \]

For $V_{ssin(\omega t)} > 0$: $D_1$ is forward biased with positive current, satisfying the properties of an ideal diode. $D_2$ is reverse biased and its current is negative, which violates the properties of an ideal diode. This means $D_2$ cannot be assumed to be on when $V_{ssin(\omega t)} > 0$.

For $V_{ssin(\omega t)} < 0$: $D_1$ is reverse biased with negative current, violating the properties of an ideal diode. $D_2$ is forward biased with positive current, satisfying the properties of an ideal diode. This means $D_1$ cannot be assumed to be on when $V_{ssin(\omega t)} < 0$.

For $V_{ssin(\omega t)} = 0$: $D_1$ and $D_2$ can both be on without violating the properties of an ideal diode, especially if $i_L > 0$. An ideal diode supplies positive current while forward biased.
5. $|V_{IN}| > V_{DC}$

$[V_{IN}] = 2I_{IN} R + V_{OUT} + V_{DC}$

$V_{OUT} = \frac{|V_{IN}| - V_{DC}}{3}$

$V_{OUT} = \begin{cases} \frac{|V_{IN}| - V_{DC}}{3} & \text{for } |V_{IN}| > V_{DC} \\ 0 & \text{for } |V_{IN}| \leq V_{DC} \end{cases}$
Schematics and diode configuration are shown on the printed page.

Transformer secondary want

\[ 5V + 0.15V + 1V + 1V = 7.15V \]

\( \Rightarrow \text{from ripple} \)

Transformer ratio \( \frac{12.05V}{7.15} = 23.735 \)

Diode voltage rating: \( 7.15V - 1V = 6.15V \).

(can be obtained by reading the diode voltage in simulation)

Diode current rating:

\[ \begin{align*}
\text{max} &: 35.16\text{A} \\
\text{rms} &: 5.73\text{A}
\end{align*} \]

\[ C_{\text{designed}} = \frac{\text{Jtot}}{2 + \Delta V} \quad \text{Jtot} = \frac{12\text{W}}{5V} = 2.4\text{A} \]

\[ \Delta V = 2\cdot(5.3\%) = 0.3 \]

\[ = 0.0667\text{F} \]

\[ R_{\text{out}} = \frac{V_{\text{out}}^2}{P_{\text{out}}} = \frac{25}{12} = 2.0835 \]

The plots of the output voltage and input current are shown on the printed page.

Ripple \[ 5.14 - 4.87 = 0.27(V) \]

within spec.
.tran 0 1.75 1.5 0.000001
.model Diode D(Vfwd=1)
Vin, rms = \frac{7.15}{\sqrt{2}} = 5.05 \text{ (V)}

I_{in, rms} = 8.10 \text{ A}

\langle P_{in} \rangle = 16.95 \text{ W}

PF = \frac{\langle P_{in} \rangle}{Vin, rms \cdot I_{in, rms}} = 0.415

V_{ripple} = 5.14 - 4.87 = 0.27 \text{ (V)}

ii.

I_{in, rms} = 4.69 \text{ A}

\langle P_{in} \rangle = 8.65 \text{ W}

PF = 0.365

V_{ripple} = 5.138 - 5 = 0.138 \text{ (V)}

iii.

I_{in, rms} = 4.39 \text{ A}

\langle P_{in} \rangle = 12.959 \text{ W}

PF = 0.585

V_{ripple} = 5.15 - 3.30 = 1.85 \text{ V}

iv.

I_{in, rms} = 2.8078 \text{ A}

\langle P_{in} \rangle = 7.3509 \text{ W}

PF = 0.518

V_{ripple} = 5.15 - 4.04 = 1.11 \text{ V}
1. The larger the capacitance is, the lower the PF is. This is because the larger the capacitance is, the shorter time the input source will provide current. This makes the input current to be less close to an ideal sine wave, which causes the power factor to be low.

2. The larger the output power is, the higher the PF is, because when $P_{out}$ is larger, the length of time the input source provides current is larger. This makes the input current to be closer to an ideal sine wave, and increases the power factor.

3. The larger the capacitance is, the smaller the voltage ripple is, because $i_c = \frac{C \, dV_c}{dt}$, with the same $i_c$ provided to load, larger $C$ causes smaller $\frac{dV_c}{dt}$, and smaller $\Delta V_c$.

4. The larger the output power is, the larger the voltage ripple is, because when all diodes are off, the load is solely supplied by the capacitor. A larger load current causes a larger $\Delta V_c$. 
To visualize the power factor and ripple voltage results for the four cases, a figure is made as shown below. It can be seen that in general, the larger the ripple voltage is, the larger the power factor is. For the two cases when the capacitance is large, the ripple voltages are significantly lower than the other two cases when the capacitance is small. Also the power factor for these two cases are lower than the other two cases. Moreover, it can be noticed that for the two cases when the output power is increased from 6 W to 12 W (while keeping the capacitance the same), the power factor also increases.

![Ripple voltage vs power factor for the four cases](image)

Another interesting thing that can be done using LTSpice is investigating the influence of diode forward drop on power factor. Below is the calculated power factors for 1 V vs 0 V diode forward drops from simulation. It can be seen that if the forward drop is reduced to 0 V, the power factor is larger for all four cases. Thus the diode forward drop does negatively affect the power factor.

<table>
<thead>
<tr>
<th></th>
<th>1 V forward drop</th>
<th>0 V forward drop</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>0.415</td>
<td>0.441</td>
</tr>
<tr>
<td>ii</td>
<td>0.365</td>
<td>0.388</td>
</tr>
<tr>
<td>iii</td>
<td>0.585</td>
<td>0.617</td>
</tr>
<tr>
<td>iv</td>
<td>0.518</td>
<td>0.552</td>
</tr>
</tbody>
</table>