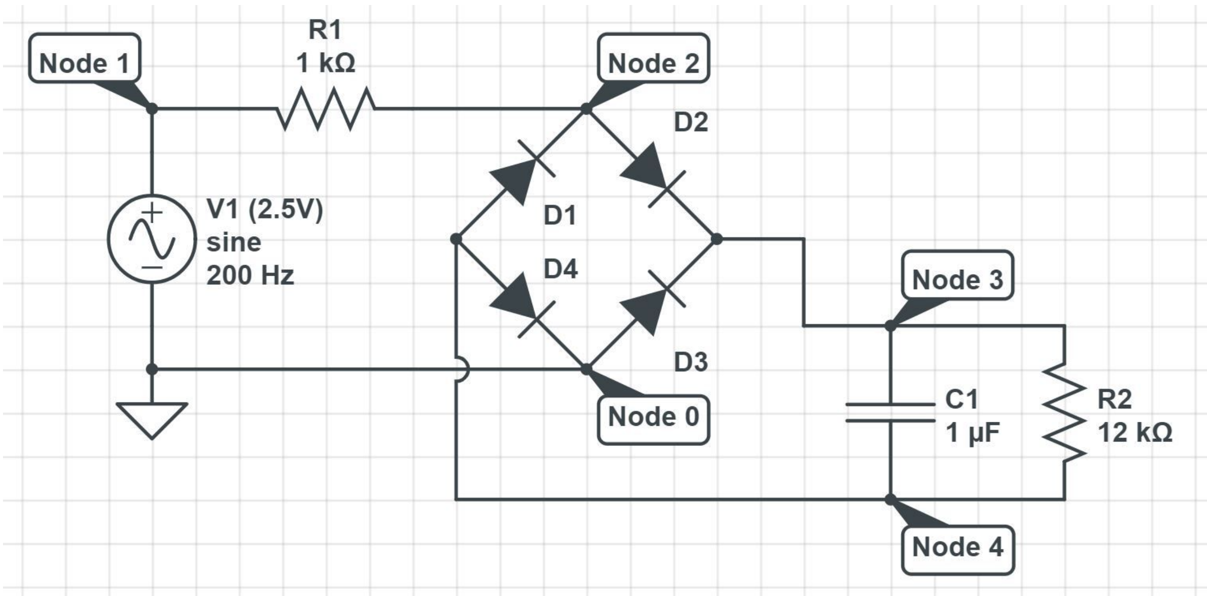
5. Using SPICE, analyze the following Full Wave (Bridge) Rectifier Circuit by plotting the input waveform across AC source V1 and output waveform across resistor R2:
   (a) Without Smoothing Capacitor C1
   (b) With Smoothing Capacitor C1
   Using these two simulations, explain the role of the Smoothing Capacitor. Can you also identify the path that the current traces during the positive wavecycle and the negative wavecycle?

   Now, plot the output waveform by changing the capacitance of C1 to:
   (a) 20 nF
   (b) 20 uF
   Can you now understand the relation between the capacitance value and the AC source frequency? Explore further by changing the source frequency.

   NOTE: Use transient analysis in order to plot all waveforms.

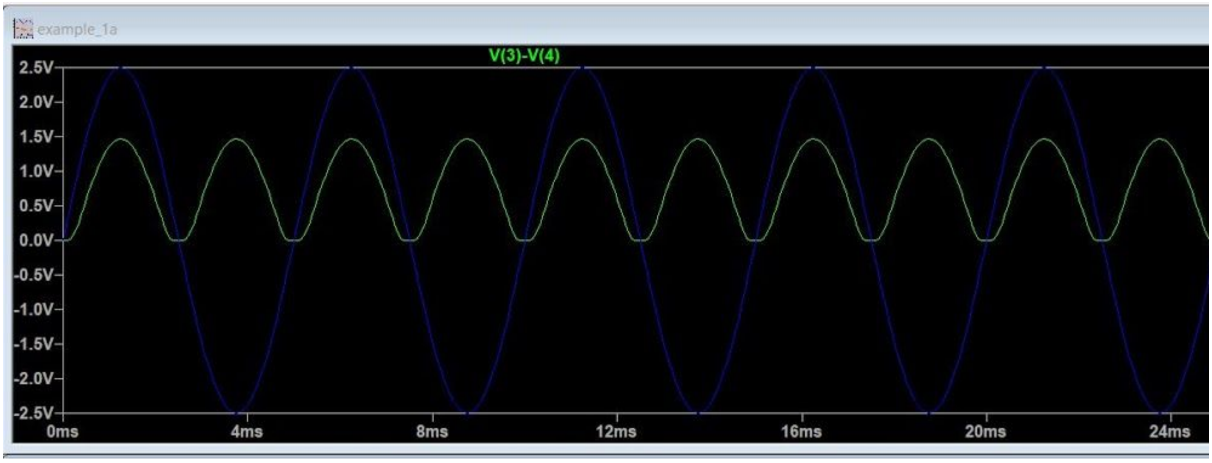


NETLIST:

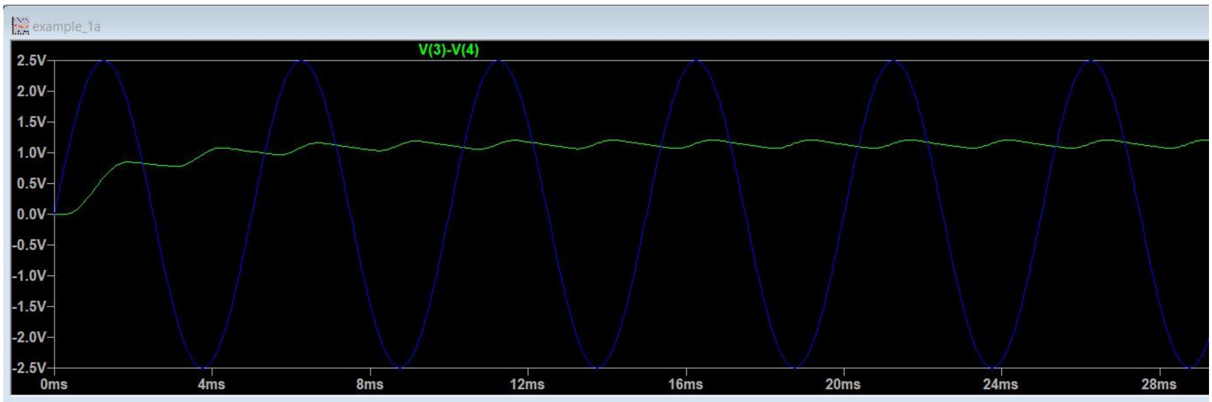
```
Full Wave Bridge Rectifier with Smoothing Capacitor
.MODEL DIN4007 d(IS=7.02767e-09 RS=0.0341512 N=1.80803 EG=1.05743
+XTI=5 BV=1000 IBV=5e-08 CJO=1e-11
+VJ=0.4 M=0.5 FC=0.5 TT=1e-07
+KF=0 AF=1)

V1 1 0 Sin(0 2.5 0.2k)
R1 1 2 1k
R2 3 4 12k
C1 3 4 1u
D1 4 2 DIN4007
D2 2 3 DIN4007
D3 0 3 DIN4007
```

```
D4 4 0 DIN4007

*Add trace V(3)-V(4) to view rectified DC output
*Add trace V(1) to view AC input
*Uncomment C1 statement to view smoothening effect of the
capacitor

.trans 1m 40m
.END
```

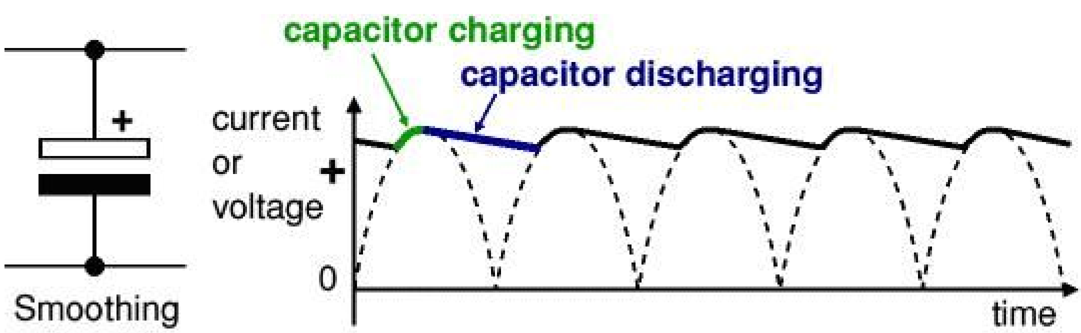
Plot without smoothing capacitor:



Plot with smoothing capacitor:



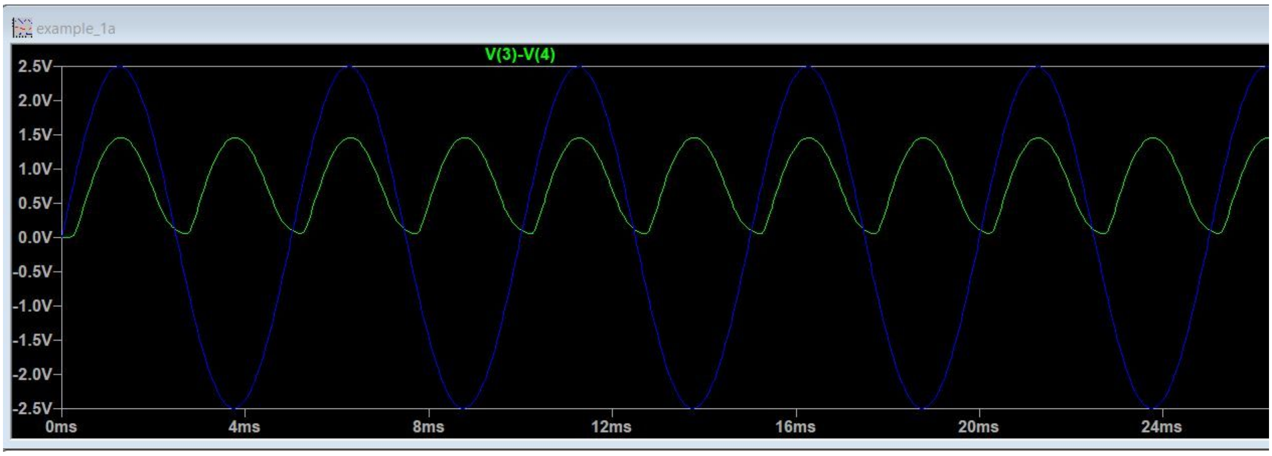
The output of the Full Wave (Bridge) Rectifier is a fully rectified positive (or negative) DC pulse that fluctuates between a maximum value and zero. In order to smoothen the fluctuating DC wave, we can place a smoothing capacitor C1 in parallel with the load resistor R2, so that the output is maintained at a somewhat constant DC level (with small ripples in the DC level). See the figure below to understand the operation performed by the capacitor:



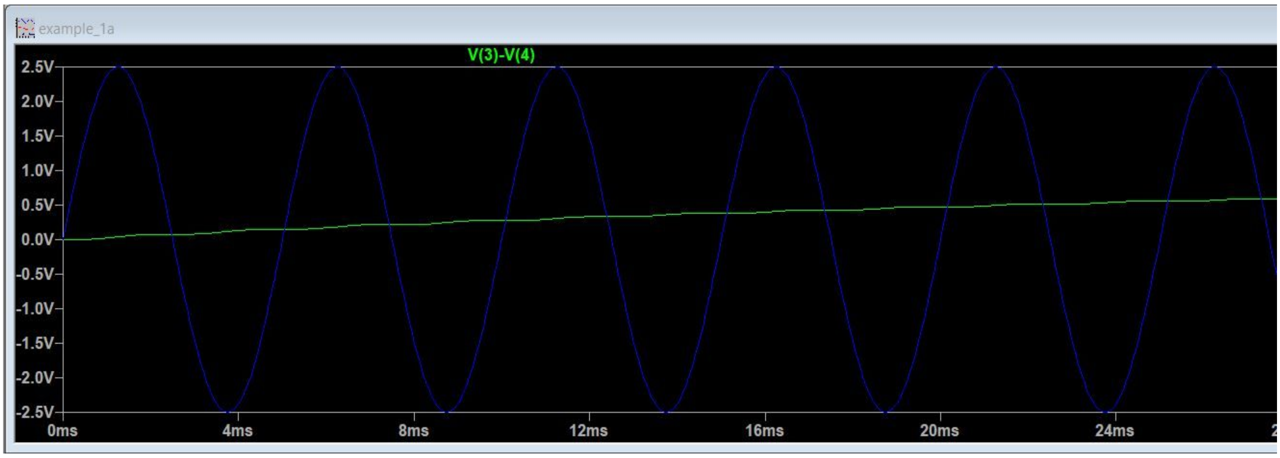
In the positive wavecycle, the path traced by the circuit is Node 1 -> Node 2 -> Node 3 -> Node 4 -> Node 0. In this positive wavecycle, diodes **D2 and D4** are **forward biased (conducting)** while diodes **D1 and D3** are **reverse biased (non-conducting)**.

In the negative wavecycle, the path traced by the circuit is Node 0 -> Node 3 -> Node 4 -> Node 2 -> Node 1. In this negative wavecycle, diodes **D1 and D3** are **forward biased (conducting)** while diodes **D2 and D4** are **reverse biased (non-conducting)**.

C1 as 20 nF:



C1 as 20 uF:



Clearly, we can see that the capacitor discharging time must be significantly larger than the time period of the rectified wave so that the capacitor can retain a majority of it's charge (hence voltage) until the rectified wave returns to it's peak. In this way, we can approximate $f_{operating}$ as:

$$f_{operating} > \frac{1}{2\pi R_2 C_1}$$

Therefore, we observe that if $f_{actual} < f_{operating}$ then the capacitor cannot help in smoothing the rectified output wave. Also note that if $f_{actual} >> f_{operating}$ then the capacitor would function properly as a smoothing capacitor but the charging time for the output will also increase!