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Lab 2 - Power Characterization. Diodes and Controlled Rectifiers

Lab Section 021
TA's Name: Zijin Pan

Introduction:

The objective for the lab is to become familiar with the half-wave rectification, particularly with capacitive loads. We will design a basic battery charger as a constant voltage source. We will understand the use of capacitors as constant voltage sources and inductors as constant current sources. Along with this we will also understand the principles of commutation.

Theory:

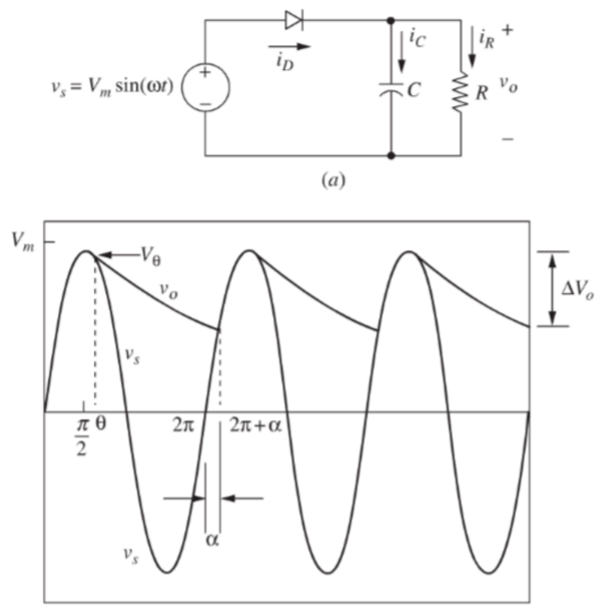
Rectifiers converts AC inputs to DC outputs, and it serves two main purposes:

1. Generating a clean DC output.
2. Shaping voltage or current waveforms to meet specific DC criteria.

Second theory:

In battery chargers, half-wave rectifiers are often used. Rechargeable batteries generally maintain a relatively stable voltage (E) over time, making it a consistent value for analysis. Additionally, transformers are assumed to be ideal, meaning they don't store energy and don't impact the circuit's operation.

Third theory:



Single phase half-wave rectifier with capacitive load

Fourth theory:

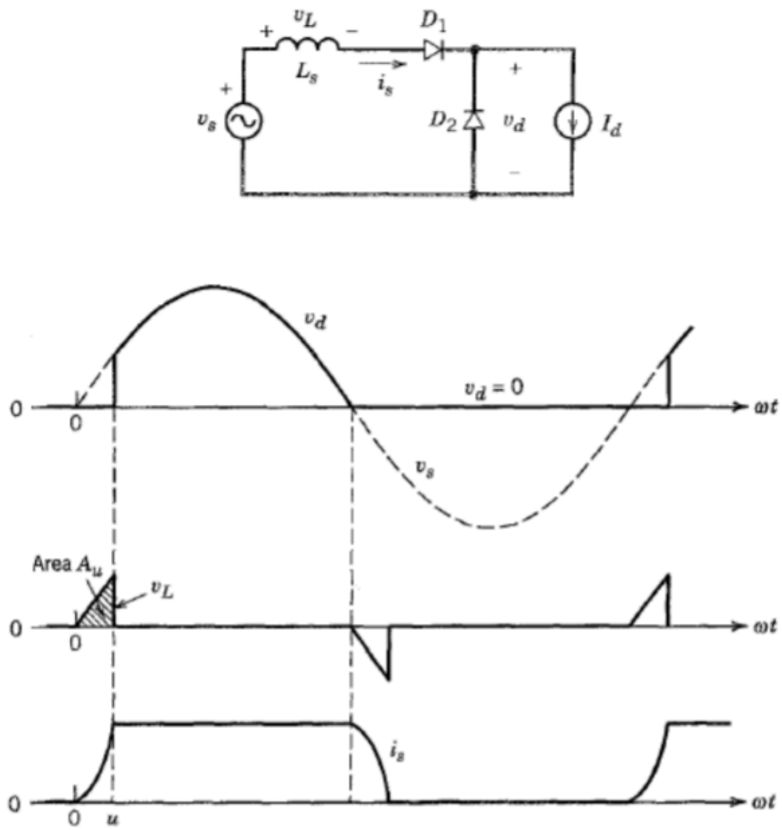


Figure 3.1 Single-phase half-wave rectifier powering a constant current load and an inductive power source[‡‡].

In circuits with freewheeling diodes, if there are no inductive or capacitive elements (whether intentional or unintentional), the diodes would carry maximum currents instantly when they're on. But since these elements are always there, diodes conduct current for a brief period before reaching maximum levels. This transition of current from one part of the circuit to another is called commutation, and the time it takes for this switch is called the commutation time.

Prelab

Design the battery charger for Experiment 1 (find the resistor value R1);
Given

1. The battery charge voltage $E = 12\text{V}$, and its capacity is $W = 100$ Wh
2. The average charging current should be $I_{dc} = 5\text{A}$
3. The primary input voltage is $V_{p,rms} = 120\text{V}$, 60 Hz
4. The transformer has a turn ratio $n = N_s/N_p = ½$

$$(1.9) \qquad I_{dc} = \frac{1}{2\pi}\int_{\alpha}^{\beta} \frac{V_m \sin \omega t - E}{R} d(\omega t) = \frac{1}{2\pi R}(2V_m \cos\alpha + 2E\alpha - \pi E)$$

$$(1.4) \qquad \alpha = \sin^{-1}\frac{E}{V_m}$$

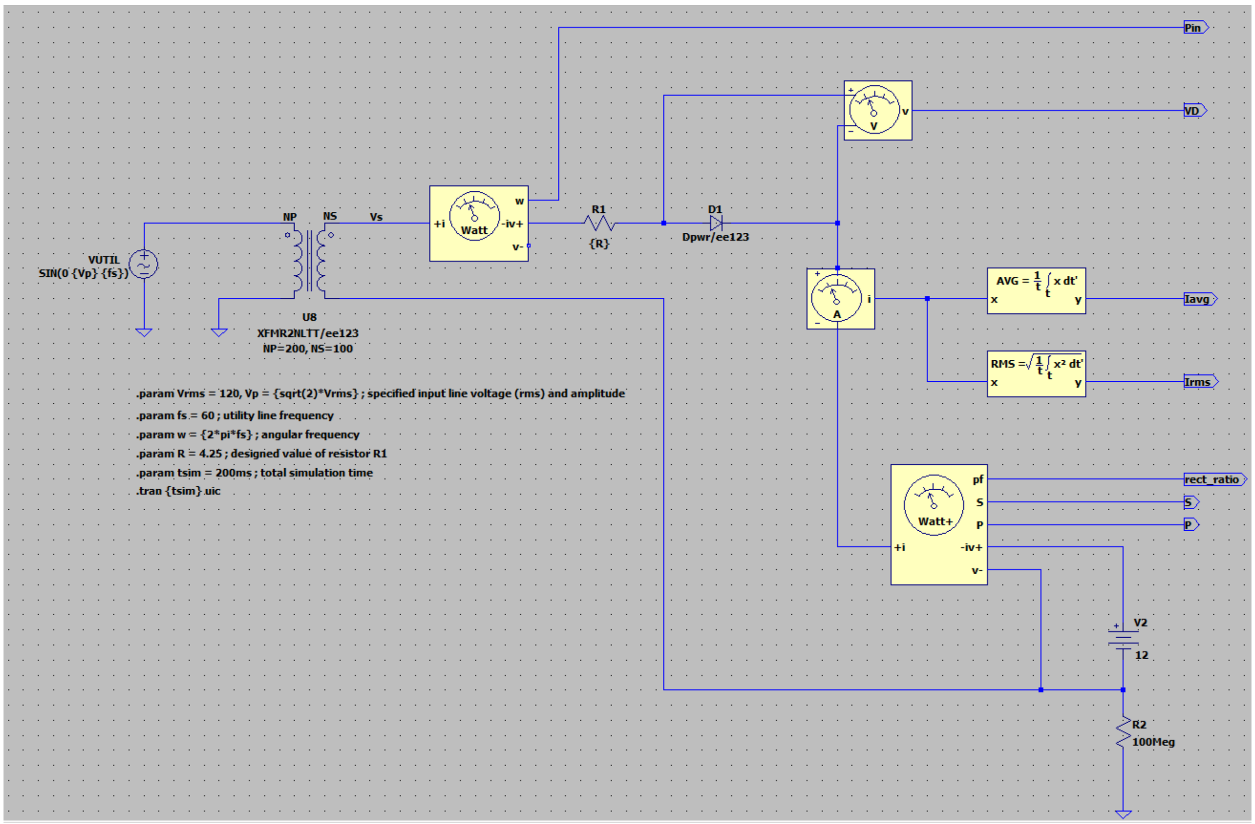
$V_{s,m}$ = 60*sqrt(2) = 84.85281374 = 84.85V
α = sin^-1 (12V/84.85) = 0.0707697366 = 0.141901792
$V_{s,rms}$ = 120/2 = 60

We can make this equal to R
I_{DC} = (1 / 2πR) * [2$V_m$cos(α) + 2Eα - πE)
R1 = (1 / 2πI_{DC}) * [2$V_m$cos(α) + 2Eα - πE)
R1 = (1/(2π*5A) * [2*84.85V*cos(0.142) + 2*12V*0.142 - π*12V] = 4.245109898 = 4.25
=> R1 = 4.25Ω

Design Calculations and Circuit Schematic, including Experimental Data and Data Analysis:

1.2

1)



The value of resistor R1 would be 4.25Ω

E = 12 V

$V_{s,\ RMS}$ = 60 V (due to transformer)

$V_{s,\ m}$ = sqrt(2) * V_{RMS} = sqrt(2) * 60V = 84.85V

a = sin^-1(E/Vm) = a = sin^-1(12V/84.85V) = 0.142

6)

Experimental:

We can see that it approaches steady- state at 5A

Theoretical

$$(1.9) \qquad I_{dc} = \frac{1}{2\pi}\int_{\alpha}^{\beta}\frac{V_m \sin\omega t - E}{R}d(\omega t) = \frac{1}{2\pi R}\left(2V_m\cos\alpha + 2E\alpha - \pi E\right)$$

I_{DC} = (1 / 2πR) * [2$V_m$cos(α) + 2Eα - πE)

= (1 / (2*3.14*4.25Ω) * (2*84.85V*cos(0.142) + (2*12V*0.142) - (3.14*12V)

= 5.01 A

Both Theoretical and Experimental are close enough to one another to be considered the same

7)

We can see that it approaches steady- state at 8.2A

$$(1.10) \quad I_{rms} = \frac{1}{2\pi}\int_{\alpha}^{\beta}\frac{(V_m \sin\omega t - E)^2}{R}d(\omega t) = \frac{1}{2\pi R^2}\left[\left(\frac{V_m^2}{2}+E^2\right)(\pi-2\alpha)+\frac{V_m^2}{2}\sin 2\alpha - 4V_m E\cos\alpha\right]$$

I_{RMS} = (1 / 2πR^2) * [((V$_m$^2/2) + E^2)*(π - 2α) + ((V$_m$^2/2)(sin(2α) - 4V$_m$Ecos(α)]
= (1 / 2*3.14*4.25Ω^2) * [((84.85V^2/2) + 12V^2)*(3.14 - 2*0.142) + ((84.85V^2/2)(sin(2*0.142) - 4*84.85V*12V*cos(0.142)]
= 8.22 A

Both Theoretical and Experimental are close enough to one another to be considered the same

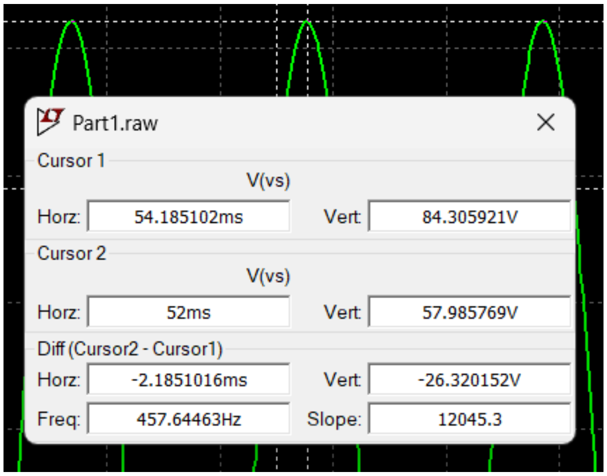
8)

(1.4) $$\alpha = \sin^{-1}\frac{E}{V_m}$$

(1.5) $$\beta = \pi - \alpha$$

(1.6) $$\delta = \beta - \alpha$$

Experimental



w = 2pi(f) = 2pi/secs
α = sin^-1 (E/V_m) = sin^-1 (12V / 84.30V) = 0.14 rad
β = π - α = 3.14 - 0.14 = 3.00 rad
∂ = β - α = 3.00 - 0.14 = 2.86 rad

Theoretical
α = sin^-1 (E/V_m) = sin^-1 (12V / 84.85V) = 0.14 rad
β = π - α = 3.14 - 0.14 = 3.00 rad
∂ = β - α = 3.00 - 0.14 = 2.86 rad

Both Theoretical and Experimental are close enough to one another to be considered the same

9)

Experimental:

We can see that it approaches steady- state at 8.2A

Theoretical:

$$P_{dc} = V_{dc} I_{dc} = E I_{dc} = E I_{avg} = P \quad (1.11)$$

$P_{DC} = EI_{DC}$ = 12V * 5.01A = 60.12W

Both Theoretical and Experimental are close enough to one another to be considered the same

10)

We can see that it approaches steady- state at 96W

We can see that it approaches steady- state at 0.6
So the rectifier ratio = 0.6

(1.12) $P_{ac} = S = V_{rms} I_{rms}$ (note: use V_{RMS} across V2

$P_{AC} = V_{RMS}I_{RMS}$ = 12V * 8.22A = 98.67W

(1.14) $\sigma = \frac{P_{dc}}{P_{ac}}$

$\sigma = P_{DC} / P_{AC}$ = 60.12W / 98.67W = 0.61

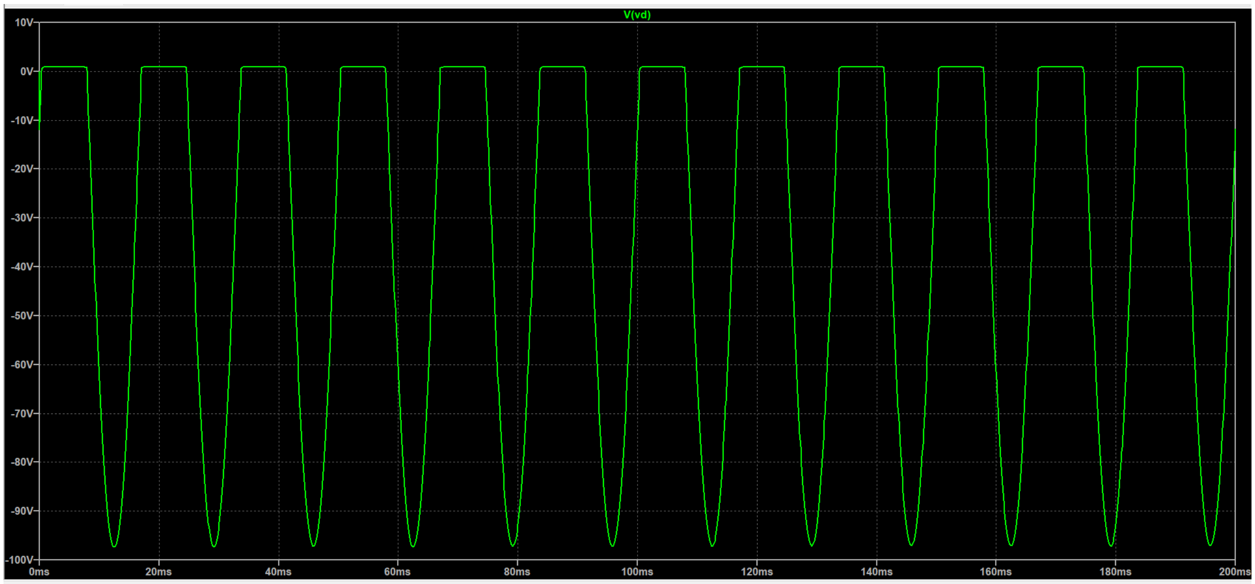
Both Theoretical and Experimental are close enough to one another

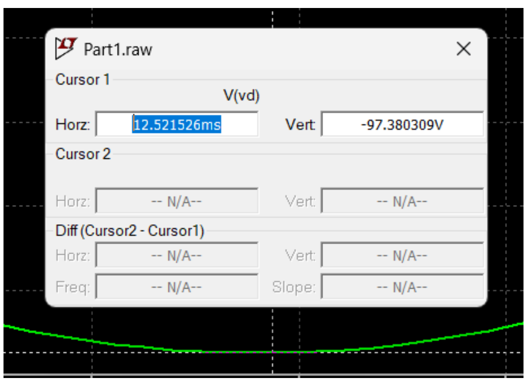
11) Determine the rectification efficiency η;

(1.13) $\eta = \frac{P_{dc}}{P_s}$ where $P_s = P_{dc} + P_R = P_{dc} + I_{rms}^2 R$

n = P_{DC} / (P_{DC} + (I_{RMS}^2 *R) = 60.12 / (60.12 + (8.22^2 * 4.26)) = 0.17

12)



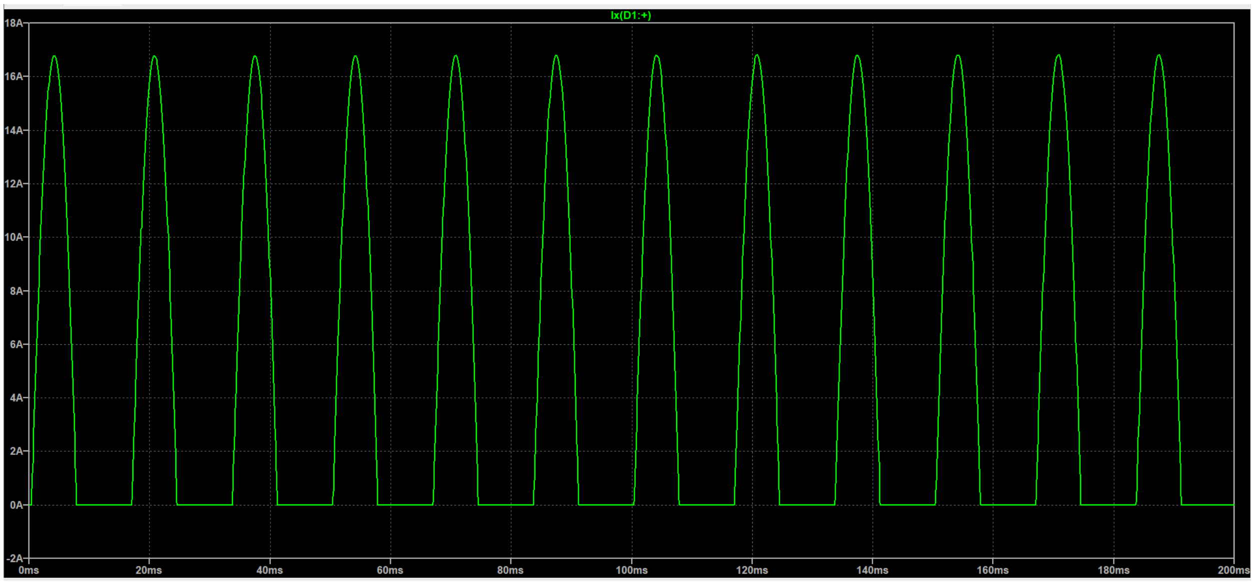


The maximum reverse voltage is a about 97.38

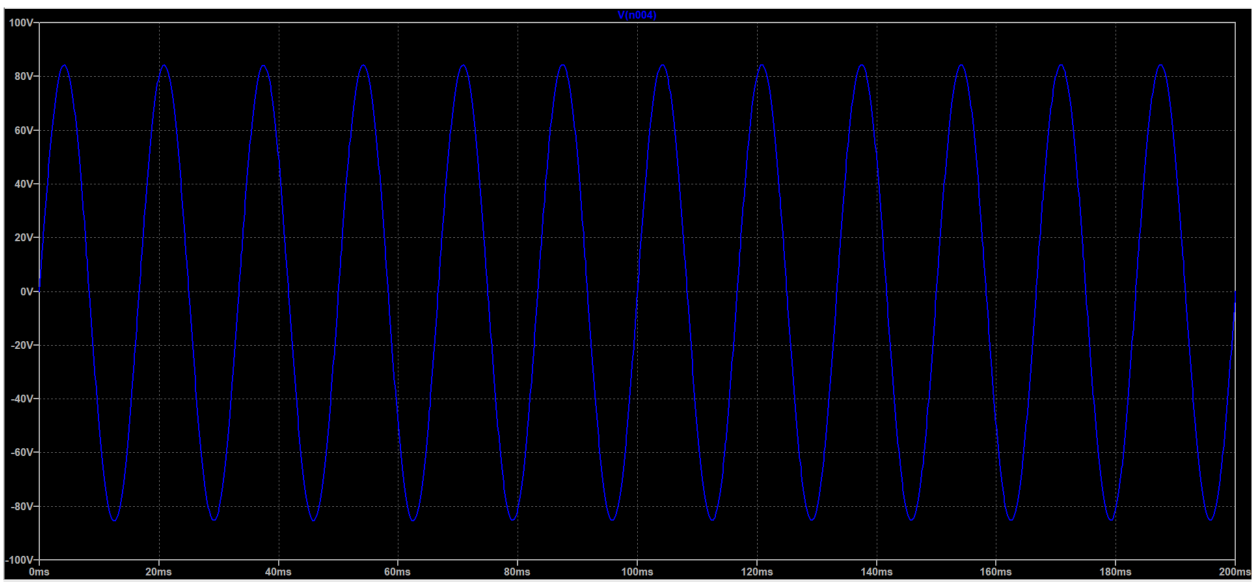
$$PIV = V_m + E \qquad (1.16)$$

PIV = V_m + E = 84.85V + 12V = 96.85

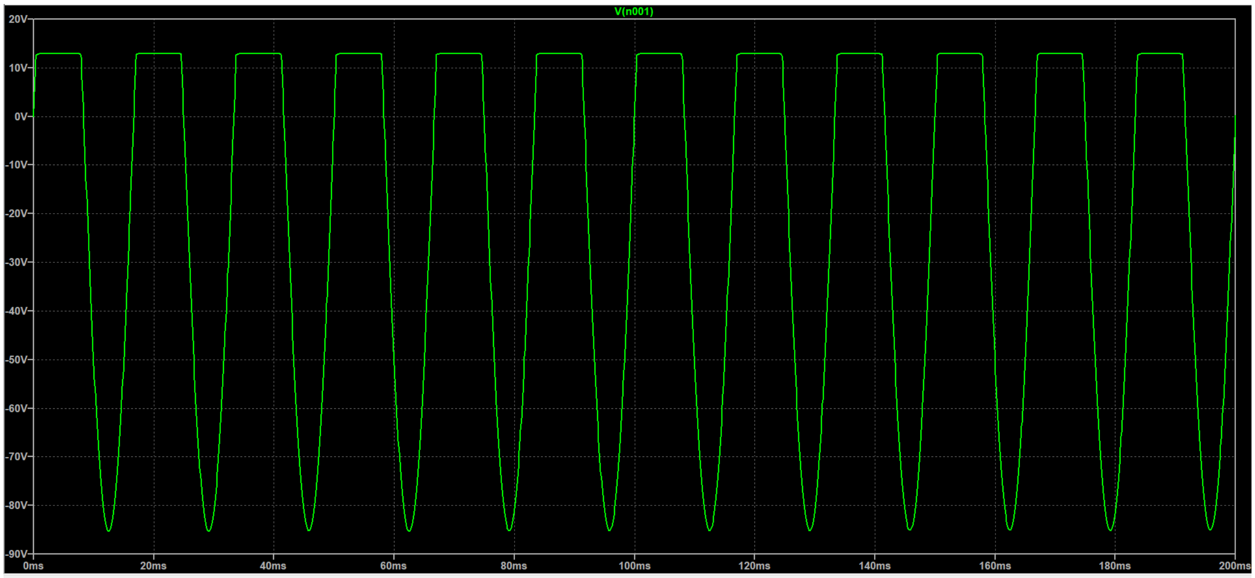
13)



Max I is about 17A



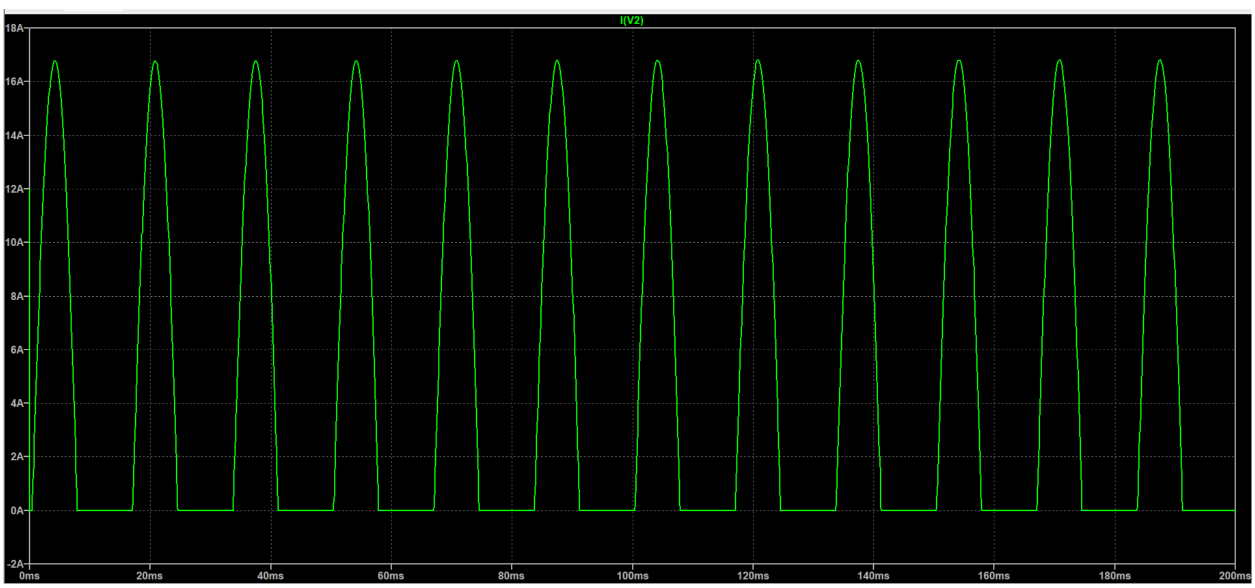
Positive Terminal Voltage = 85V

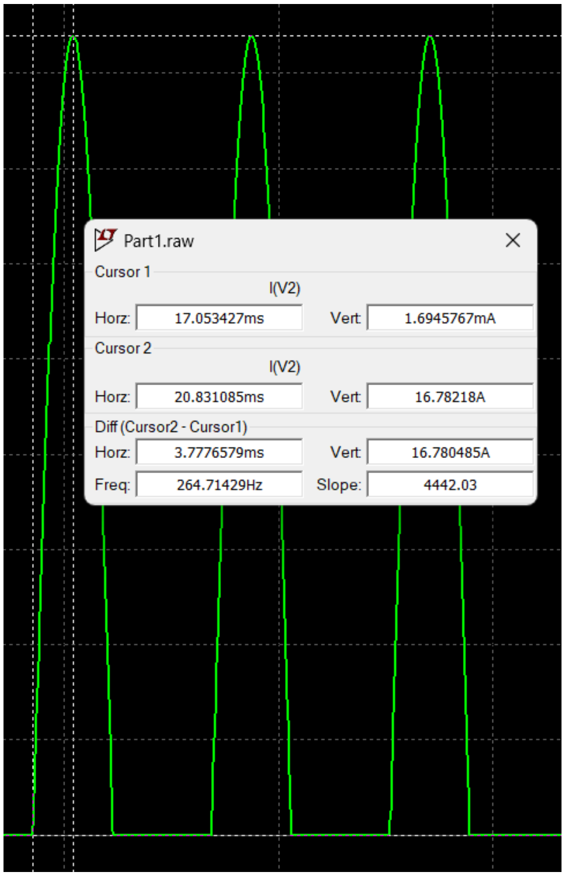


Negative terminal Voltage = 12.9V

P = VI = (85V - 12.9V) 17A = 1225.7W

14)



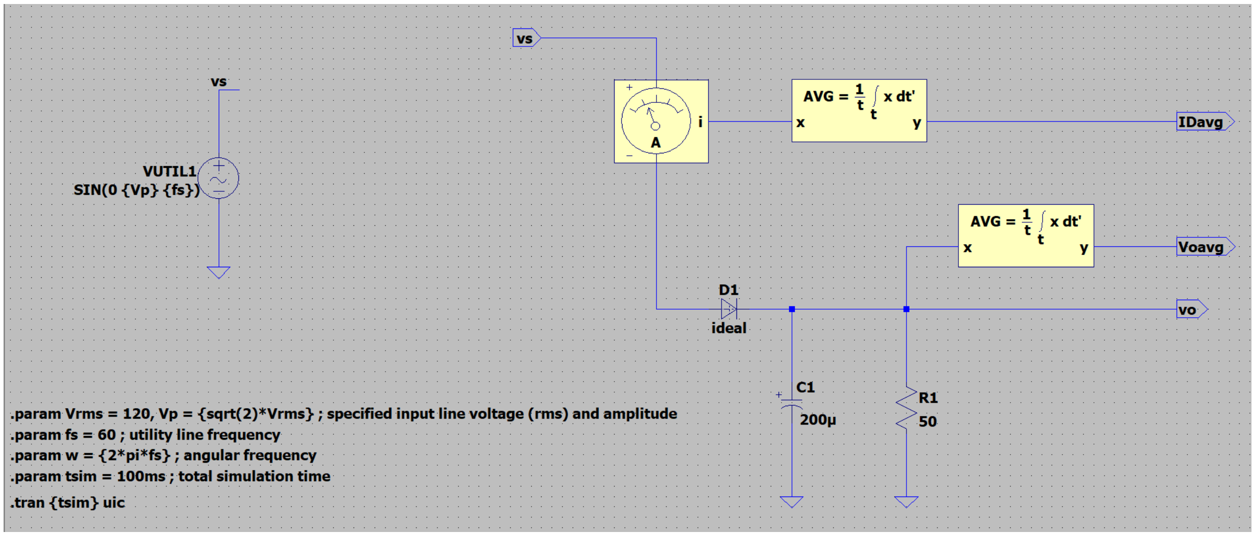


It takes about 3.77ms to fully charge the battery

16) Many of the discrepancies between theoretical and simulation results stem from the accuracy of the simulation results since when they do their calculations they use more decimal points which allow it to be more accurate.

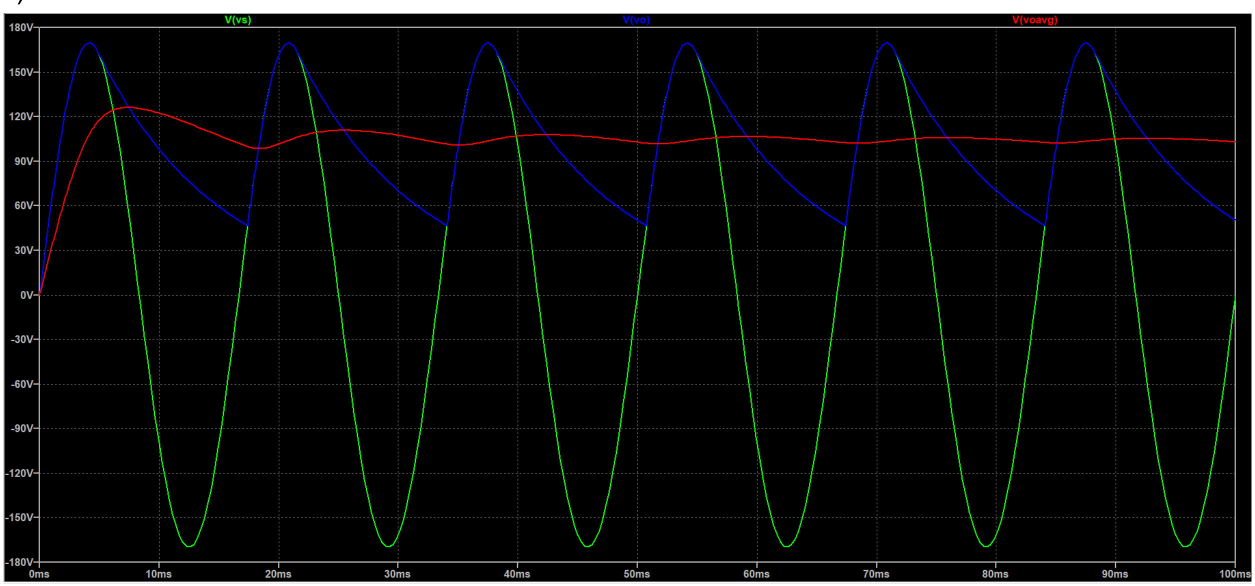
2.2

1)



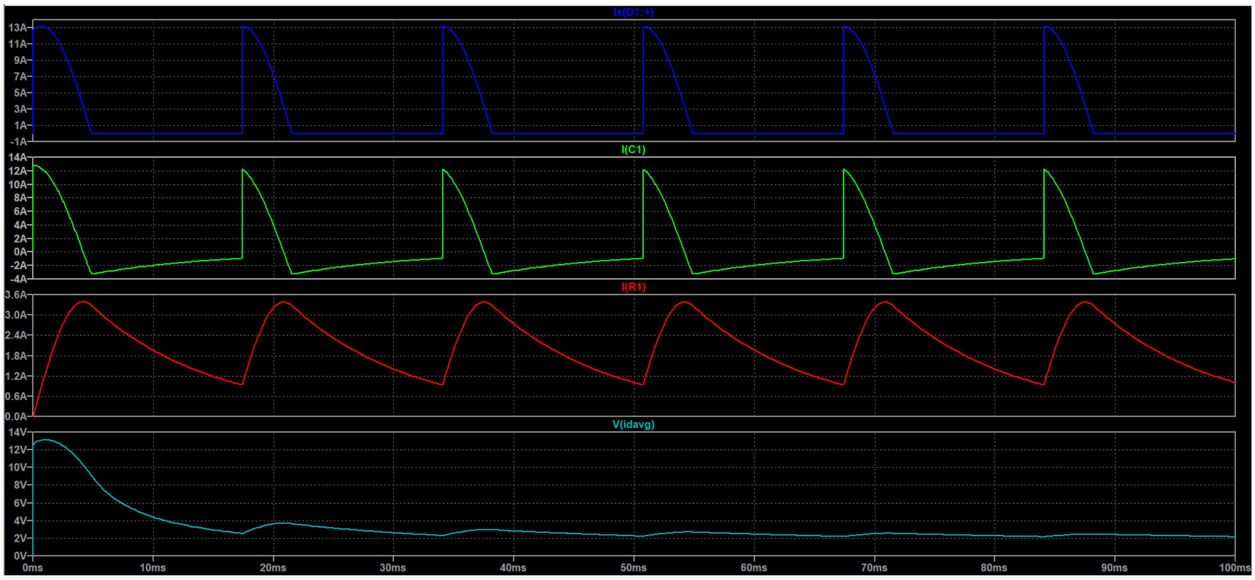
vs
vs
VUTIL1
SIN(0 {Vp} {fs})
A
i
AVG = 1/t ∫t x dt'
x
y
IDavg
AVG = 1/t ∫t x dt'
x
y
Voavg
D1
ideal
vo
C1
200µ
R1
50
.param Vrms = 120, Vp = {sqrt(2)*Vrms} ; specified input line voltage (rms) and amplitude
.param fs = 60 ; utility line frequency
.param w = {2*pi*fs} ; angular frequency
.param tsim = 100ms ; total simulation time
.tran {tsim} uic

2)



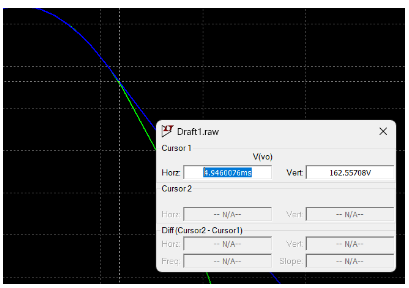
V(vs)
V(vo)
V(voavg)
180V
150V
120V
90V
60V
30V
0V
-30V
-60V
-90V
-120V
-150V
-180V
0ms
10ms
20ms
30ms
40ms
50ms
60ms
70ms
80ms
90ms
100ms

3)



4)

Experimental:



t_θ = 4.95 ms

θ = ωt_θ = 2*π*60hz*4.95ms = 1.87 rads

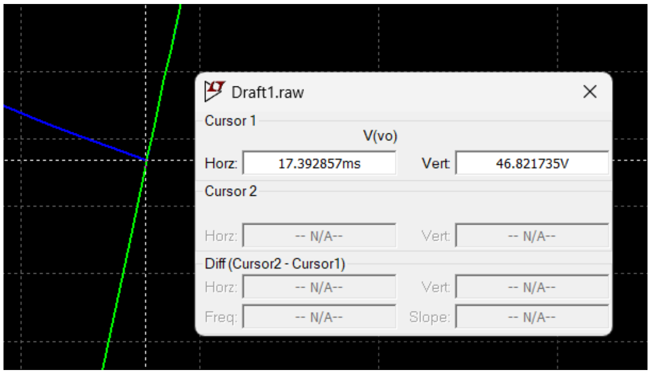
Theoretical:

(2.1) $\theta = \pi - \tan^{-1} \omega\tau$, where $\tau = RC$ is the time constant

θ = π - tan^-1(wrc) = π - tan^-1(2πfrc) = π - tan^-1(2π*60hz*50Ω*200μF) = 1.83 rads

Both Theoretical and Experimental are close enough to one another to be considered the same

5)



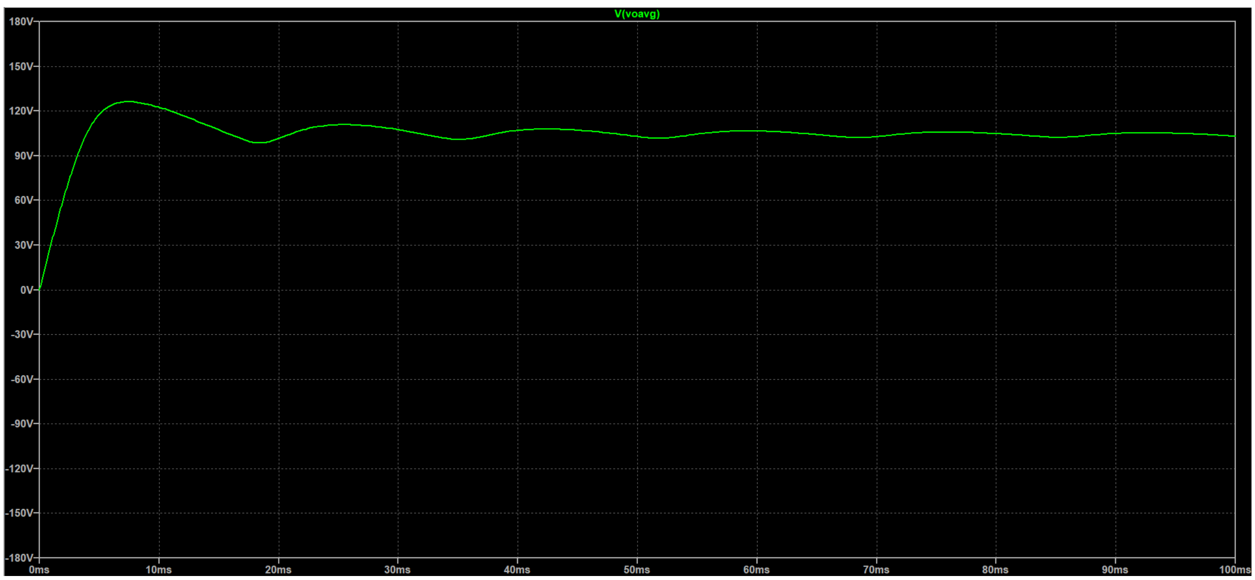
t_θ = 17.39 ms

$\theta = \omega t_\theta$ = 2*π*60hz*17.39ms = 6.55 rads

$\alpha = \theta$ - 2pi = 6.55 - 6.28 = 0.27 rads

6)

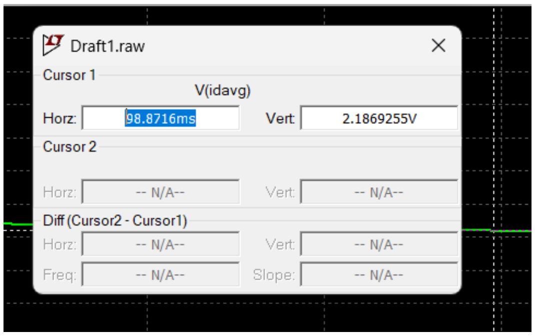
Experimental:



We can see that it approaches steady-state at 105 V

Theoretical:

$$(2.9) \qquad V_{o,avg} = I_{R,avg} R$$



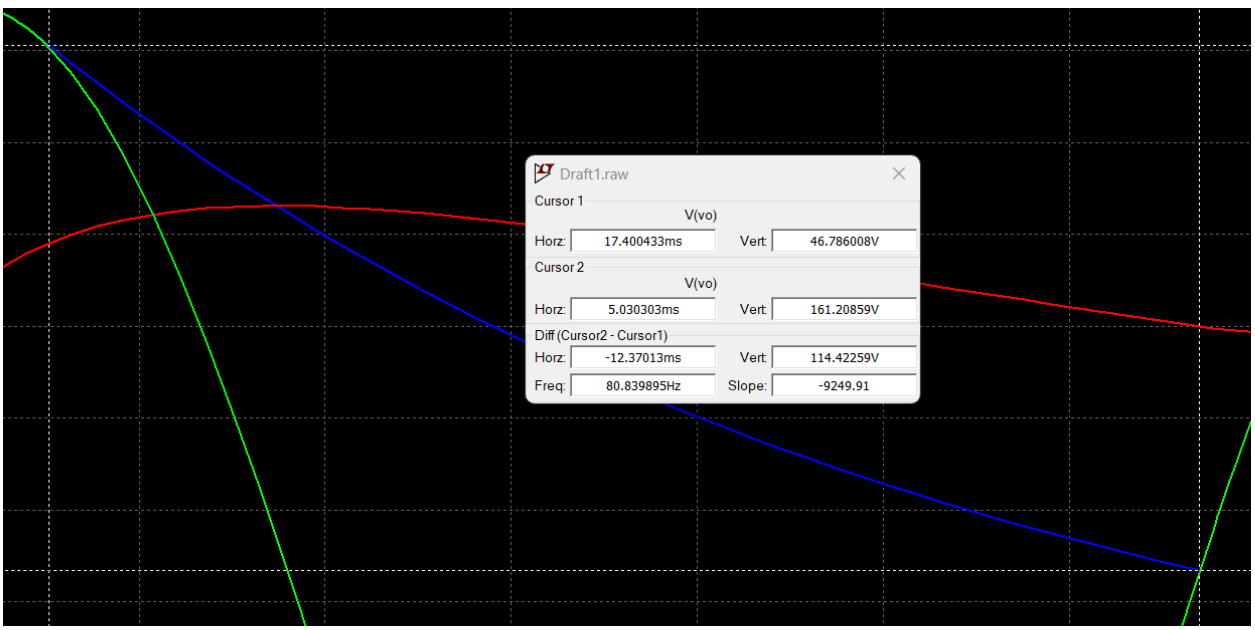
$I_{D,\ AVG} = 2.19$ A

$V_{O,\ AVG} = I_{R,\ AVG} {}^{*}R = I_{D,\ AVG} {}^{*}R = 2.19\text{A} * 50\Omega = 109.5$ V

Both Theoretical and Experimental are very close to one another to be considered the same

7)

Experimental:



From here we can see that $\Delta V_O = 114.42$ V

Theoretical:

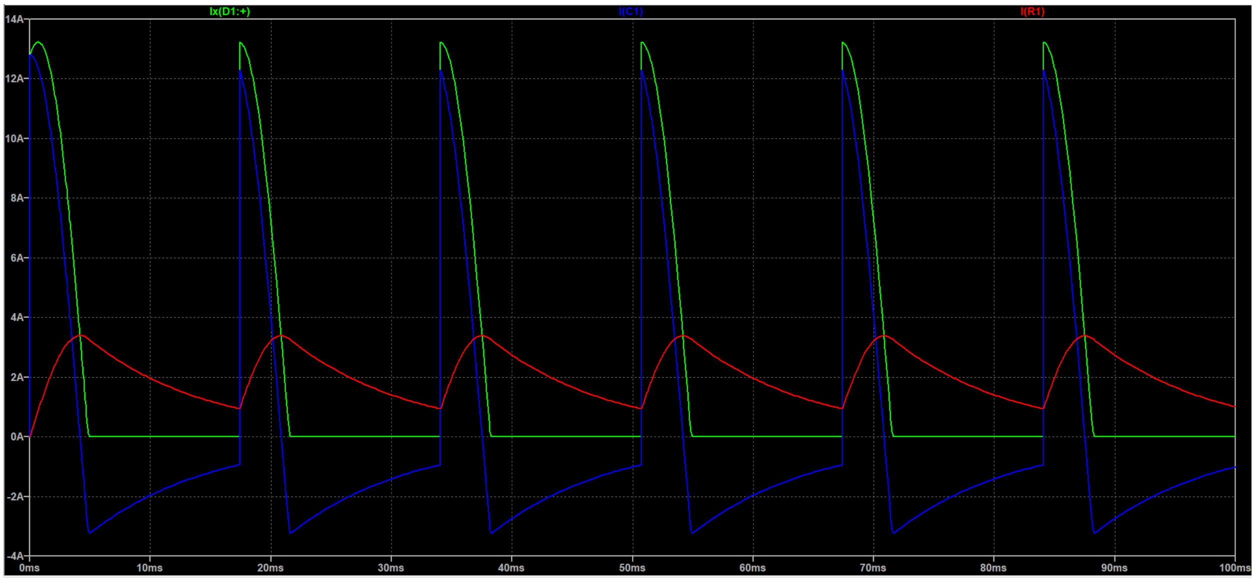
$$(2.10) \qquad \Delta V_o = V_m(1-\sin\alpha) \approx V_m \frac{2\pi}{\omega\tau} = \frac{V_m}{fRC}$$

$V_m = 169.59$ V

$\Delta V_O = V_m\,(1 - \sin(\alpha)) = 169.59\,(1 - \sin(0.27) = 124.36$ V

Both Values are close enough to one another to be considered correct but there is a larger margin between them compared to previous problems.

8)



Diode is ideal so no voltage drop

V_m = 169.59 V

$I_{R,\ MAX}$ = 3.39 A

$I_{C,\ MAX}$ = 12.29 A

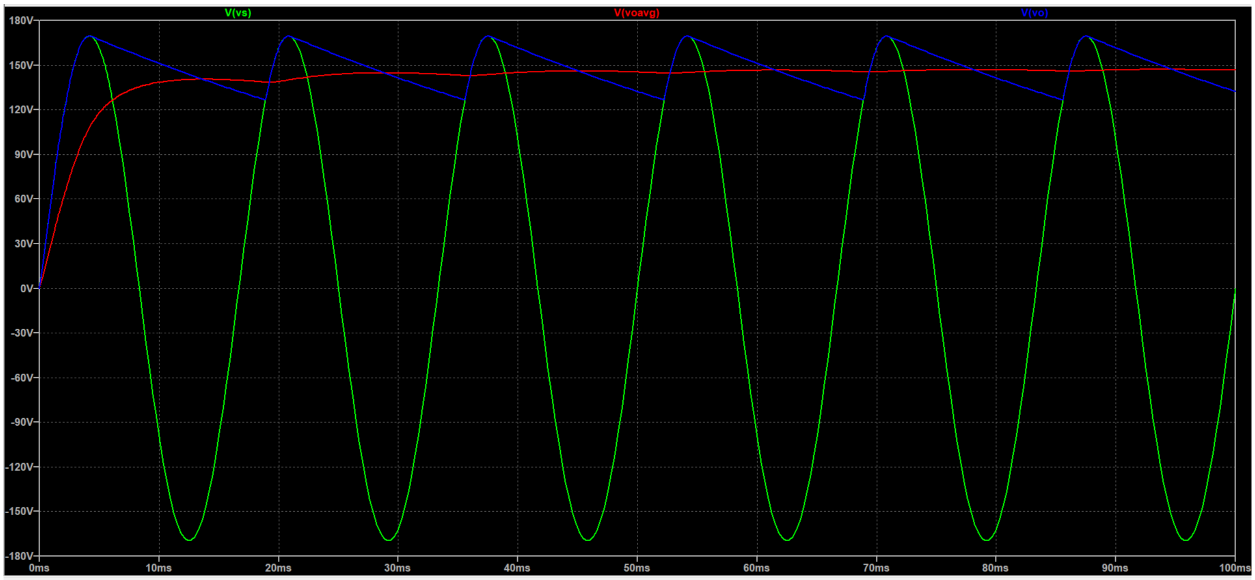
$I_{D,\ MAX}$ = 13.22 A

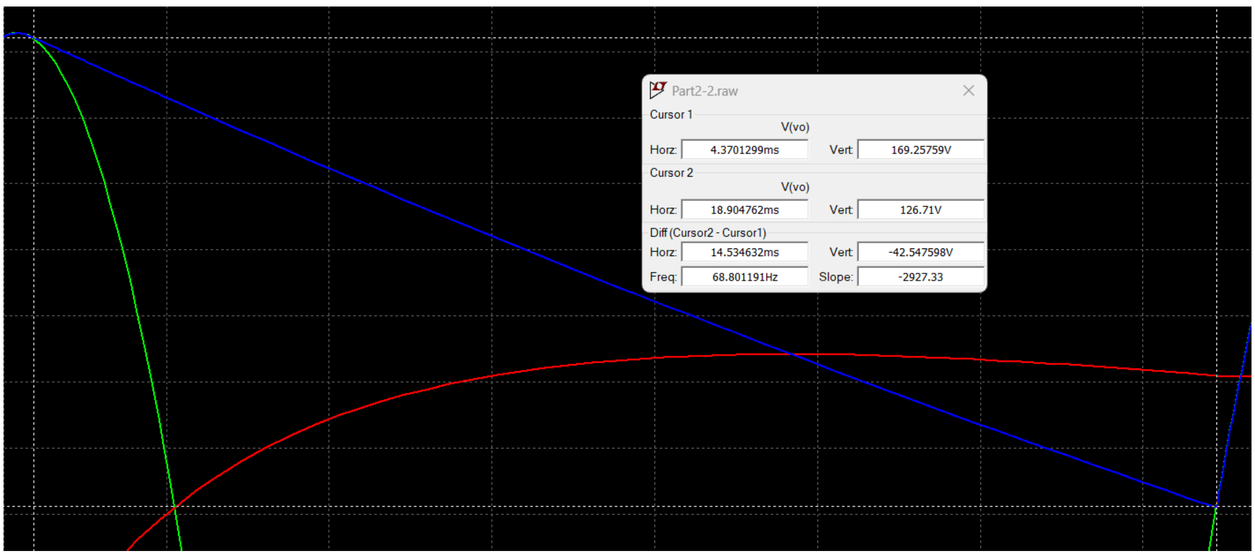
P_R = 3.39 A * 169.59 V = 574.91 W

P_C = 12.29 A * 169.59 V = 2084.26 W

P_D = 13.22 A *169.59 V = 2241.98 W

9)

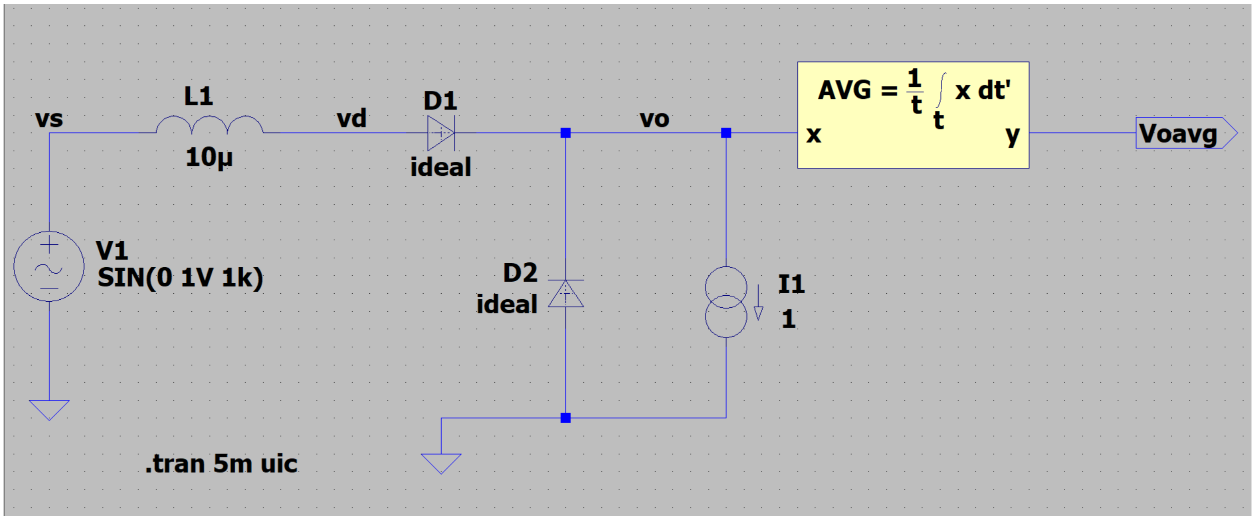




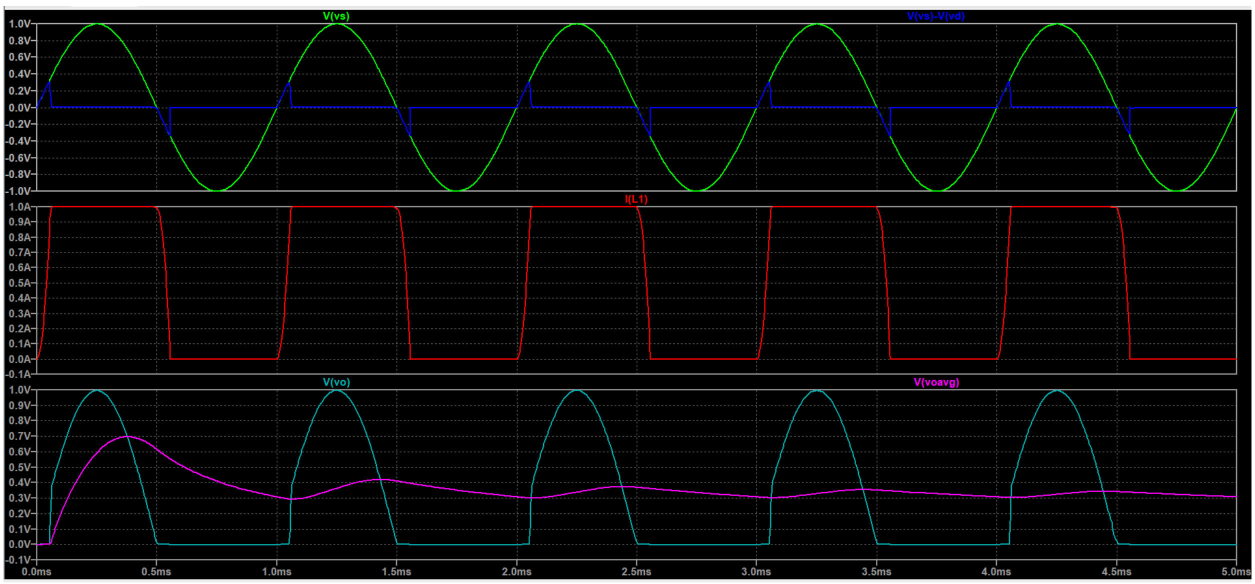
In this case ΔV_O = 41.03 V which is considerably less compared to 114.42
We would probably need to increase the capacitance even more to actually serve as a constant voltage source. This does however prove that capacitors can be used as a constant voltage source.

3.2

1)

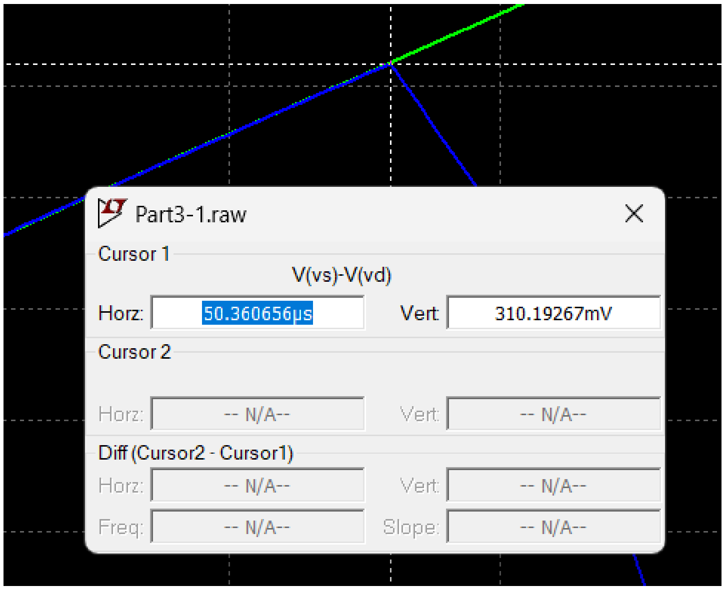

vs
L1
10μ
vd
D1
ideal
vo
AVG = 1/t ∫ x dt'
t
x
y
Voavg
V1
SIN(0 1V 1k)
D2
ideal
I1
1
.tran 5m uic

2)


V(vs)
V(vs)-V(vd)
I(L1)
V(vo)
V(voavg)

3)

Experimental:



t_u = 50.36us

u = wt_u = 2 * π * 1000Hz * 50.36s *10^-6 = 0.32 rads

Theoretical:

$$u = \cos^{-1}\left(1 - \frac{\omega L_s I_d}{V_m}\right) \quad (3.1)$$

w= 2pi*f= 2π*1000 = 6280 rad/s

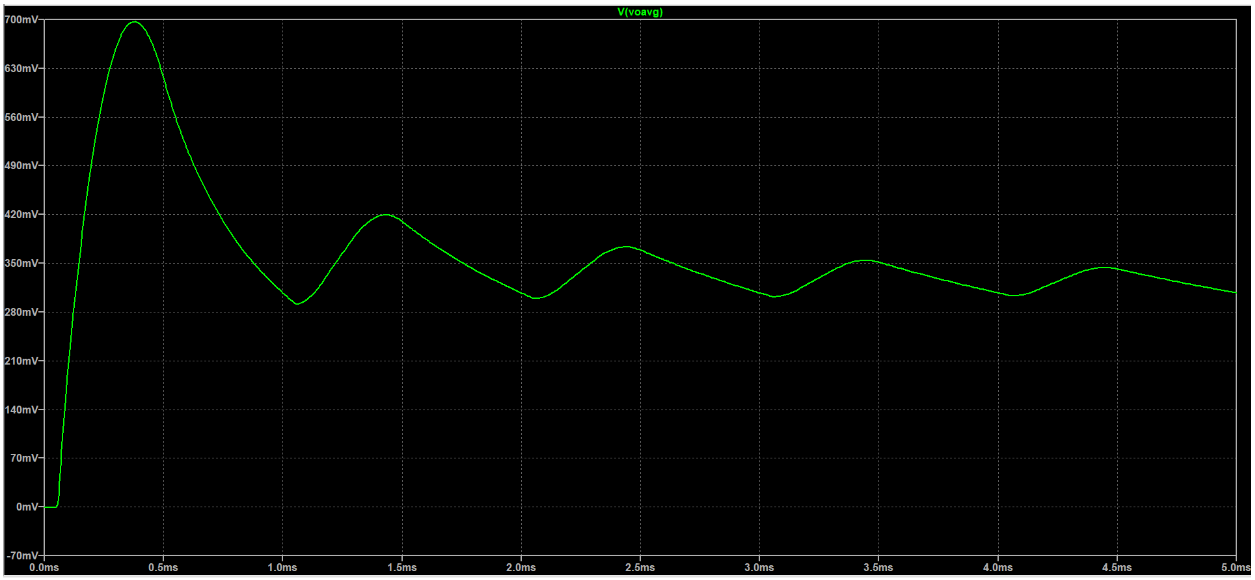
V_m= sqrt(2) * Vrms = sqrt(2) * 1V = 1.41 V

u = cos^-1 (1 - (wL_sI_d)/V_m) = cos^-1 (1 - (6280rad/s * 10H*10^-6 * 1A) / 1.41V) = 0.30 rads

Both Theoretical and Experimental values are very close to one another to be considered the same

4)

Experimental:



We can see that it approaches steady-state at about 324 mV = 0.324 V

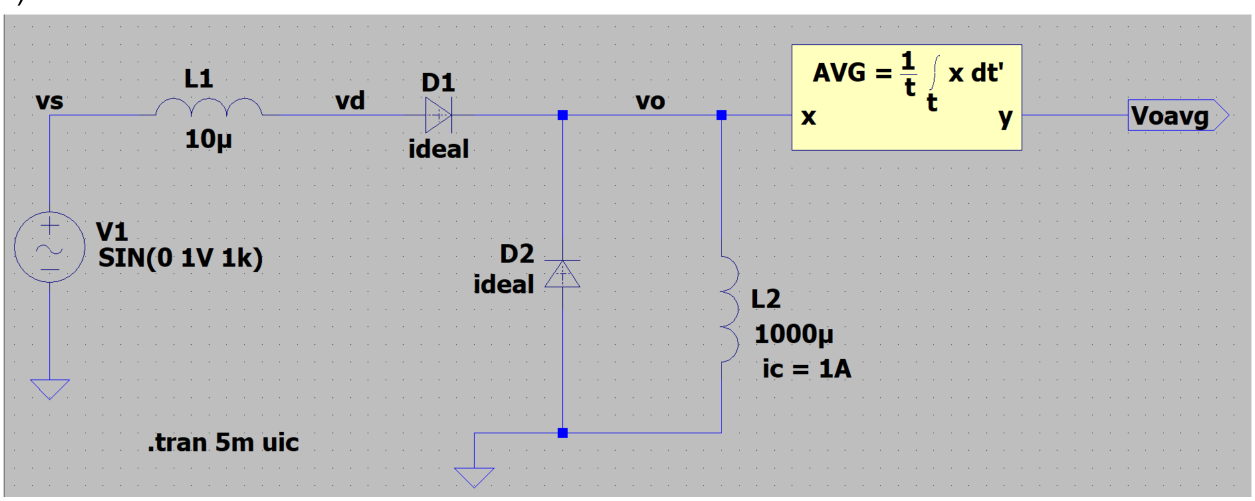
Theoretical:

$$(3.3) \qquad V_o = \frac{V_m}{\pi} - \frac{1}{2\pi}\int_o^u V_m \sin\omega t \, d(\omega t) = \frac{V_m}{\pi} - \frac{\omega L_s}{2\pi} I_d$$

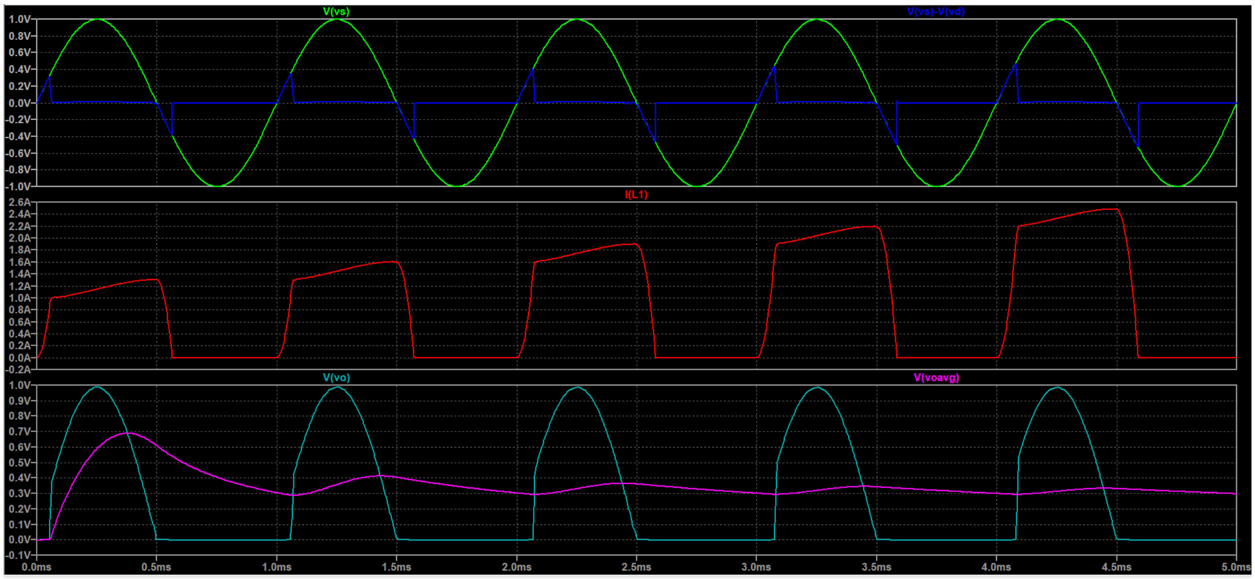
$V_O = V_m/\pi - (wL_sI_d)/2\pi = 1.41V/\pi - (6280rad/s * 10H*10^{-6} * 1A) / 2\pi = 0.439$ V

Yes, it's pretty close to the simulation. In the simulation, we got around 0.324 V

6)

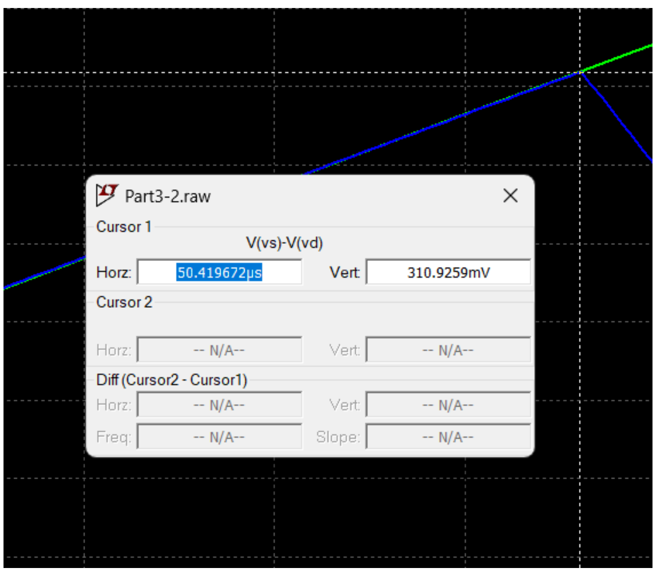


9)



Commutation angle

Experimental:



t_u = 50.42us

u = wt_u = 2 * π * 1000Hz * 50.36s *10^-6 = 0.32 rads

Theoretical:

$$u = \cos^{-1}\left(1 - \frac{\omega L_s I_d}{V_m}\right) \quad (3.1)$$

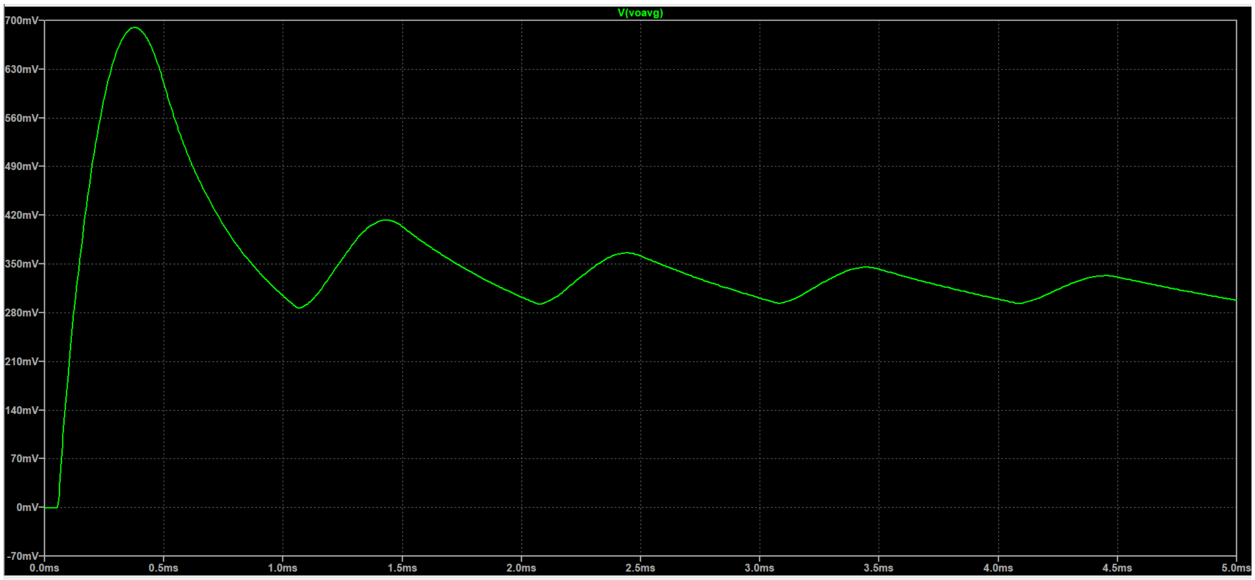
w= 2pi*f= 2π*1000 = 6280 rad/s

V_m= sqrt(2) * Vrms = sqrt(2) * 1V = 1.41 V

u = cos^-1 (1 - (wL_sI_d)/V_m) = cos^-1 (1 - (6280rad/s * 10H*10^-6 * 1A) / 1.41V) = 0.30 rads

Both Theoretical and Experimental values are very close to one another it is also similar to when we used a current source

Average Output Voltage
Experimental:



We can see that it approaches steady-state at about 315 mV = 0.315 V

Theoretical:
$V_O = V_m/\pi - (wL_sI_d)/2\pi = 1.41V/\pi - (6280rad/s * 10H*10^{-6} * 1A) / 2\pi = 0.439$ V

Here we notice that we use the same values to find the output voltage which results in the same result from when we used a current source.
Overall, inductors can act as current sources, we can see this due to almost no changes in any of our calculations. The major difference is that I_{L1} takes longer to reach its maximum value.

Practice Problem Encounters:

The common problem we encountered during this lab was mainly on the calculation. There are so many components we need to calculate, and sometimes we made mistakes along the way. It was quite overwhelming in calculation for this lab.

Conclusion:

The overgoal of this lab is to be able to understand the concept of the half-wave rectifier circuit schematic, and the simulation. For the first part of the lab, the goal was to understand the half-wave rectifier battery charger schematic circuit and run the simulation to find out the values of all the components from the formula or according to the questions. For the second part of the lab, the objective was to be able to do analysis of Half-Wave Rectifiers with Capacitive Loads on LTSpice simulation by understanding the concept of circuit schematic. For the last part of the lab, the objective was to be able to do analysis of Half-Wave Rectifiers Powering Inductive Loads on LTSpice simulation by understanding the concept of circuit schematic.