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Lab 1 - Power Characterization. Diodes and Controlled Rectifiers

Lab Section 021

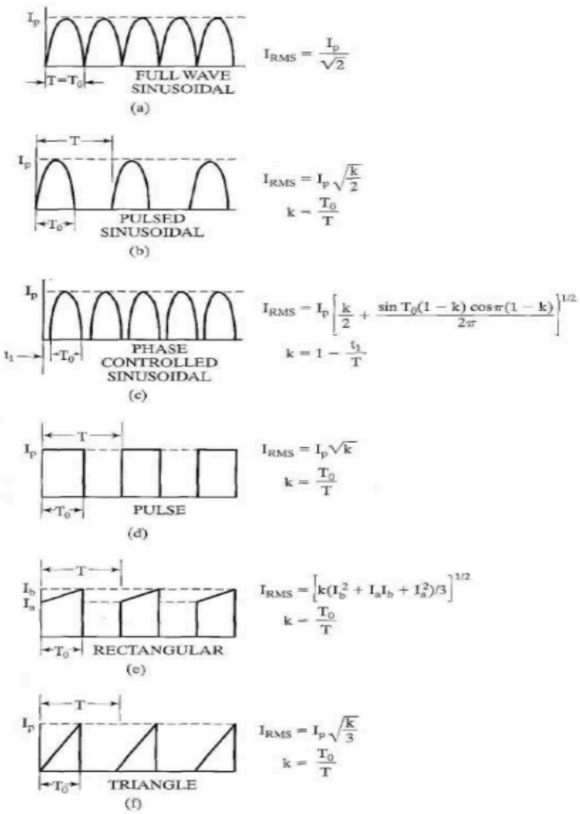
TA’s Name: Zijin Pan

Introduction:

The objectives for the lab are to familiarize ourselves with the LTspice IV® software* environment. We hope to gain an understanding of different power characterization quantities such as instantaneous, average, rms power, power generation and consumption, power factor. We will find the i-v characterization and operation principles of fundamental power switching of regular rectifiers (diodes) and controlled rectifiers (SCRs and Triacs). We will recognize the basic evaluation of power consumption by switching power components and comparing them.

Theory:

The theoretical of this lab is to calculate the average rms by applying these formula below:



Voltage RMS and Current RMS

$$(1.14)\quad V_{rms} = \frac{1}{\sqrt{2}}V_m, \text{ and } I_{rms} = \frac{1}{\sqrt{2}}I_m$$

Average or Real or True Power

$$(1.13)\quad P \equiv P_{ave} = \lim_{t\to\infty}\frac{1}{t}\int_{t_0}^{t} p(\tau)d\tau = \frac{1}{2}V_m I_m \cos(\theta_V - \theta_I) \qquad \text{[W]}$$

Apparent Power

$$(1.15)\quad S = V_{rms} I_{rms} = \frac{1}{2}V_m I_m \qquad \text{[VA]}$$

Power Factor

$$(1.16)\quad \text{p.f.} = \frac{P}{S} = \cos(\theta_V - \theta_I)$$

Thyristors theories:

Both the SCR and the Triacs are time-independent in nature of switching. The diode switching action can only be achieved with AC power sources. Voltage controlled switches are considered a class of the relay type electromagnetic switches whose state of being closed or open is controlled by the applied voltage. The diode lacks applicability to controlled switching and that is where the thyristor comes in

For SCR(Silicon-Controlled Rectifiers)

SCR will only begin to conduct as soon as the source becomes positive

$$V_o = V_{avg} = \frac{1}{2\pi}\int_0^{\pi} V_m \sin\omega t \, d(\omega t) = \frac{V_m}{2\pi}(1+\cos\alpha)$$

$$V_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} [V_m \sin\omega t]^2 \, d(\omega t)} = \frac{V_m}{2}\sqrt{1-\frac{\alpha}{\pi}+\frac{\sin 2\alpha}{2\pi}}$$

$$P_{rms} = V_{rms} I_{rms} = V_{rms}^2 / R$$

For Triacs

Triacs act like SCRs but allow current to be turned on in both directions

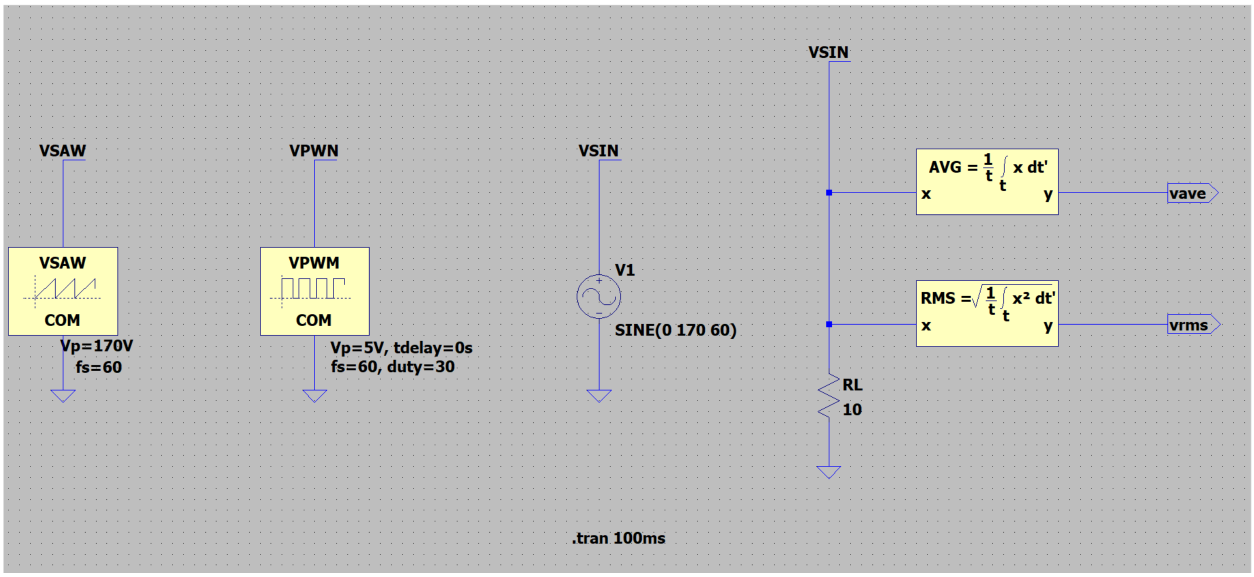
$$V_{rms} = \frac{V_m}{\sqrt{2}}\sqrt{\frac{1}{\pi}\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)}$$

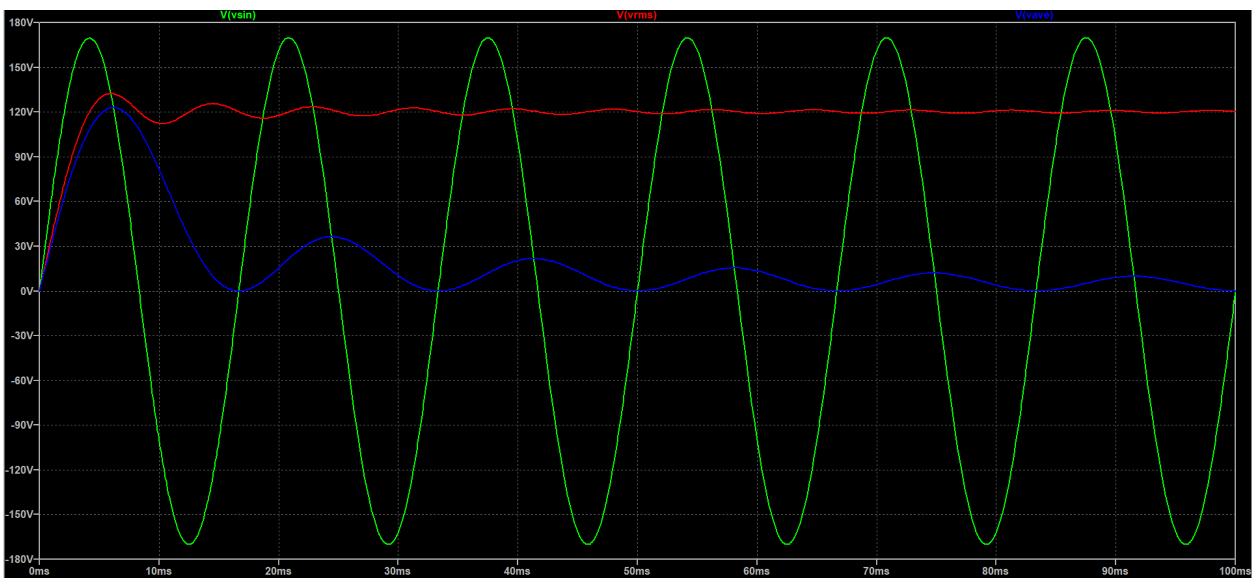
$$P_{rms} = V_{rms} I_{rms} = V_{rms}^2 / R$$

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

1.5.1 Average and RMS Values of Waveforms

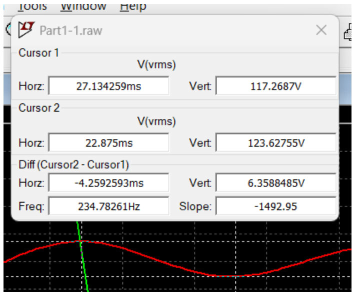
1)



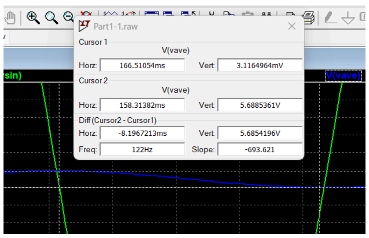


V_{SIN} = Green, V_{RMS} = Red, V_{AVE} = Blue

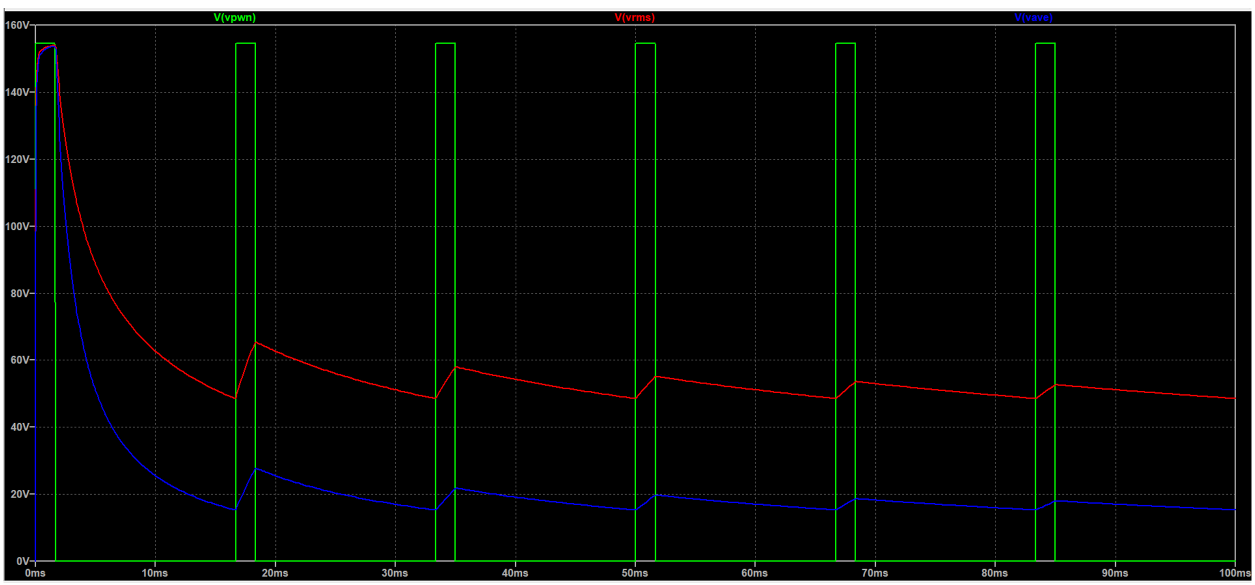
2)
V_{RMS}
Peak = 132.5 V
5% = 6.625
3 Oscillations



V_{AVE}
Peak 123.2
5% = 6.16
10 Oscillations

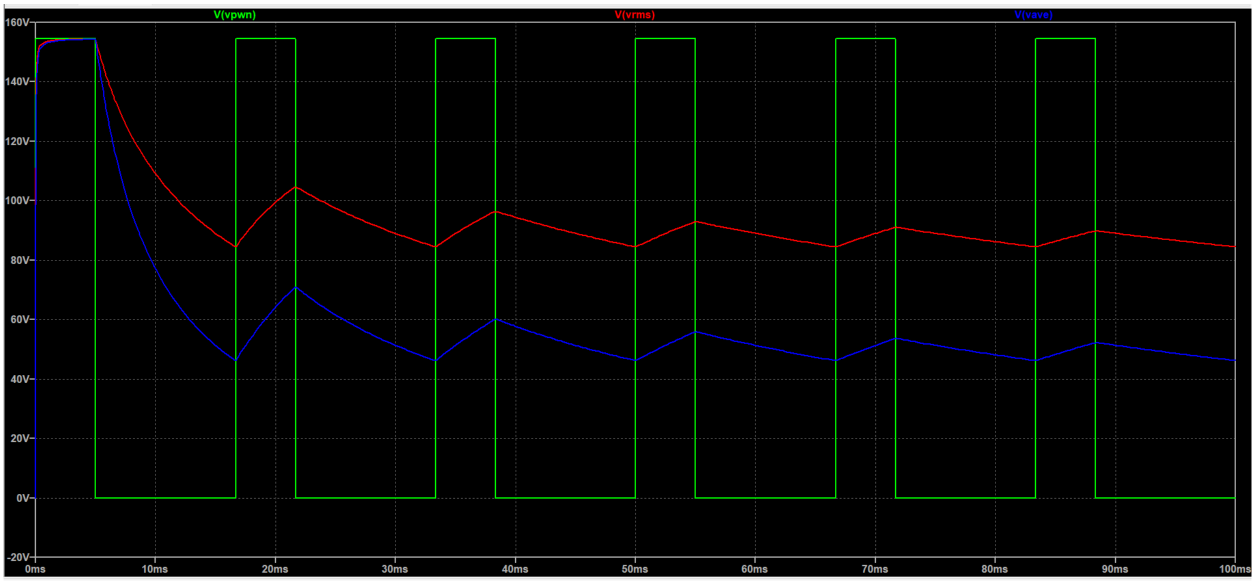


3) V_{PWM}
For the Duty Cycle = 10:



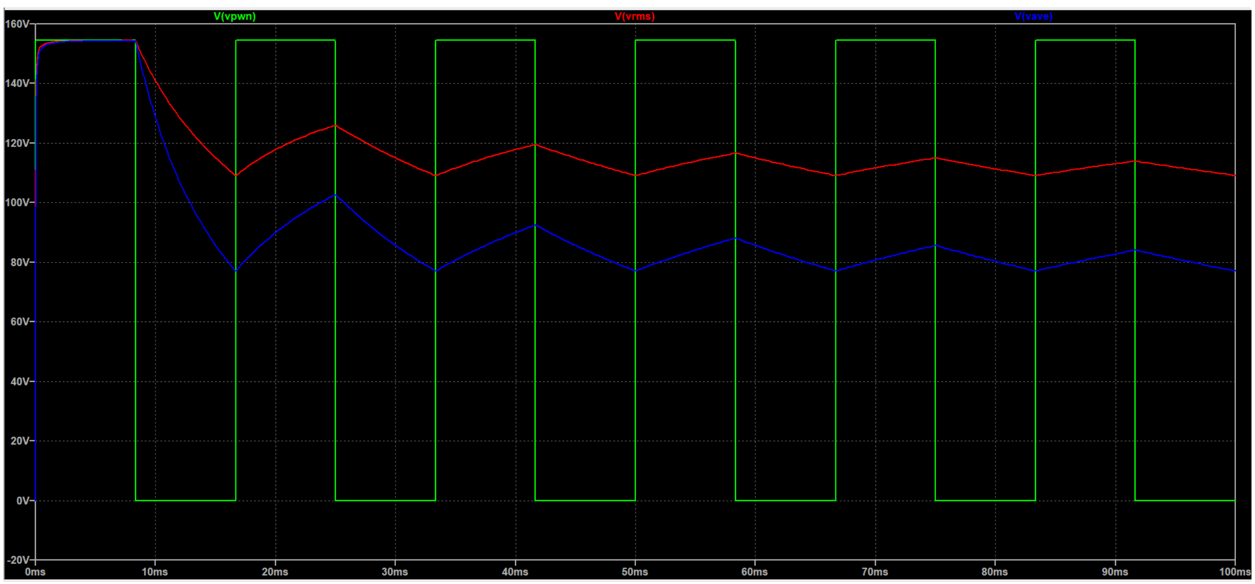
V_{PWM} = Green, V_{RMS} = Red, V_{AVE} = Blue

For the Duty Cycle = 30:



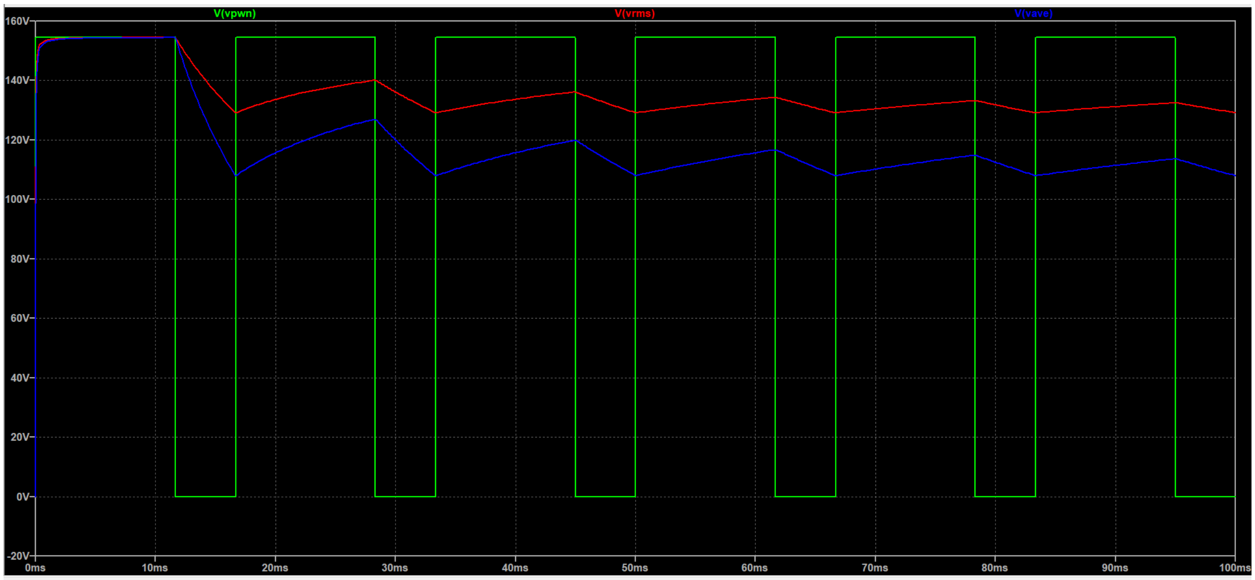
V_{PWM} = Green, V_{RMS} = Red, V_{AVE} = Blue

For the Duty Cycle = 50:



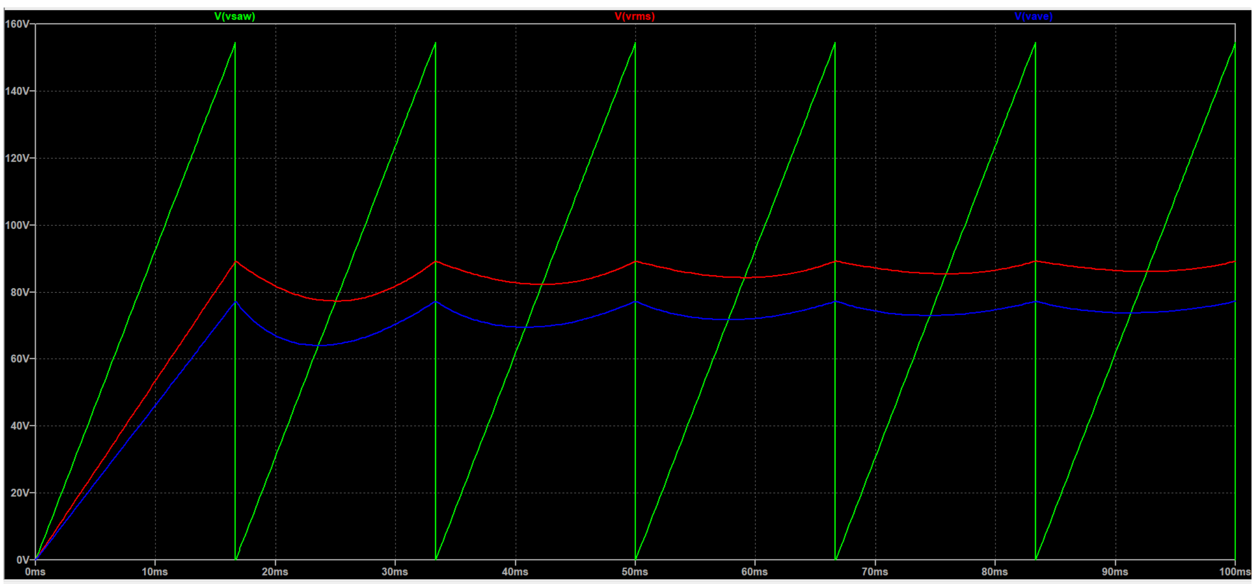
V_{PWM} = Green, V_{RMS} = Red, V_{AVE} = Blue

For the Duty Cycle = 70:



V_{PWM} = Green, V_{RMS} = Red, V_{AVE} = Blue

V_{SAW}

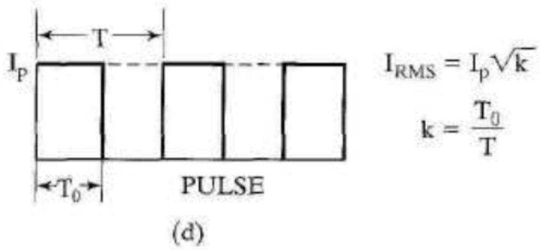


V_{SAW} = Green, V_{RMS} = Red, V_{AVE} = Blue

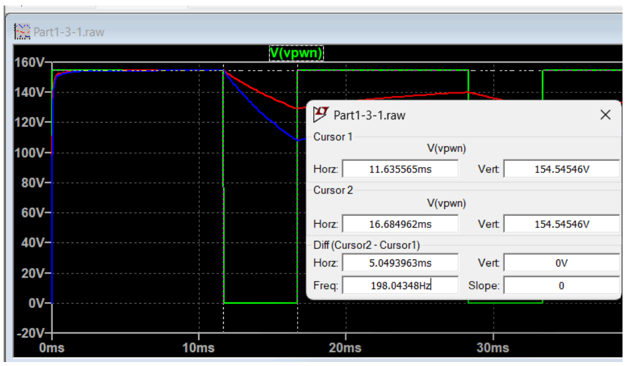
V_{RMS} always has greater voltage compared to the V_{AVE}. V_{RMS} and V_{AVE} follow the trend of the given input voltage. For V_{PWM}, we can see that the duty cycle affects how high the peaks of the V_{RMS} and the V_{AVE}. As the duty cycle increases the V_{RMS} and the V_{AVE} steady states also increases. The on part of the duty cycle also dictates how long the V_{RMS} and the V_{AVE} increase and vice versa. For V_{SAW}, we can see that it is similar to the V_{PWM} as it follows the trend of the input voltage but we can see that V_{RMS} and V_{AVE} are located at about the middle of the sawtooth. For V_{SIN}, we can see that the V_{RMS} is about 10V below the peak of the input voltage and the V_{AVE} is located at slightly above 0V.

V_{RMS}

V_{PWM}



Duty Cycle = 70



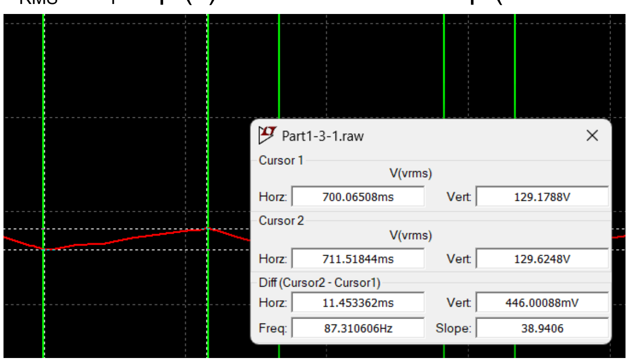
V_P = 154.54546 V

T_0 = 11.635565 ms

T = 16.684962 ms

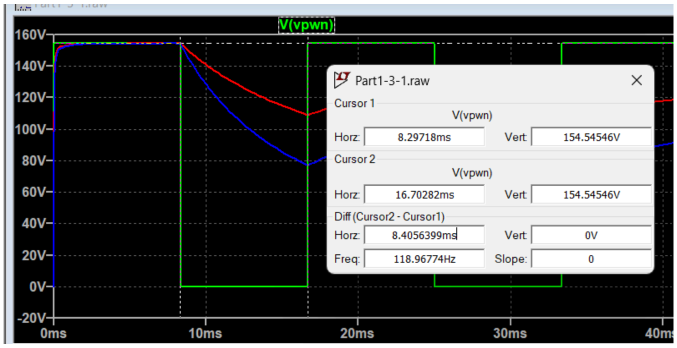
k = T_0 / T = 11.635565 ms / 16.684962 ms = 0.6973683848

V_{RMS} = V_P*sqrt(k) = 154.54546 V * sqrt(0.6973683848) = 129.0587276 V



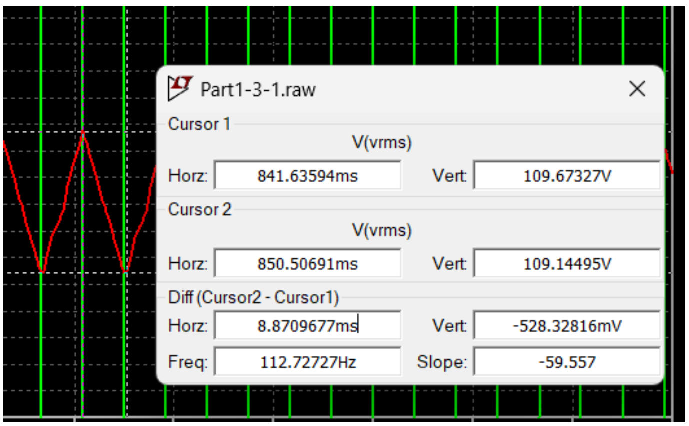
The theoretical V_{RMS} is similar enough to the LTSpice V_{RMS}

Duty Cycle = 50



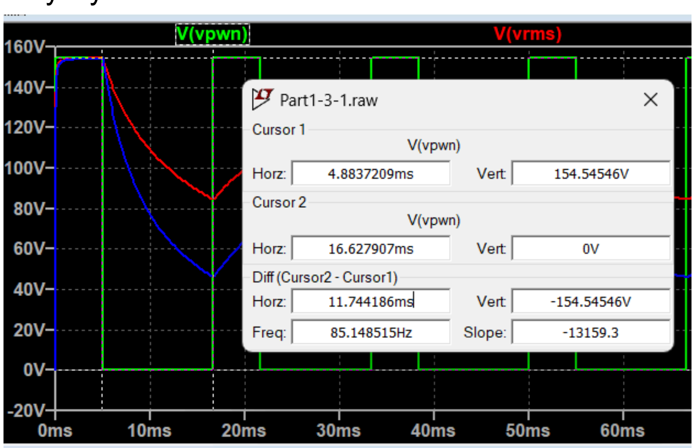
V_P = 154.54546 V
T_0 = 8.29718 ms
T = 16.70282 ms
k = T_0 / T = 8.29718 ms / 16.70282 ms = 0.4967532429

V_{RMS} = V_P*sqrt(k) = 154.54546 V * sqrt(0.4967532429) = 108.9247588 V



The theoretical V_{RMS} is similar enough to the LTSpice V_{RMS}

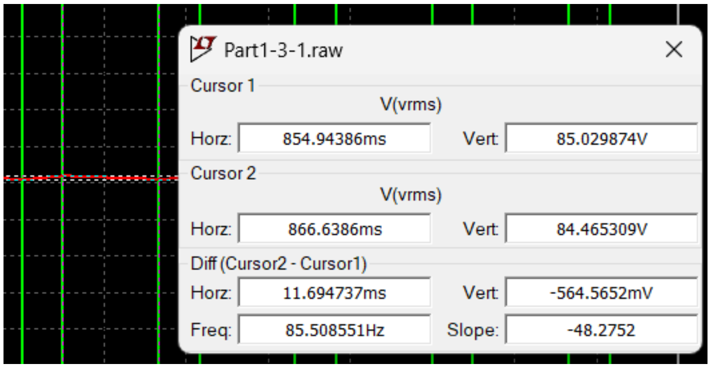
Duty Cycle = 30



V_P = 154.54546 V
T_0 = 4.8837209 ms
T = 16.627907 ms

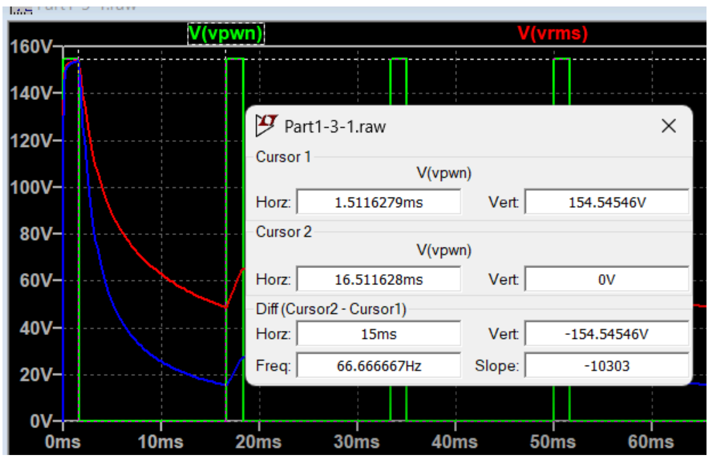
$k = T_0 / T$ = 4.8837209 ms / 16.627907 ms = 0.2937062915

$V_{RMS} = V_P$*sqrt(k) = 154.54546 V * sqrt(0.2937062915) = 84.75541144 V



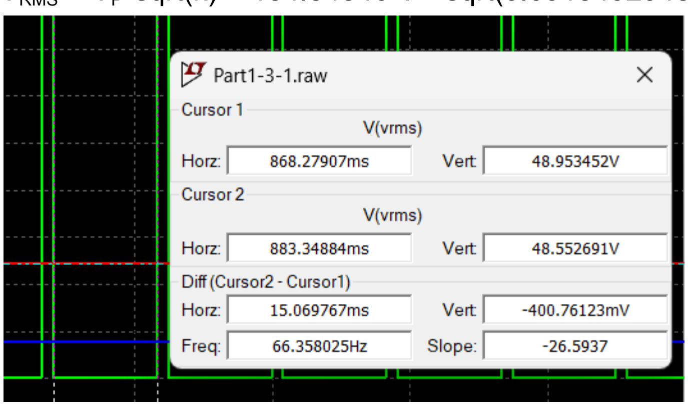
The theoretical V_{RMS} is similar enough to the LTSpice V_{RMS}

Duty Cycle = 10



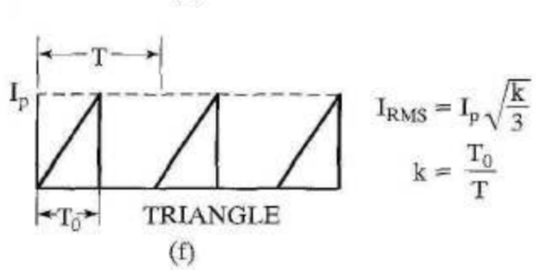
V_P = 154.54546 V
T_0 = 1.5116279 ms
T = 16.511628 ms
$k = T_0 / T$ = 1.5116279 ms / 16.511628 ms = 0.0915492948

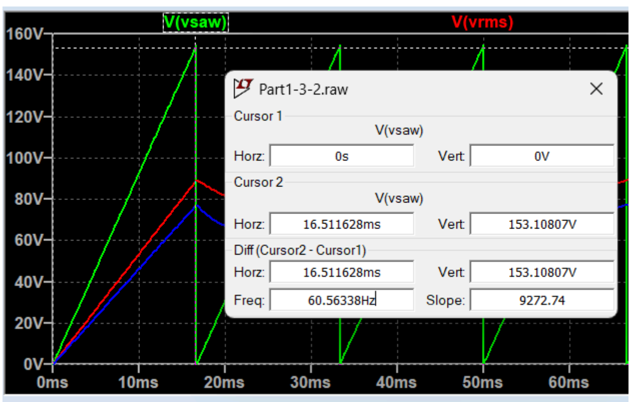
$V_{RMS} = V_P$*sqrt(k) = 154.54546 V * sqrt(0.0915492948) = 46.76099602 V



The theoretical V_{RMS} is similar enough to the LTSpice V_{RMS}

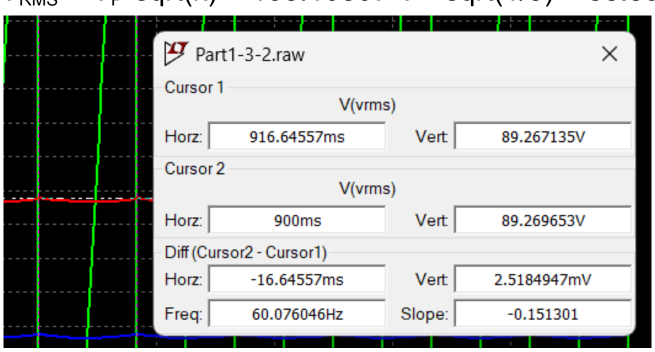
V_{SAW}





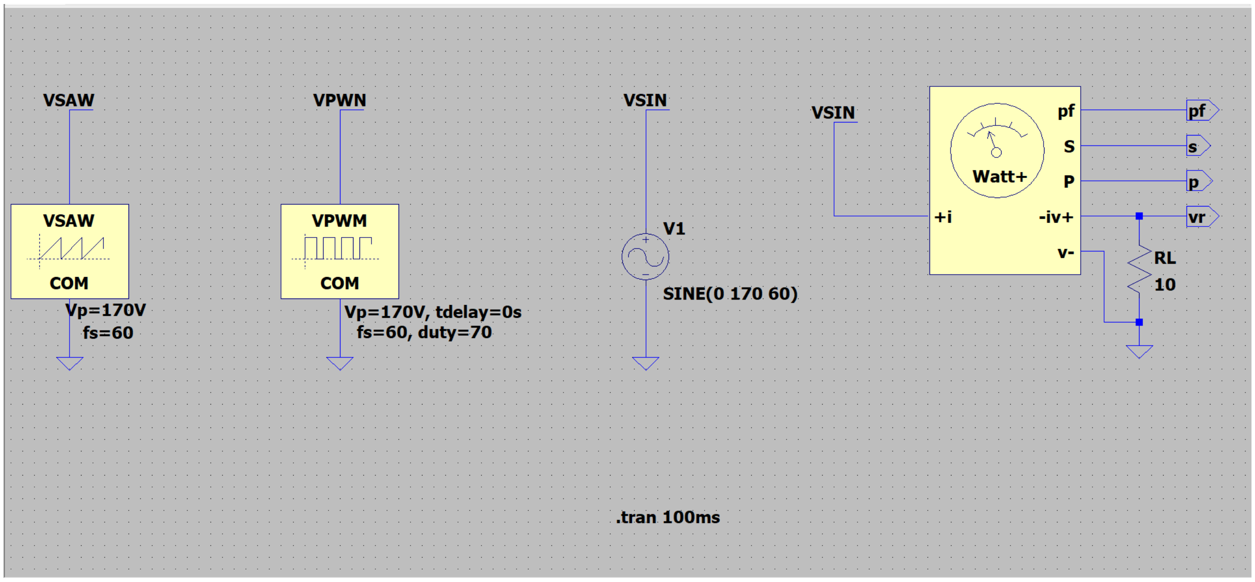
V_P = 153.10807 V
T_0 = 16.511628 ms
T = 16.511628 ms
k = T_0 / T = 16.511628 ms / 16.511628 ms = 1

V_{RMS} = V_P*sqrt(k) = 153.10807 V * sqrt(1/3) = 88.39698543 V



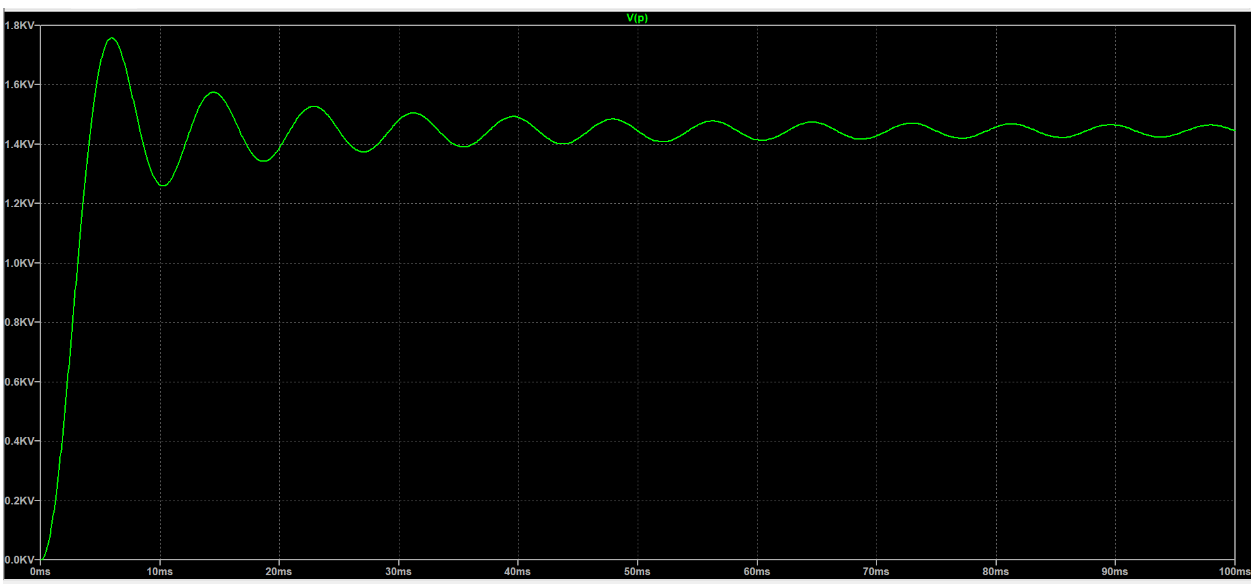
The theoretical V_{RMS} is similar enough to the LTSpice V_{RMS}

4)

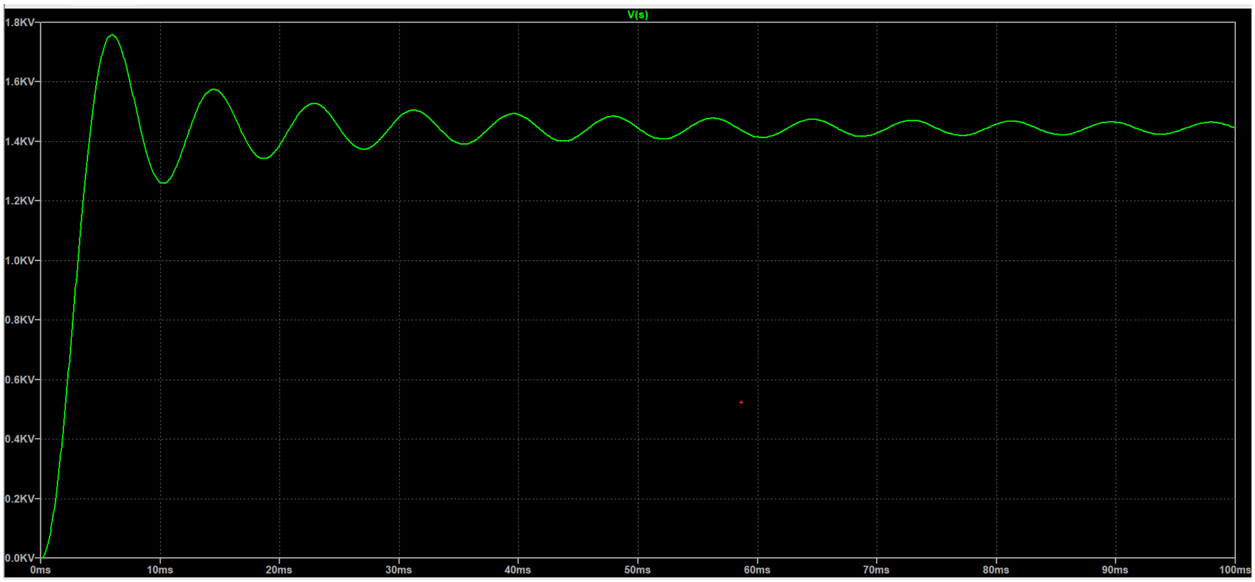


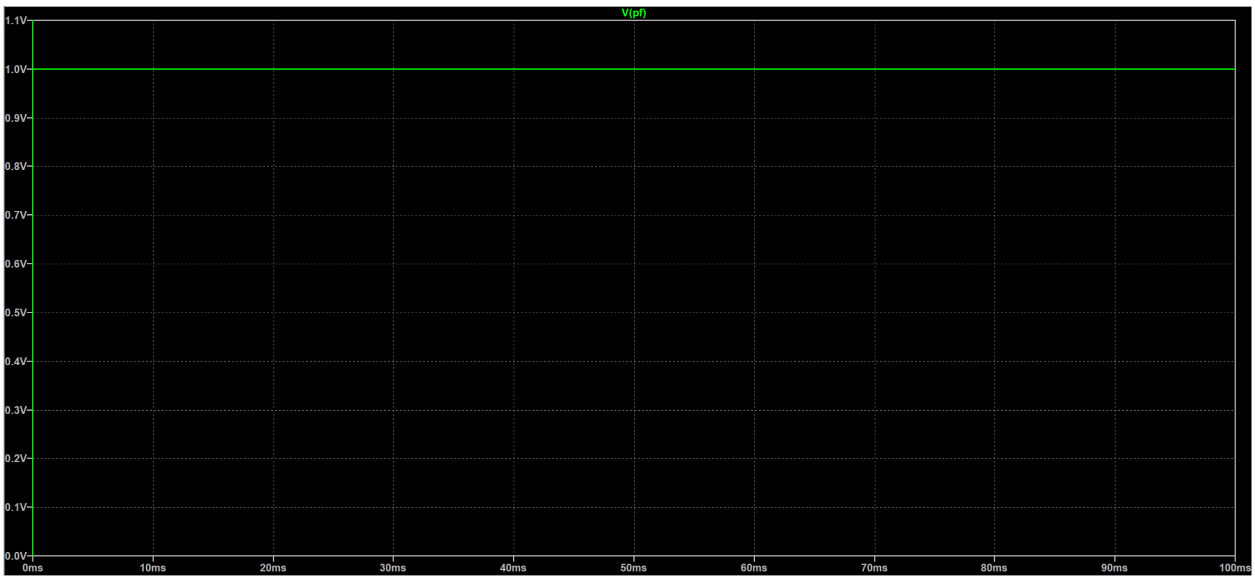
VSAW
VPWN
VSIN
VSIN
VSAW
COM
Vp=170V
fs=60
VPWM
COM
Vp=170V, tdelay=0s
fs=60, duty=70
V1
SINE(0 170 60)
Watt+
pf
S
P
+i
-iv+
v-
pf
s
p
vr
RL
10
.tran 100ms

5)

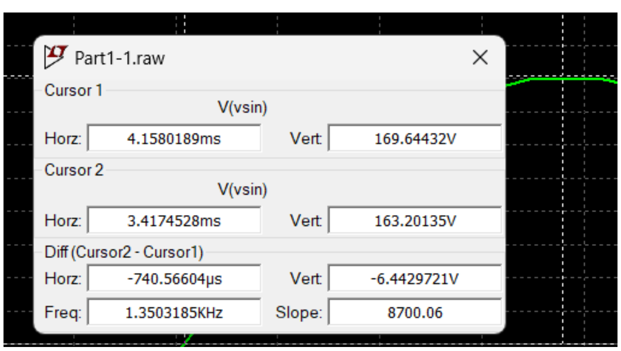


V(p)
1.8KV
1.6KV
1.4KV
1.2KV
1.0KV
0.8KV
0.6KV
0.4KV
0.2KV
0.0KV
0ms
10ms
20ms
30ms
40ms
50ms
60ms
70ms
80ms
90ms
100ms

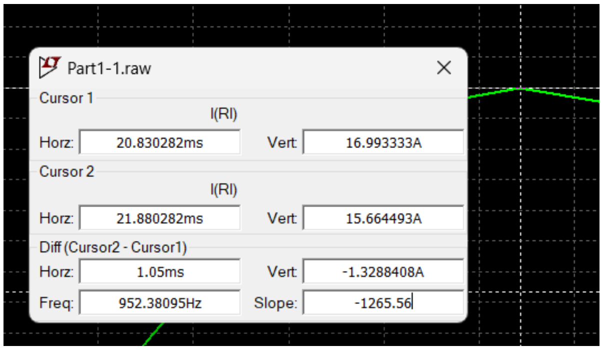




(1.14) $V_{rms} = \frac{1}{\sqrt{2}} V_m$, and $I_{rms} = \frac{1}{\sqrt{2}} I_m$



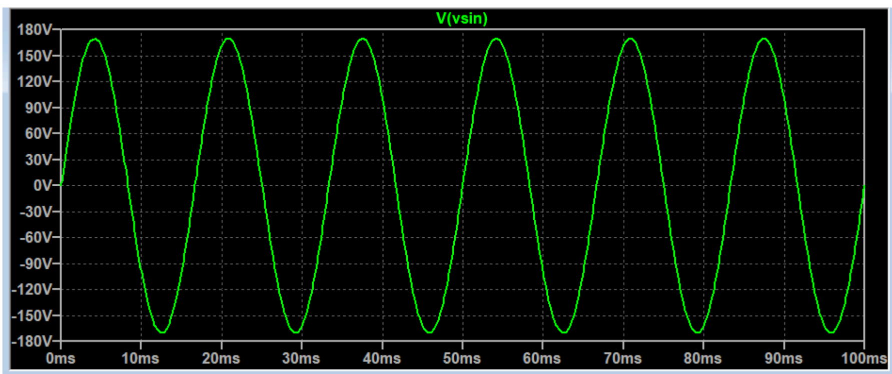
V_p = 169.64432 V



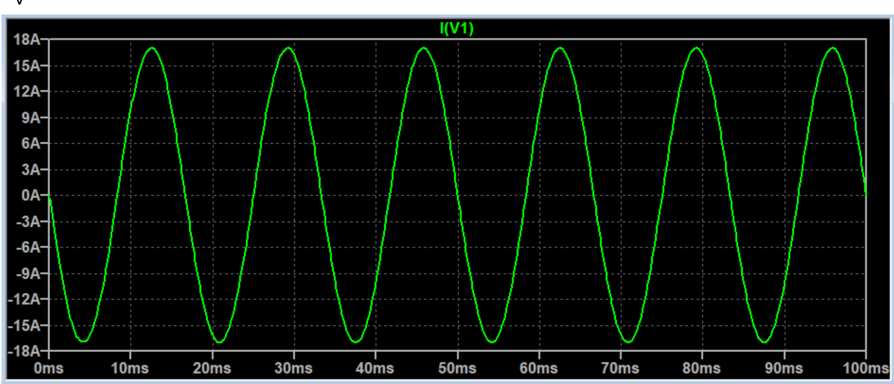
I_p = 16.993333 A

V_{RMS} = V_p * sqrt(2) = 169.64432 V / 1.414213562 = 119.9566491 V
I_{RMS} = I_p * sqrt(2) = 16.997565 A / 1.414213562 = 12.01909348 A

$$(1.13)\quad P \equiv P_{ave} = \lim_{t\to\infty}\frac{1}{t}\int_{t_0}^{t} p(\tau)d\tau = \frac{1}{2}V_m I_m \cos(\theta_V - \theta_I) \qquad [\mathrm{W}]$$



θ_V = π/ 2



θ_I = 3π / 2

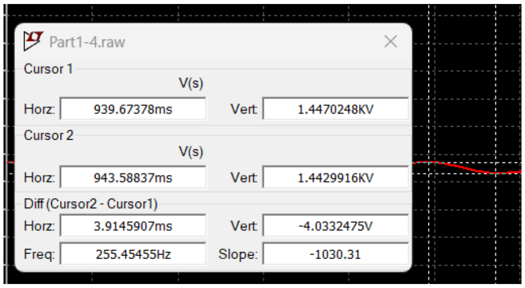
P = ½ V_m I_m cos(θ_V - θ_I) = 0.5 * (1.414213562 * 119.9566491 V) * (1.414213562 * 12.01909348 A) * cos (π/ 2 - 3π / 2) = 1441.770178 W

$$(1.15)\quad S = V_{rms} I_{rms} = \frac{1}{2}V_m I_m \qquad [\mathrm{VA}]$$

S = ½ $V_m I_m$ = (½) * (sqrt(2)*V_{RMS}) * (sqrt(2)*I_{RMS})
= 0.5 * (1.414213562 * 119.9566491 V) * (1.414213562 * 12.01909348 A) = 1441.770178 VA

$$(1.16) \quad \text{p.f.} = \frac{P}{S} = \cos(\theta_V - \theta_I)$$

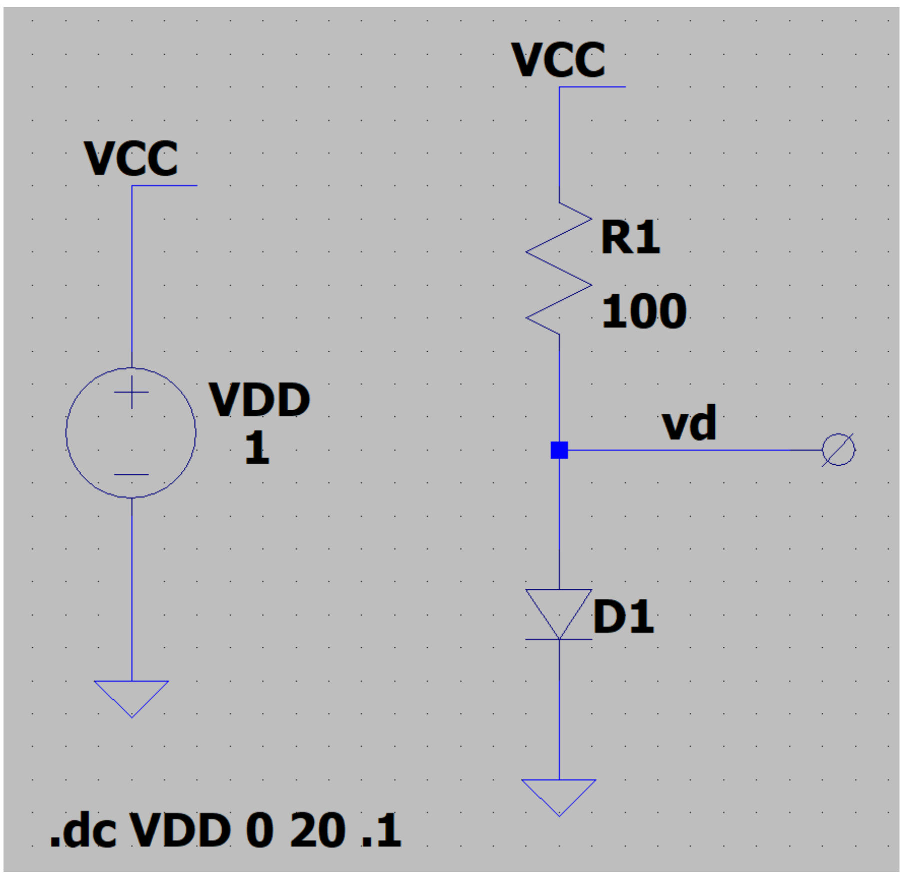
p.f. = P/S = 1441.770178 W / 1441.770178 VA = 1



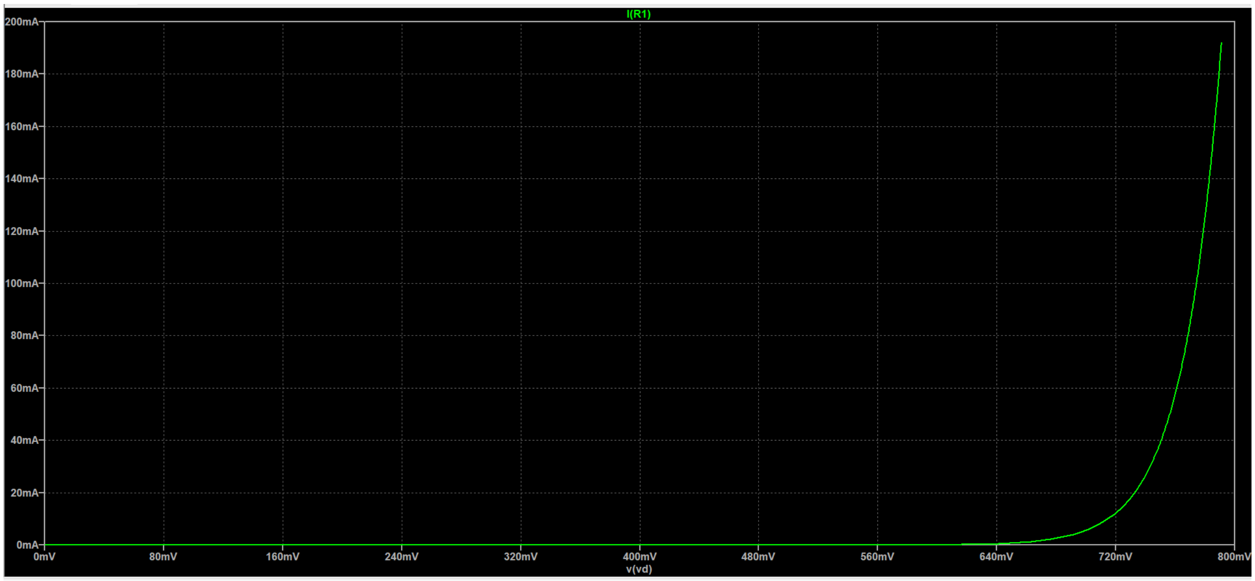
The theoretical P,S, and p.f. is similar enough to the LTSpice P,S, and p.f.

2.5.1 i-v Characteristics of Diodes, SCR's and Triac's

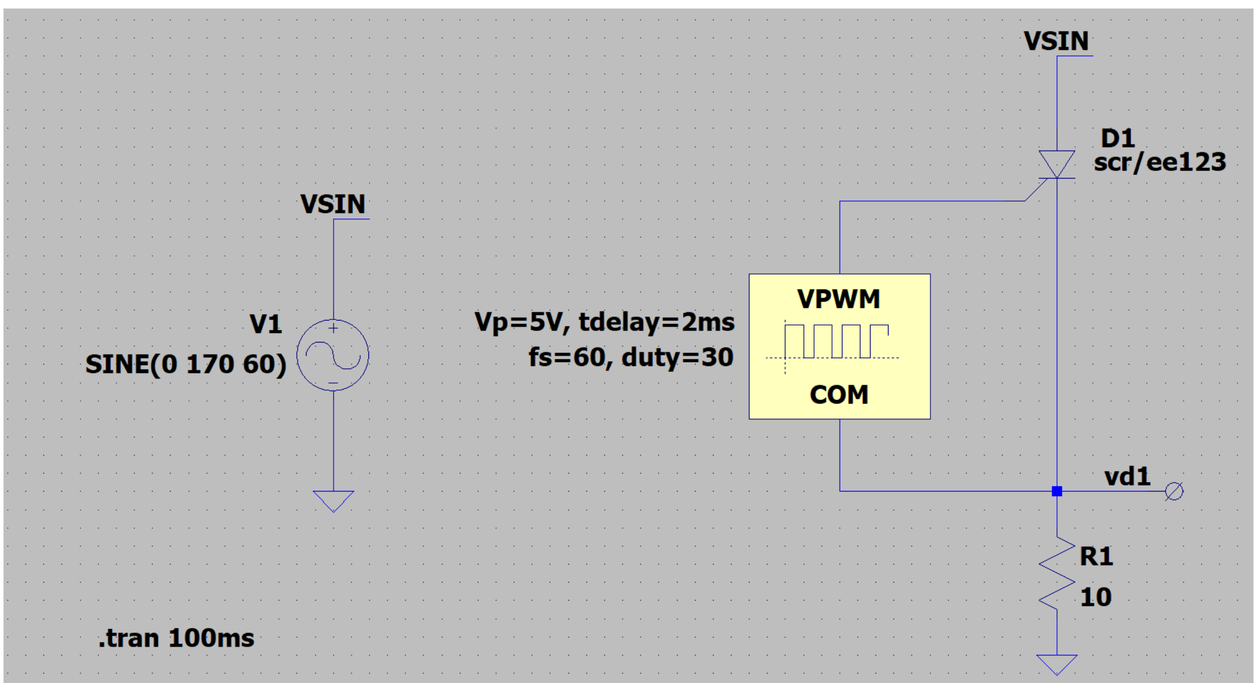
1)

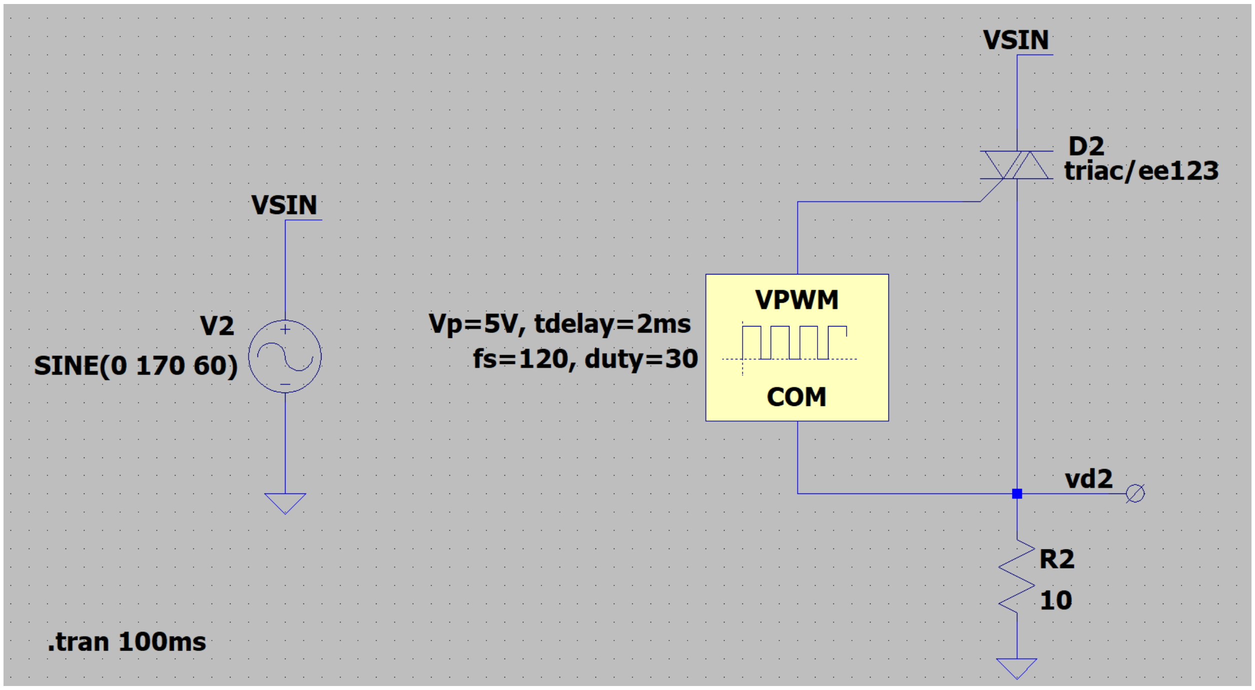


2)

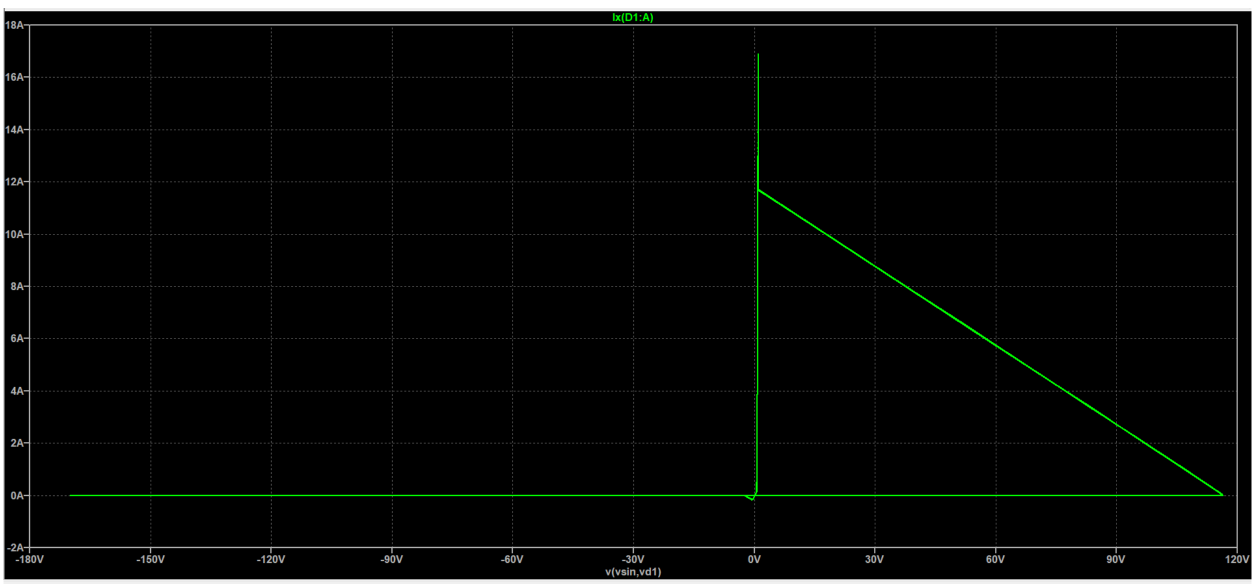

I(R1)
200mA
180mA
160mA
140mA
120mA
100mA
80mA
60mA
40mA
20mA
0mA
0mV
80mV
160mV
240mV
320mV
400mV
480mV
560mV
640mV
720mV
800mV
v(vd)

3)

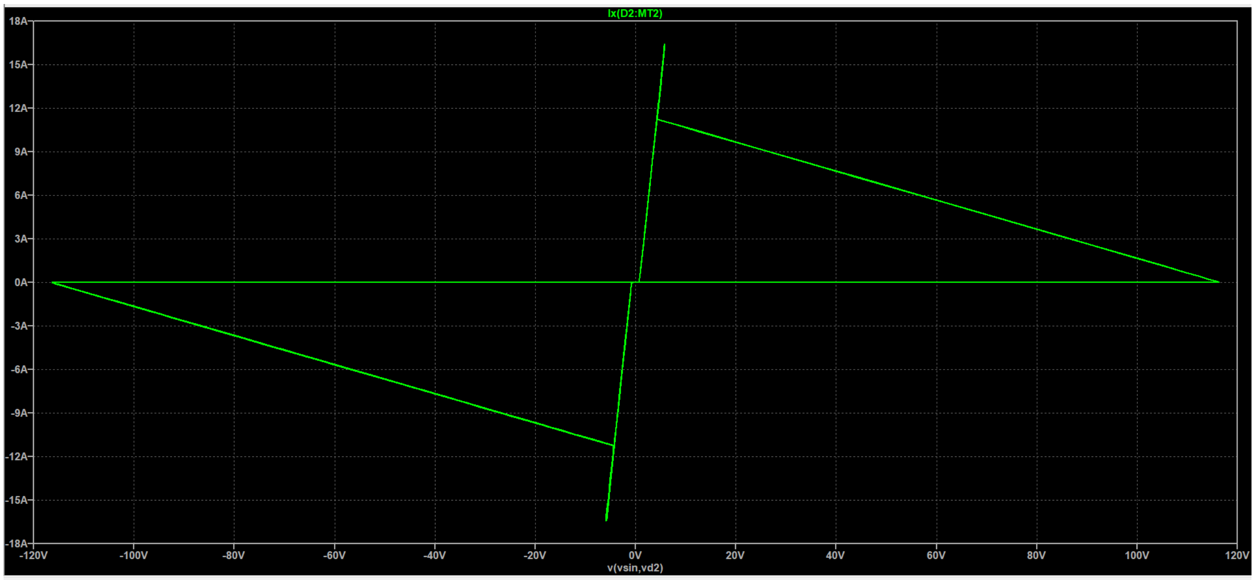

VSIN
D1
scr/ee123
VSIN
V1
SINE(0 170 60)
Vp=5V, tdelay=2ms
fs=60, duty=30
VPWM
COM
vd1
R1
10
.tran 100ms


VSIN
D2
triac/ee123
VSIN
VPWM
V2
SINE(0 170 60)
Vp=5V, tdelay=2ms
fs=120, duty=30
COM
vd2
R2
10
.tran 100ms

4)
For SCR


Ix(D1:A)
18A
16A
14A
12A
10A
8A
6A
4A
2A
0A
-2A
-180V
-150V
-120V
-90V
-60V
-30V
0V
30V
60V
90V
120V
v(vsin,vd1)

For Triac



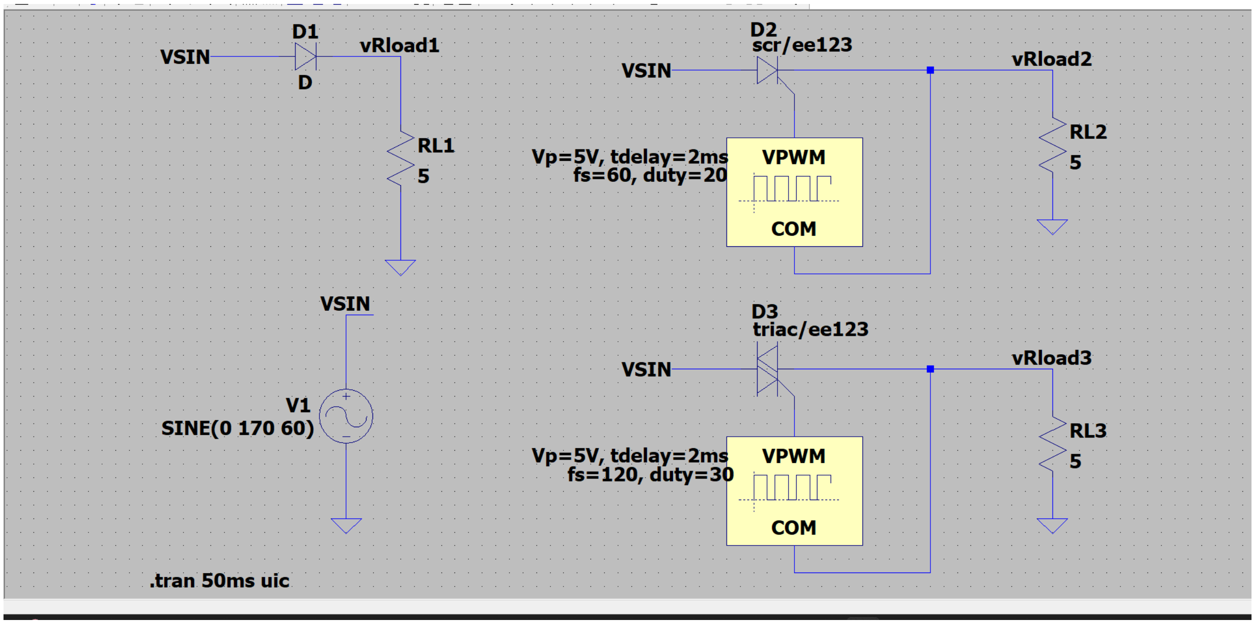
5)

Obtaining the i-v characteristics in this experiment is similar compared to the ones shown in figure 2.5 and 2.7.

For the SCR in figure 2.5, when the load line slope goes down means the SCR will be conducted at the positive region, indicating forward conduction region . Any currents greater than 11A will be getting cut off. In the SCR region, its behavior deviates from that of the Triac's linear conduction phase. When the SCR conducts, it acts as a diode, flowing in only one direction. As compared to the figure 2.5, there’s only positive source for the SCR begins to conduct. In this case of our experiment, the slope gradually decreases, which means that the small change in current is effective because the change in current is small.

For the Triacs in figure 2.7, similarly to the SCR, when the slope resistance of a Triac refers to how its voltage across the main terminals changes with the current flowing through it during its conduction state. It's like how much the voltage changes when you increase or decrease the current. When the Triac is working in its linear region, this slope resistance tells us how steep that relationship is. So, if the slope resistance is low, it means that a small change in current results in a small change in voltage, indicating efficient conduction. On the other hand, a high slope resistance means that the Triac doesn't conduct as effectively. In this case of our experiment, the slope gradually decreases, it means that the small change in current is effective.

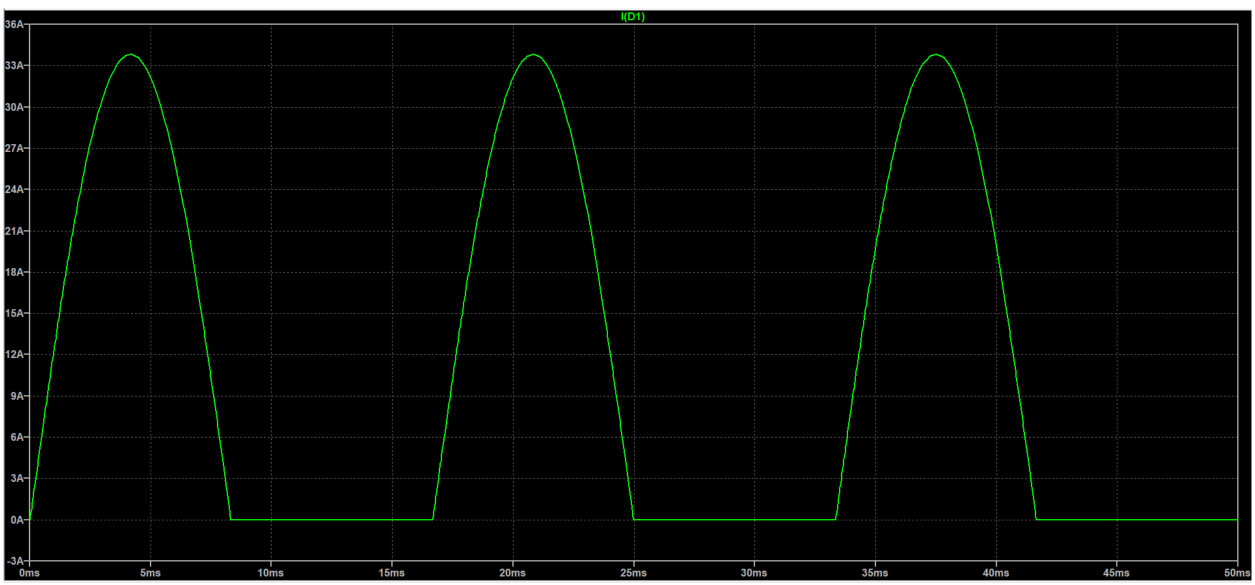
6)



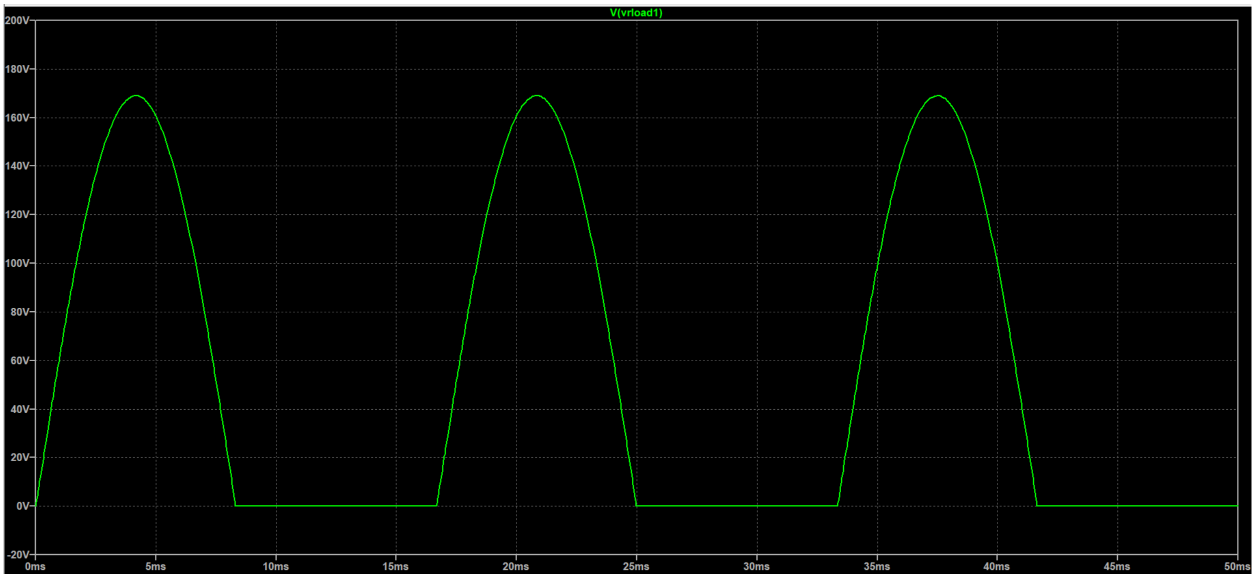
7)

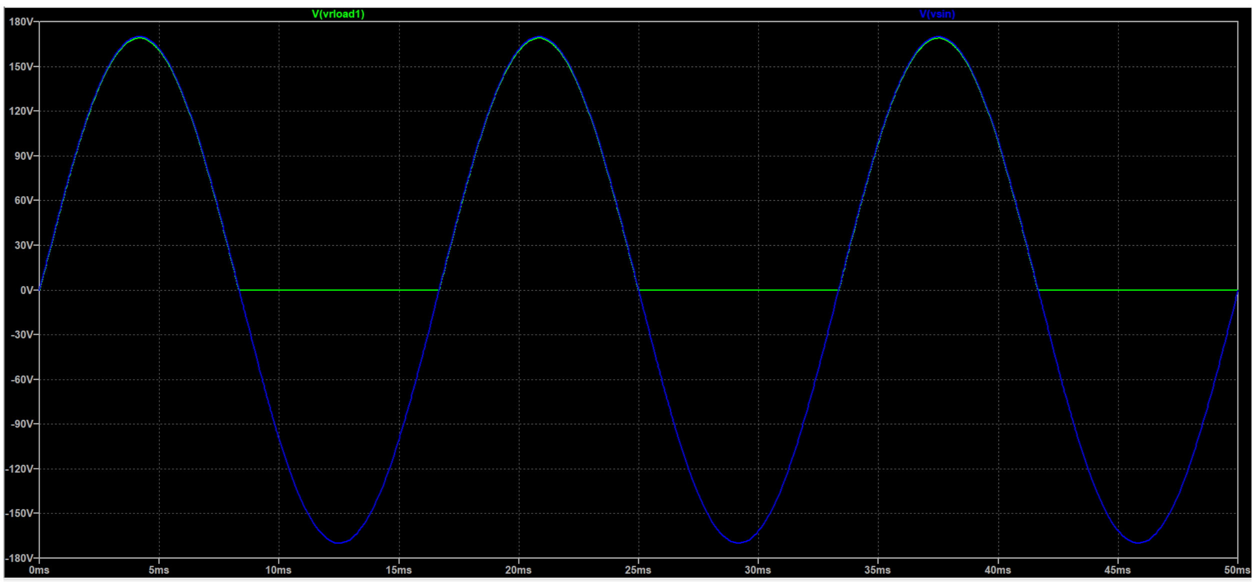
For D1-Diode:

Current-Time



Voltage-Time

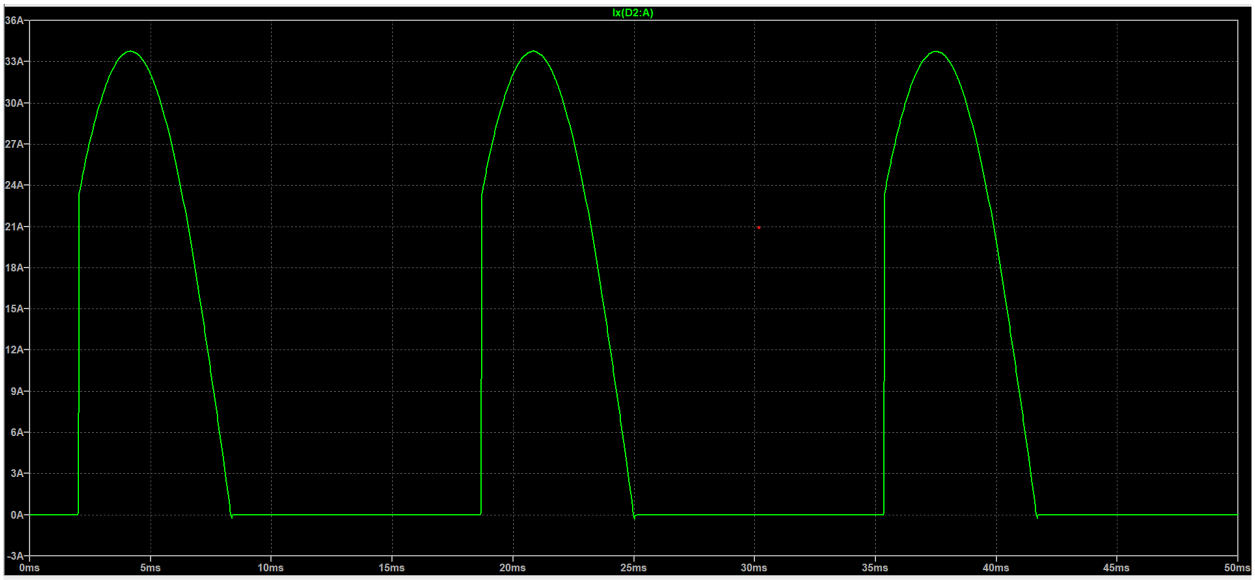




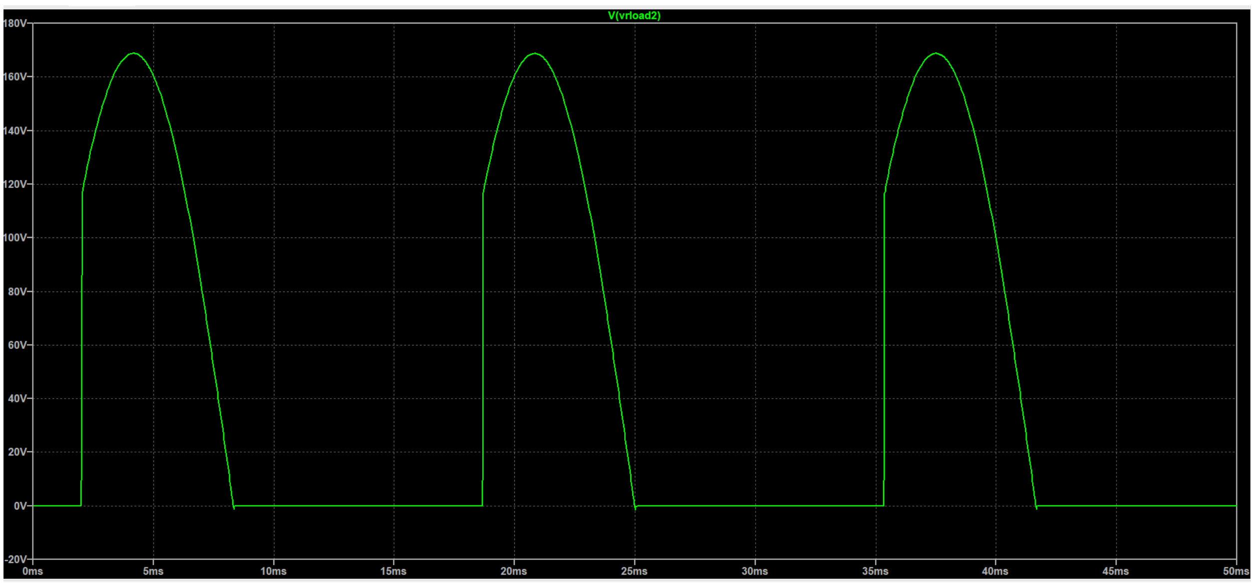
V_{SIN} = Blue, $V_{vRload1}$ = Green
Sinusoidal Half-Wave Rectifier

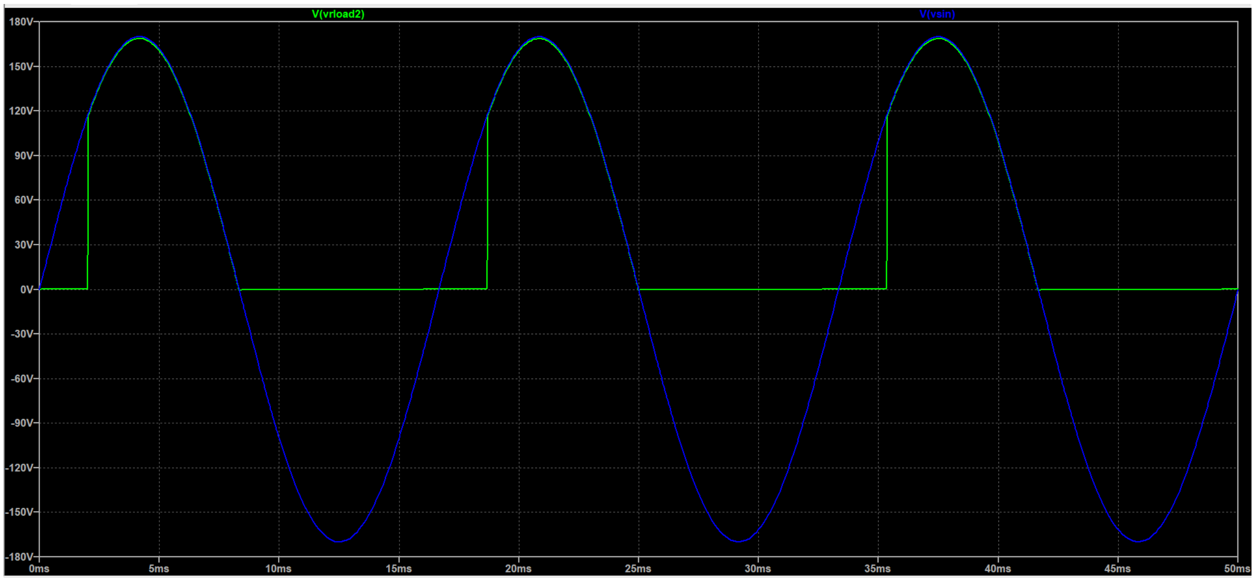
For D2-SCR:

Current-Time



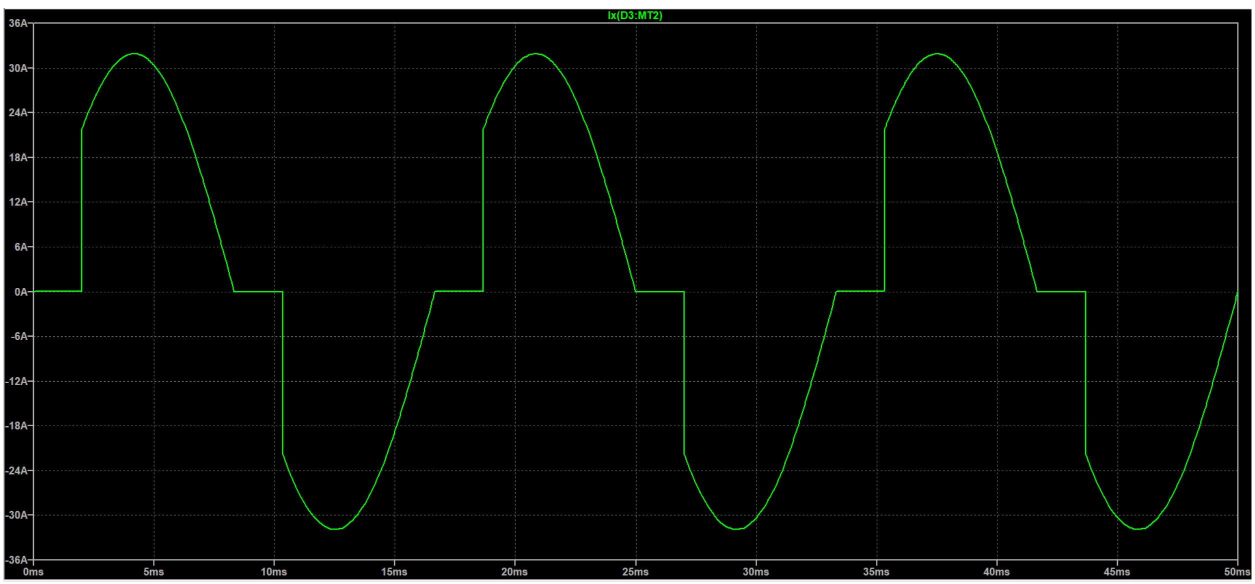
Voltage-Time



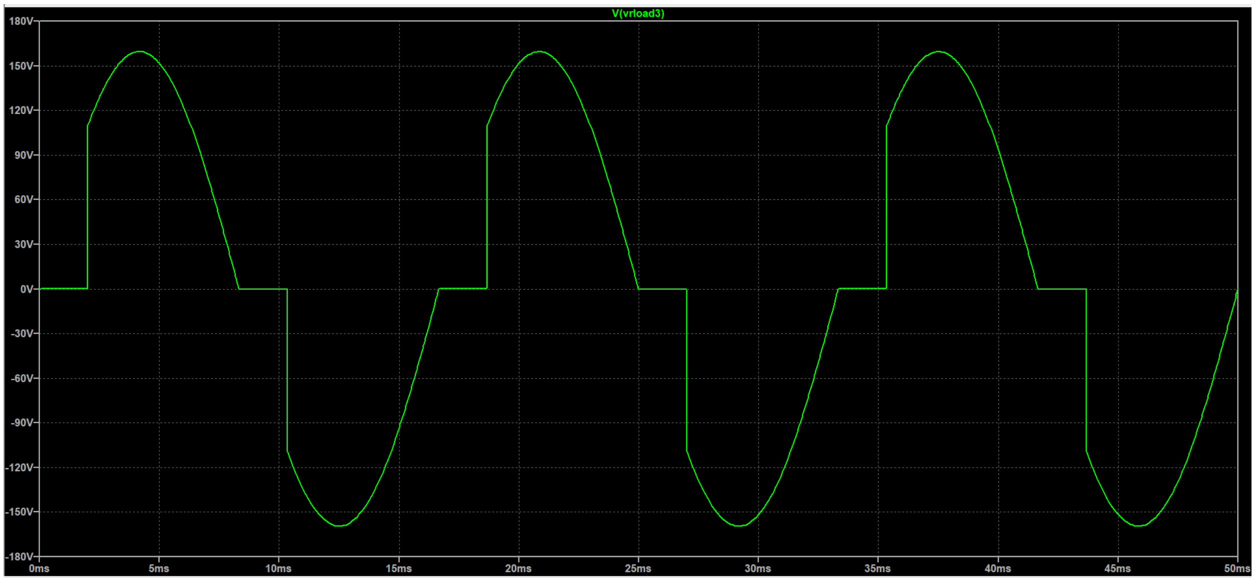


V_{SIN} = Blue, $V_{vRload2}$ = Green
Sinusoidal Half-Wave Rectifier

For D3-Triac:
Current-Time

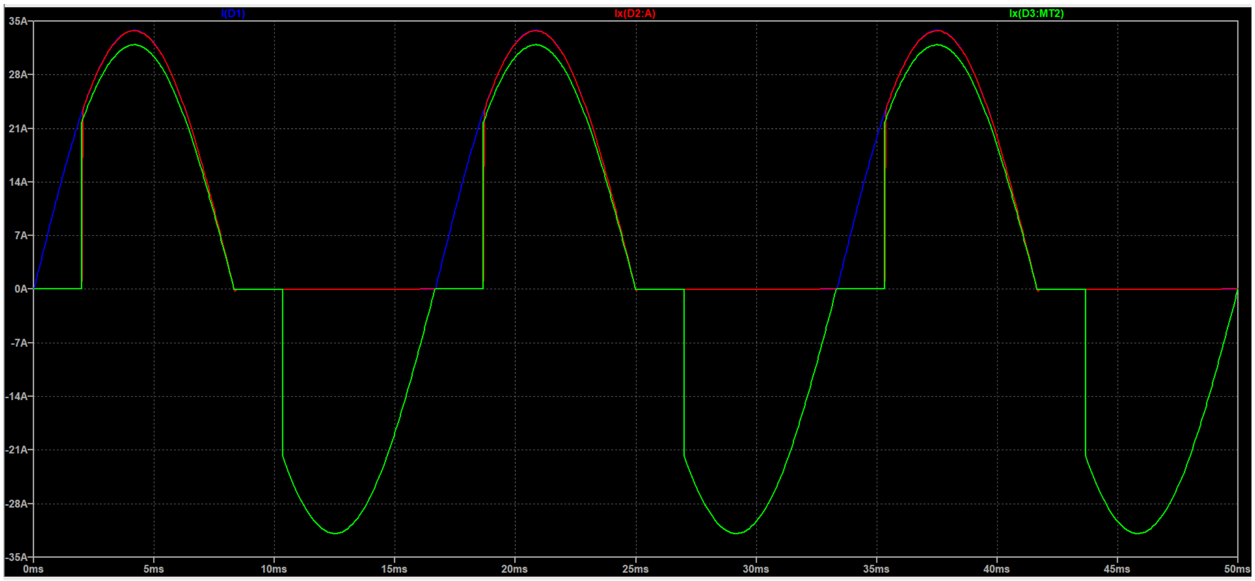


Voltage-Time



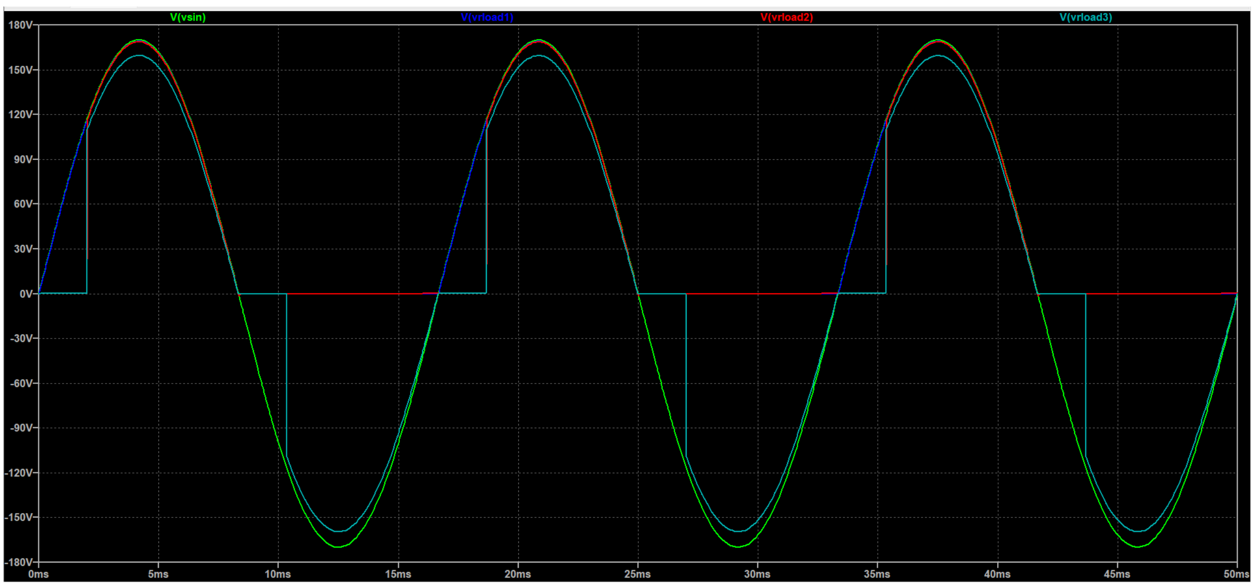
V_{SIN} = Blue, $V_{vRload3}$ = Green
Sinusoidal Full-Wave Rectifier

For D1-Diode,D2-SCR,D3-Triac:
Current-Time



I_D = Blue, I_{SCR} = Red, I_{TRIAC} = Green

Voltage-Time

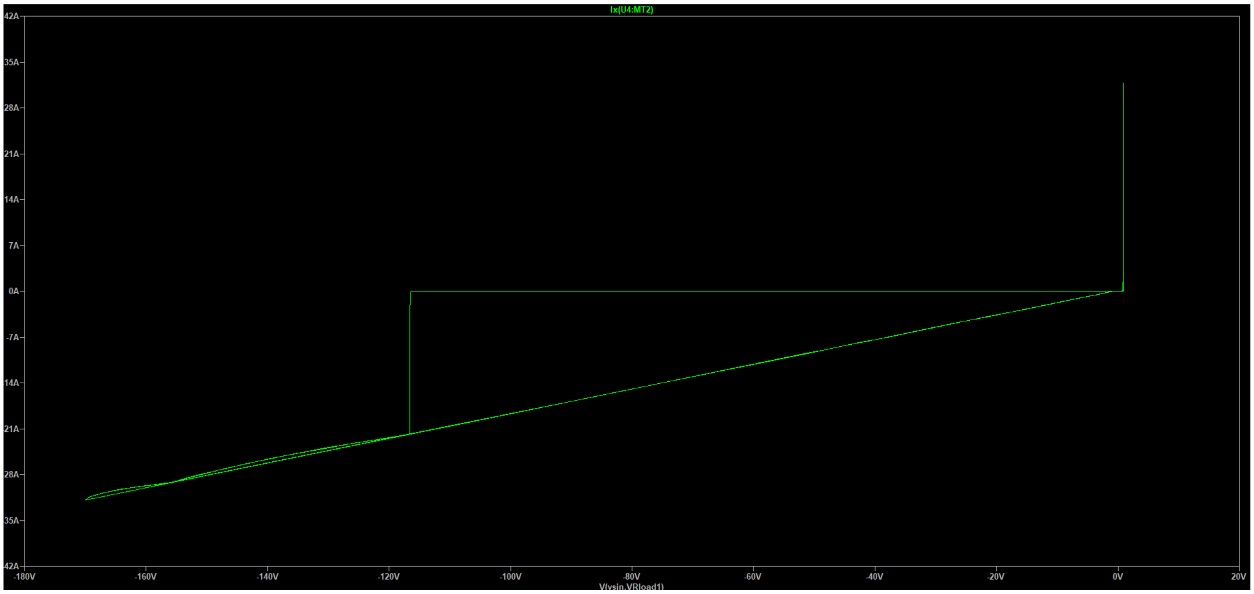


V_{SIN} = Green, $V_{vRload1}$ = Blue, $V_{vRload2}$ = Red, $V_{vRload3}$ = Aqua

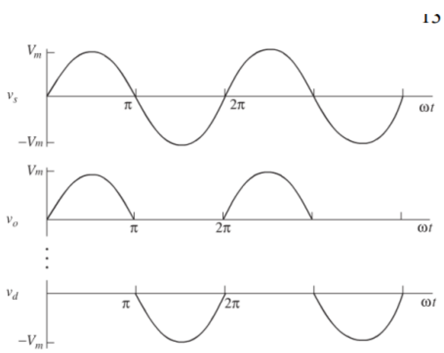
VRload1:

I(D1)
36A
33A
30A
27A
24A
21A
18A
15A
12A
9A
6A
3A
0A
-3A
-20V
0V
20V
40V
60V
80V
100V
120V
140V
160V
180V
v(vRload1)

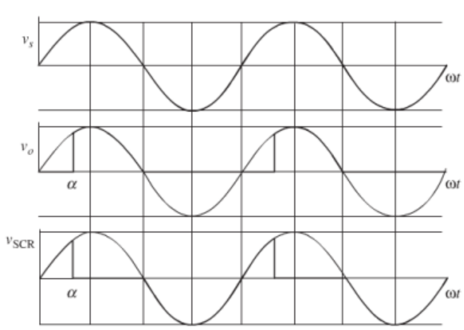
Ix(D2:A)
Ix(D3:MT2)
35A
28A
21A
14A
7A
0A
-7A
-14A
-21A
-28A
-35A
-20V
0V
20V
40V
60V
80V
100V
120V
140V
160V
180V
V(vRload1)



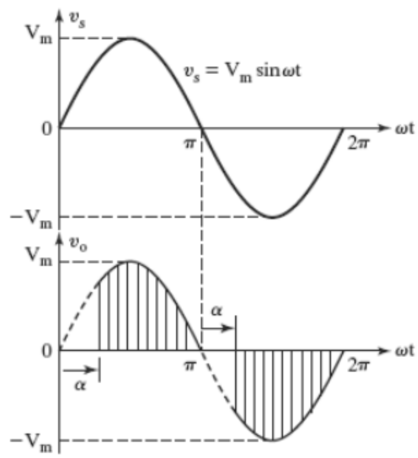
8)



For the diode: The resulting graph is a half-wave AC rectifier. The behavior of the I-V characteristic is in forward bias since the half wave is on the positive side of the graph. The I-V characteristic shows a rapid increase in current as the voltage across the diode increases linearly. We also see that in comparison to the sine input voltage, vRload1 has a 0.94V decrease in amplitude.



For the SCR: The resulting graph is a half-wave AC rectifier. The behavior of the I-V characteristic is in forward bias since the half wave is on the positive side of the graph. The I-V characteristic shows a rapid increase in current as the voltage across the diode increases linearly. We see that in comparison to the sine input voltage, vRload2 has a 1.2V decrease in amplitude. We can also clearly see when the SRC allows current to flow through by looking at PWM voltage offset



For the triac: The resulting graph is a full-wave AC rectifier. It does not matter whether the input voltage is positive or negative, it will always allow current to flow. When conducting, the current increases rapidly as the voltage across it increases. During both halves of the input AC waveform, the current rises as the voltage rises which results in a linear increase on the I-V characteristics graph. We see that in comparison to the sine input voltage, vRload3 has a 10.45V decrease in amplitude. We can also clearly see when the triac allows current to flow through by looking at PWM voltage offsets. We also noticed that there is a bigger voltage drop when using a triac.

Practice Problem Encounters:

The experimental problems we have encountered in this lab during the measurement is the calculation of the Vrms. Sometimes, the result doesn't match with the graph from the simulation. Because of this, we have to measure it again a couple of times. Or the issue with the library from the ee123 folder. For example the VPWM and VSAW are supposed to be set at 170V but when measured separately, we noticed that it normally peaks at 167 V or 168 V Sometimes, our measurements were off when we checked with TA, especially V_P= 170 V in the first part. So, by reinstalling the library again, it somehow works as expected.

Conclusion:

We successfully familiarized ourselves with the LTspice IV® software* environment. We now understand the different power characterization quantities such as instantaneous, average, rms power, power generation and consumption, power factor. By capturing these data, we can compute and manipulate the average power, and the power factor. We successfully graphed the i-v characteristics of diodes, SCRs, and Triacs based on the thyristors theories. By that, we now understand the difference in behavior between these electrical components. If we were to attempt this experiment again, we would probably try to find more accurate components to ensure that V_P was more accurate.