

1909750

by Ethan Joel

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Executive Summary

This report will focus on studying the Transient behaviour of various types of circuits including R-L (Resistor, Inductor) circuits and R-C (Resistor, Capacitor) circuits. Calculations will be undertaken to determine various characteristics including voltages, currents and time constants. A simulation package (NI Multisim) will be used to create simulation circuits as a method of comparison with my other results. As a third method for comparison, a practical activity will be used to help to compare with the other two methods. A table of results will be created to present each methods readings and a conclusion will be made from these results.

Task 1/Task 2 –

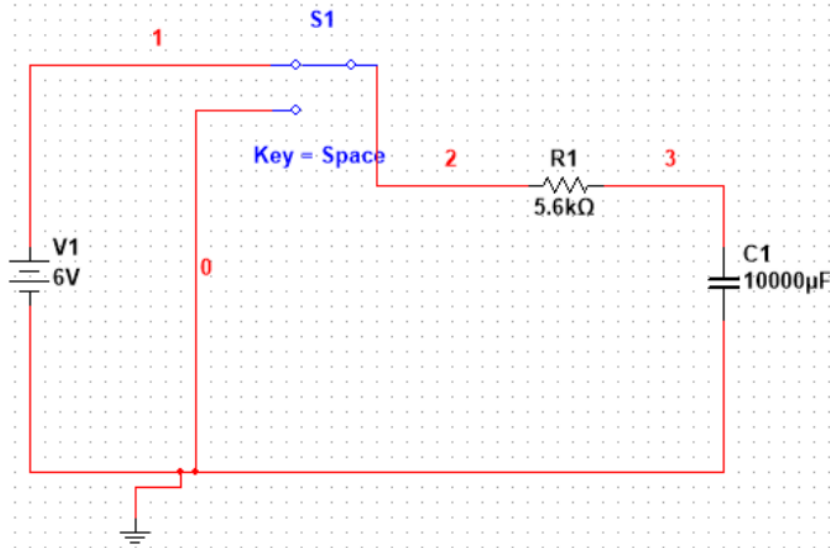


Figure 1 - Task 1/2 Circuit

Above is a circuit created on Multisim which uses a 6V DC power supply, a 5.6KΩ resistor and a 10,000uF capacitor. These values were used as the voltage and current had to be measured over the time it took the capacitor to fully charge.

The time constant of a circuit (represented as Tau (τ)) is calculated by the following formula;

$$\tau = R \times C$$

Therefore, the time constant for the circuit is;

$$\tau = 5.6 \times 10^{-3} \times 10000 \times 10^{-6}$$

$$\tau = 56s$$

The time constant for this circuit had to be relatively large as it gives enough time for measurements to be taken within the 56s. This is why the resistor and capacitor values were chosen. The time constant is the time for the capacitor to charge to 63.2%.

With regards to calculating the time for the capacitor to charge, this is known as the Transient period. The transient period is equivalent to 5-time constants therefore;

$$= 5 \times \tau$$

$$= 280s$$

After 280s, the capacitor would have reached the 'steady state period'. As capacitors will not charge to 100% but around 99.2%.

Practical Circuit

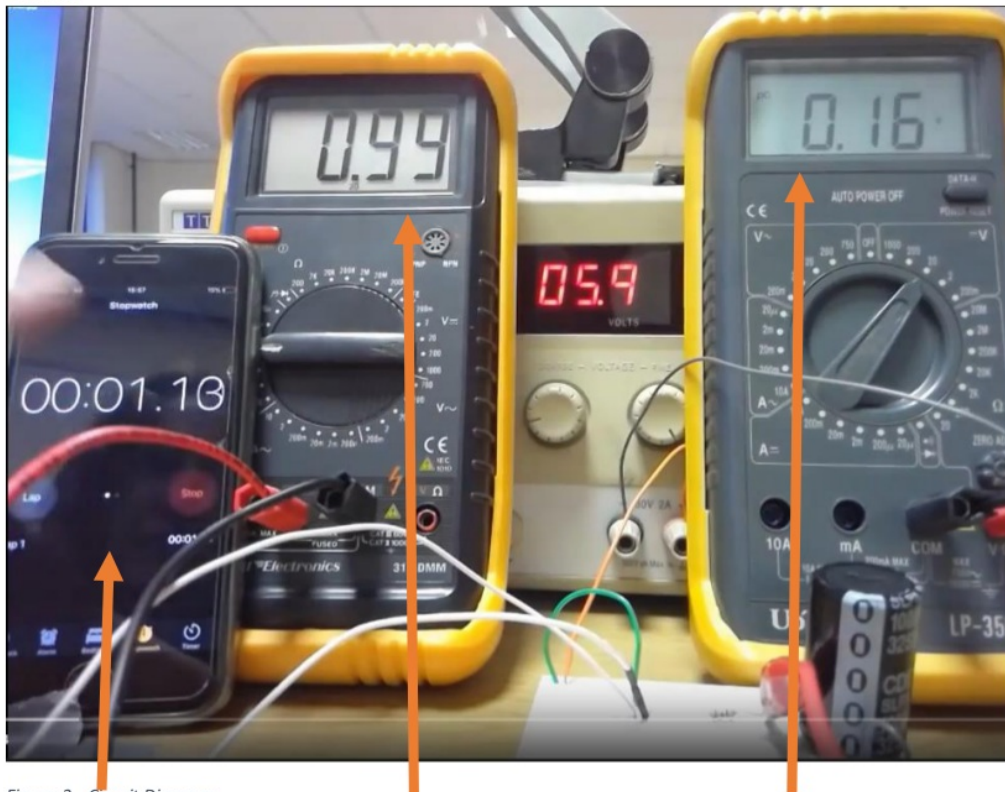


Figure 2 - Circuit Diagram

Stopwatch – For this practical, we recorded up to 1 minute in 5 second intervals. After 1 minute, results were recorded every 10 seconds up until 2 minutes. Then up until 5 minutes, they were recorded every 30seconds

Current Meter – This meter measured the current. The expected results were that the current would decrease when charging and increase when discharging.

Voltage Meter – This meter measured the Voltage. The expected results were that the voltage would increase when charging and decrease when discharging.

Method

- The following circuit was created on breadboard;

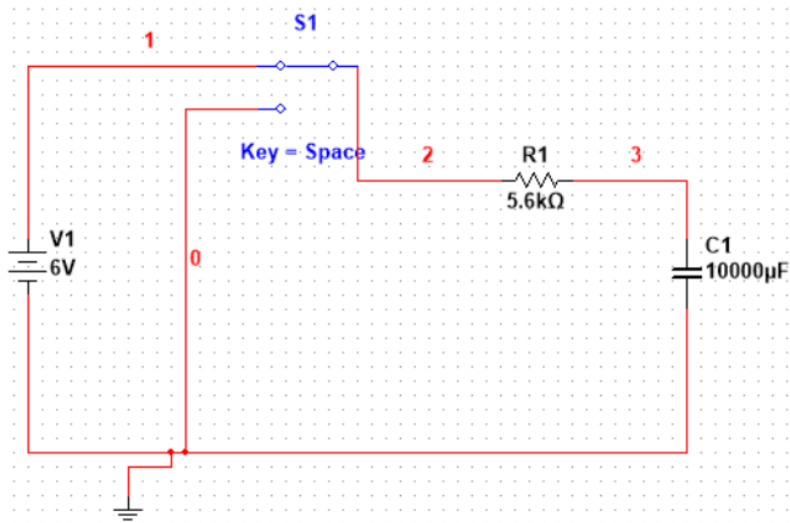


Figure 3 - Multisim created circuit

- Two multimeters were used to record the voltage and current (Voltmeter and Ammeter)
- A stopwatch was used to record the time intervals
 - o Every 5 seconds up to 1 minute
 - o Every 10 seconds from 1 minute to 2 minutes
 - o Every 30 seconds from 2 minutes to 5 minutes
- First, the Voltages and Currents were recorded for the charging of the Capacitor. These can be seen in Table 1 on page 6
- Next, the Voltages and Currents were recorded for the discharging of the capacitor. These can be seen in Table 2 on page 10

Components

- 6V DC Supply
- 5.6K Resistor
- 10000uF Capacitor

Charging –

Charging the Capacitor		
Time	Voltage (V)	Current (A)
0	0	1.07
5	0.54	0.92
10	1.04	0.84
15	1.49	0.77
20	1.86	0.7
25	2.21	0.64
30	2.55	0.59
35	2.84	0.54
40	3.13	0.49
45	3.39	0.45
50	3.61	0.41
55	3.82	0.38
56	4	0.37
60	4	0.35
70	4.34	0.29
80	4.62	0.24
90	4.85	0.21
100	5.05	0.17
110	5.21	0.15
120	5.35	0.12
150	5.65	0.07
180	5.83	0.04
210	5.93	0.03
240	5.95	0.02
270	6.03	0.01
300	6.06	0.01

Table 1 - Practical charging results

As you can see above, this is the table of results when the capacitor is charging. As shown in the previous calculations, the transient period is 280s. This means that the voltage should be around 6V after 280s, where as you can see from the above table, this is the case (Between 6.03 and 6.06V)

Results were recorded initially after every 5 seconds up to a minute. This was because it was suitable for the voltage and current to be recorded before the next time value. If it would have been any shorter, it would have been a struggle monitor and record the results in time increasing the likelihood of a human error. After 1 minute, results were then recorded every 10 seconds up until 2 minutes (120s) where they increased every 30s.

Below are the graphs created from the table of results above. As you can see the voltage graph increases rapidly until it reaches a steady state. Also, as shown by the cursor, at the time constant value of 56s, the voltage has a value of 3.85V. With the current it decreases from 1.07mA rapidly again until it reaches a steady state.

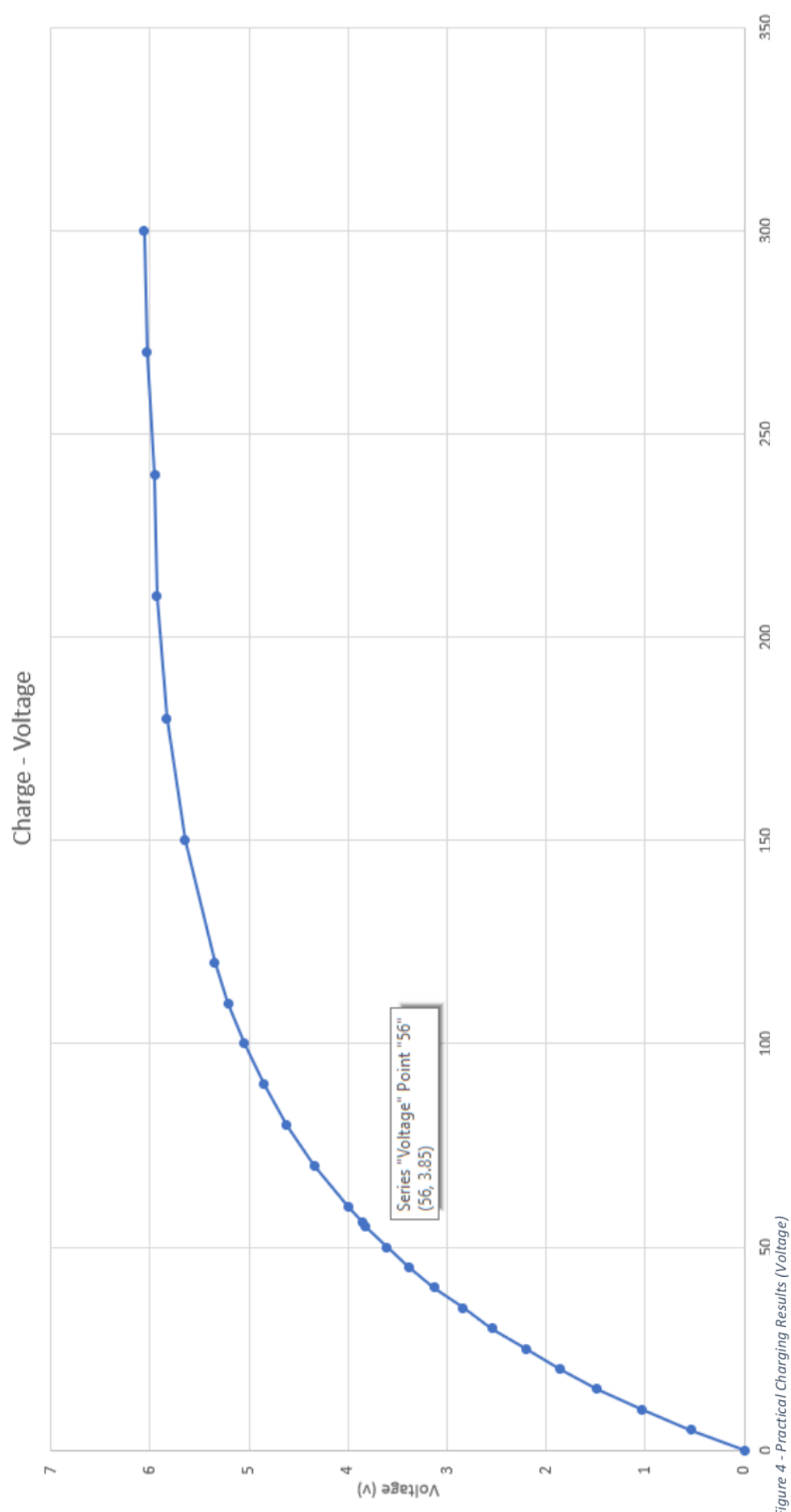


Figure 4 - Practical Charging Results (Voltage)

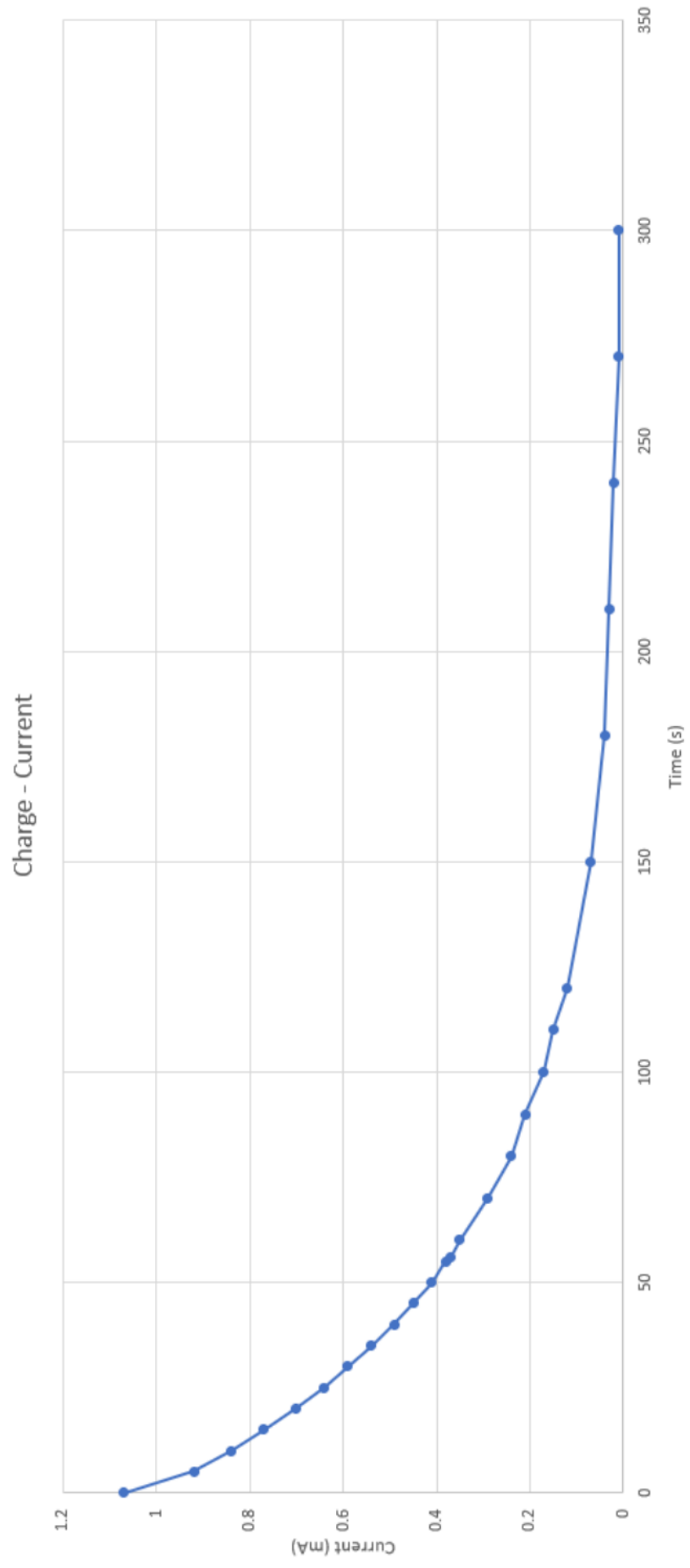


Figure 5 - Practical Charging Results (Current)

Discharging –

Discharging the Capacitor		
Time	Current (mA)	Voltage (v)
0	-1.07	6.06
5	-0.92	5.52
10	-0.84	5.07
15	-0.77	4.65
20	-0.7	4.24
25	-0.64	3.9
30	-0.59	3.56
35	-0.54	3.27
40	-0.49	2.98
45	-0.45	2.74
50	-0.41	2.5
55	-0.38	2.7
56	-0.37	2.25
60	-0.33	2.1
70	-0.29	1.76
80	-0.24	1.48
90	-0.2	1.24
100	-0.17	1.05
110	-0.14	0.88
120	-0.12	0.74
150	-0.07	0.44
180	-0.04	0.27
210	-0.02	0.16
240	-0.01	0.1
270	0	0.06
300	0	0.04

Table 2 - Practical Discharging Results

Above is a table of results for the Discharging of the capacitor. It shows both the current and voltage values. It starts discharging at a current value (I_{max}) of -1.07mA and a Voltage value of 6.06V. At our time constant (56s) we have a voltage value of -0.37A and 2.25V. See figures 6 and 7 below for the Discharge Voltage and Current;

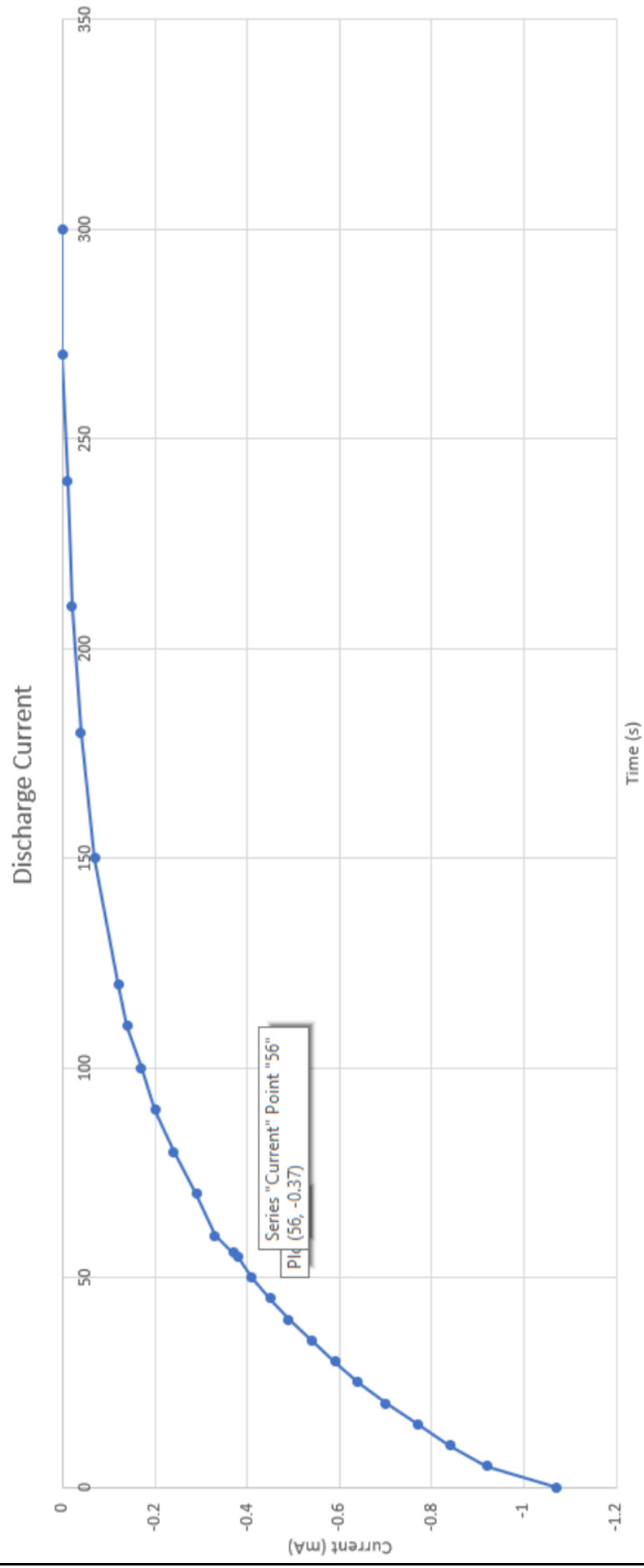


Figure 6 - Practical Discharging Results (Current)

Discharge - Voltage

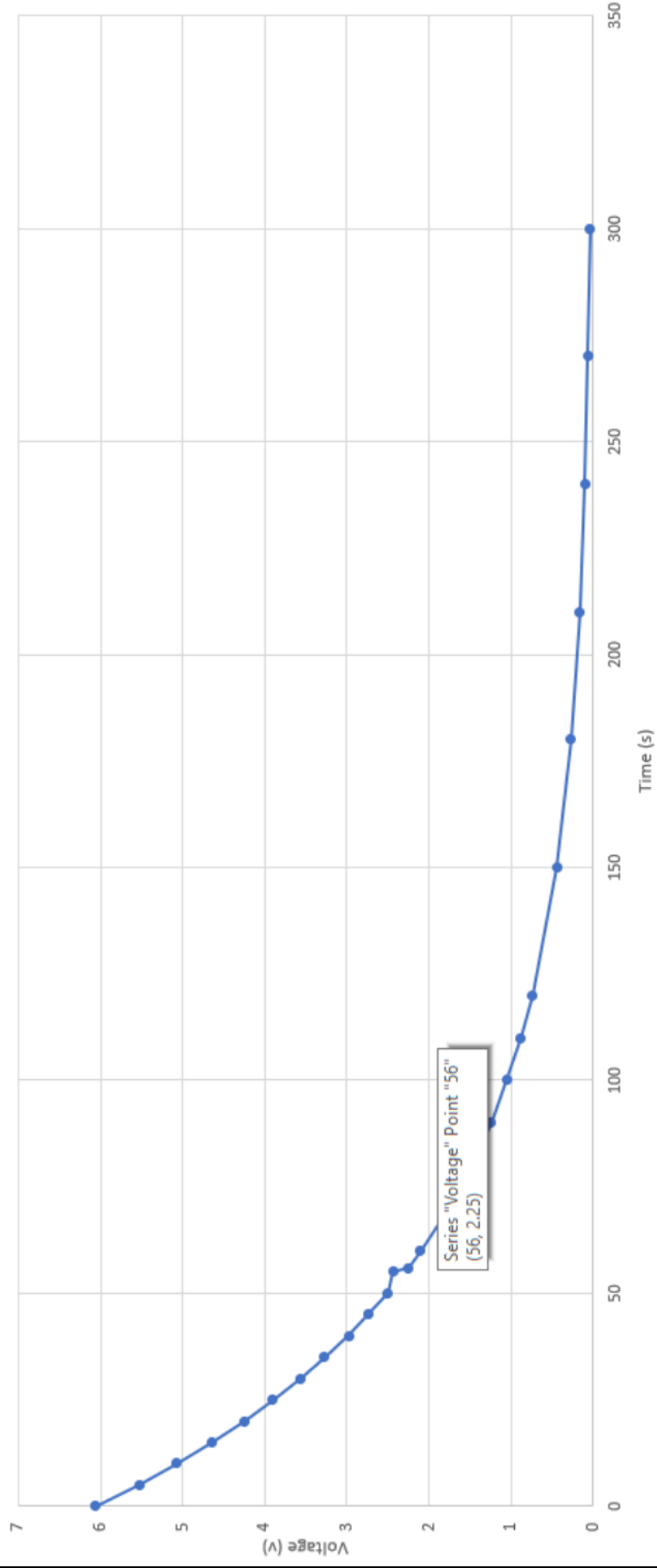


Figure 7 - Practical Discharging Results (Voltage)

Multisim
Voltage Charge and Discharge

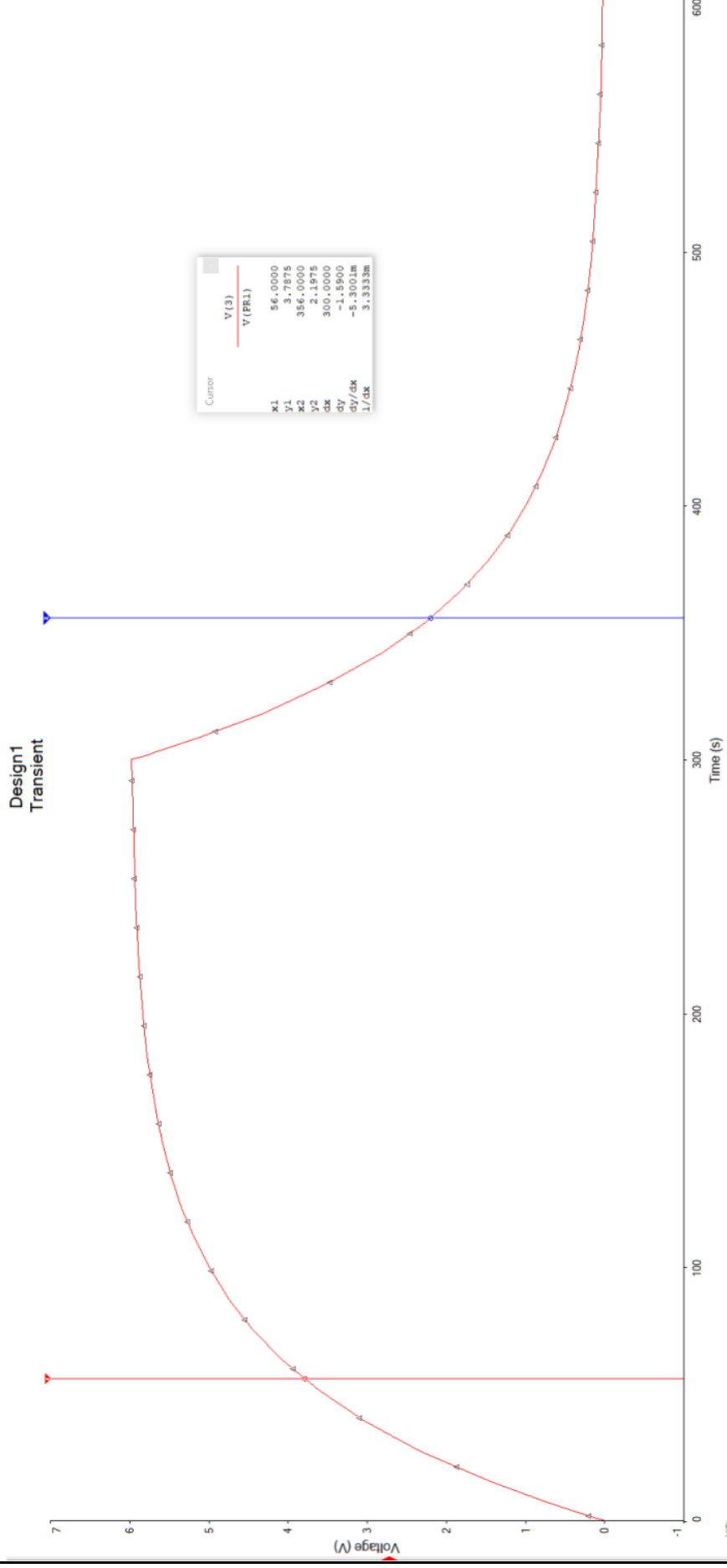


Figure 8 - Multisim Results Voltage Charge/Discharge

As you can see from the Figure 8 above, it displays both the Charge and Discharge Periods. The Charging period lasts until 300s because of the time period value of 280s. It then discharges until it reaches a steady state value.



These cursors show the time constant values during the charge and discharge phase.

At the time constant at the charging phase ($x1 = 56s$), it has a value of 3.78V.

At the time constant at the discharge phase ($x2 = 356s$), it has a value of 2.19V

Figure 9 - Multisim Results Voltage Cursors

Current charge and Discharge

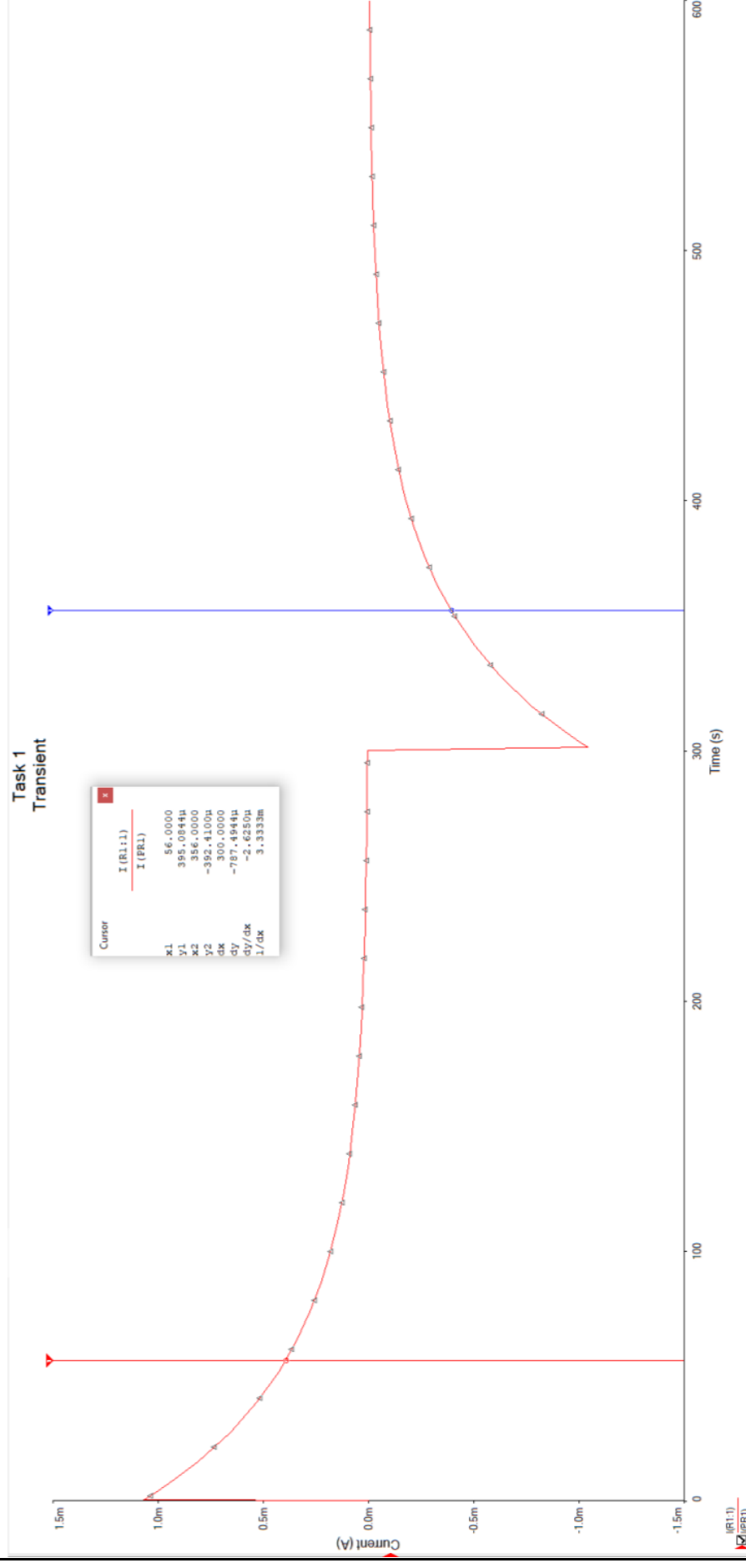
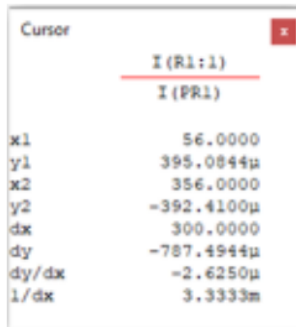


Figure 10 - Multisim Results Current Charge/Discharge

As you can see from Figure 10 above, it displays both the Current Charge and Discharge. Similarly, to the voltage graph, the charging period lasts until 300s due to the time period being 280s. After this, the discharging period takes place.



These cursors show the time constant values during the charge and discharge phase.

At the time constant at the charging phase (x1 = 56s), it has a value of 0.396mA.

At the time constant at the discharge phase (x2 = 356s), it has a value of -0.396mA

Figure 11 - Multisim Results Current Cursors

Chosen Time Values

My chosen values are as follows

15s 70s 150s

Calculations

Charging – Voltage

$$V_c = V_{Max} \left(1 - e^{\frac{-t}{\tau}}\right)$$

$$15 = 6 \left(1 - e^{\frac{-15}{56}}\right) = 1.4V$$

$$70 = 6 \left(1 - e^{\frac{-70}{56}}\right) = 4.2V$$

$$150 = 6 \left(1 - e^{\frac{-150}{56}}\right) = 5.5V$$

Discharging – Voltage

$$V = V_{Max} \left(e^{\frac{-t}{\tau}}\right)$$

$$V = 6 \left(e^{\frac{-15}{56}}\right) = 4.59V$$

$$V = 6 \left(e^{\frac{-70}{56}}\right) = 1.71V$$

$$V = 6 \left(e^{\frac{-150}{56}}\right) = 0.41V$$

Charging - Current

$$I = I_{Max} \left(e^{\frac{-t}{\tau}}\right)$$

$$I = 1.07mA \left(e^{\frac{-15}{56}}\right) = 0.81mA$$

$$I = 1.07mA \left(e^{\frac{-70}{56}}\right) = 0.3mA$$

$$I = 1.07mA \left(e^{\frac{-150}{56}}\right) = 0.07mA$$

Discharging - Current

$$I = I_{Max} \left(1 - e^{\frac{-t}{\tau}}\right)$$

$$I = 1.07mA \left(1 - e^{\frac{-15}{56}}\right) = 0.25mA$$

$$I = 1.07mA \left(1 - e^{\frac{-70}{56}}\right) = 0.76mA$$

$$I = 1.07mA \left(1 - e^{\frac{-150}{56}}\right) = 0.99mA$$

Multisim Voltage

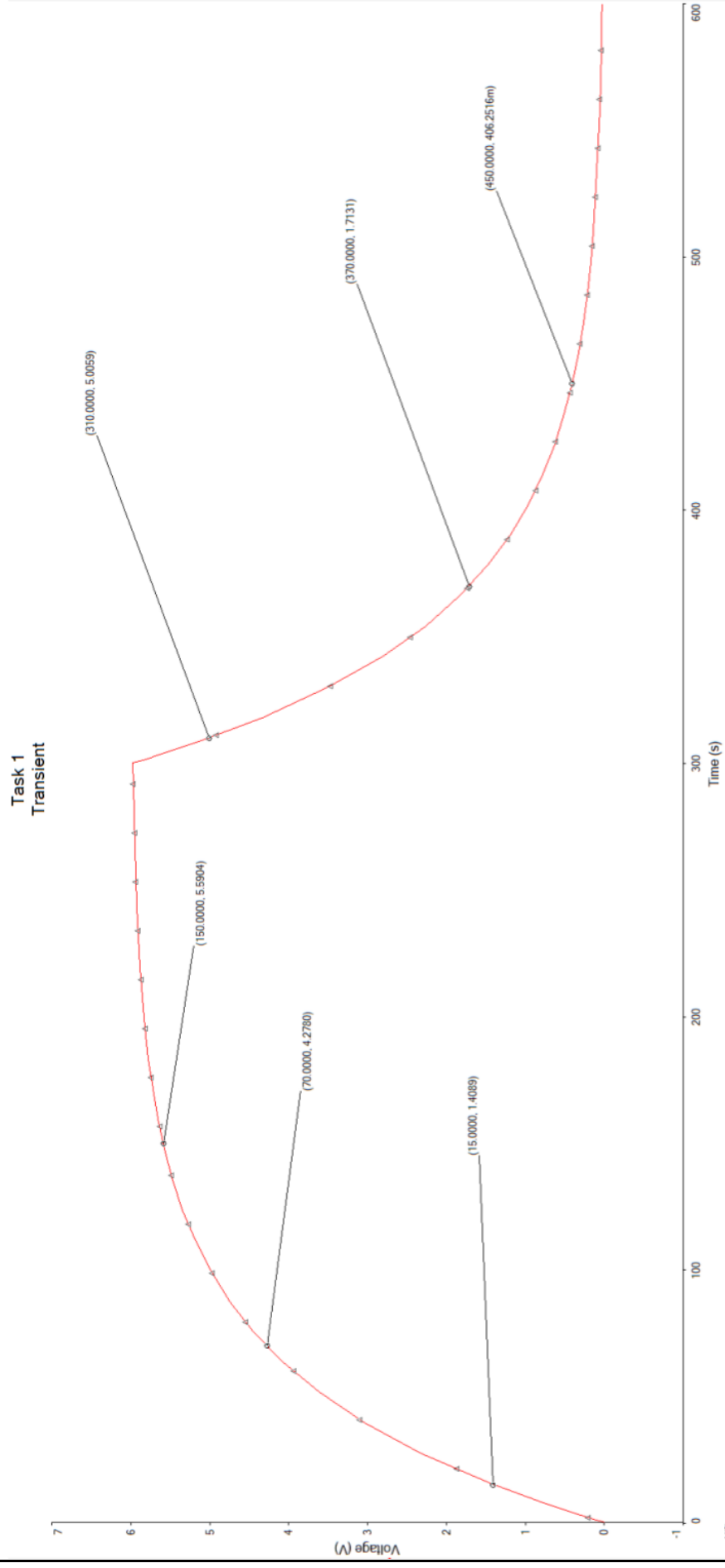
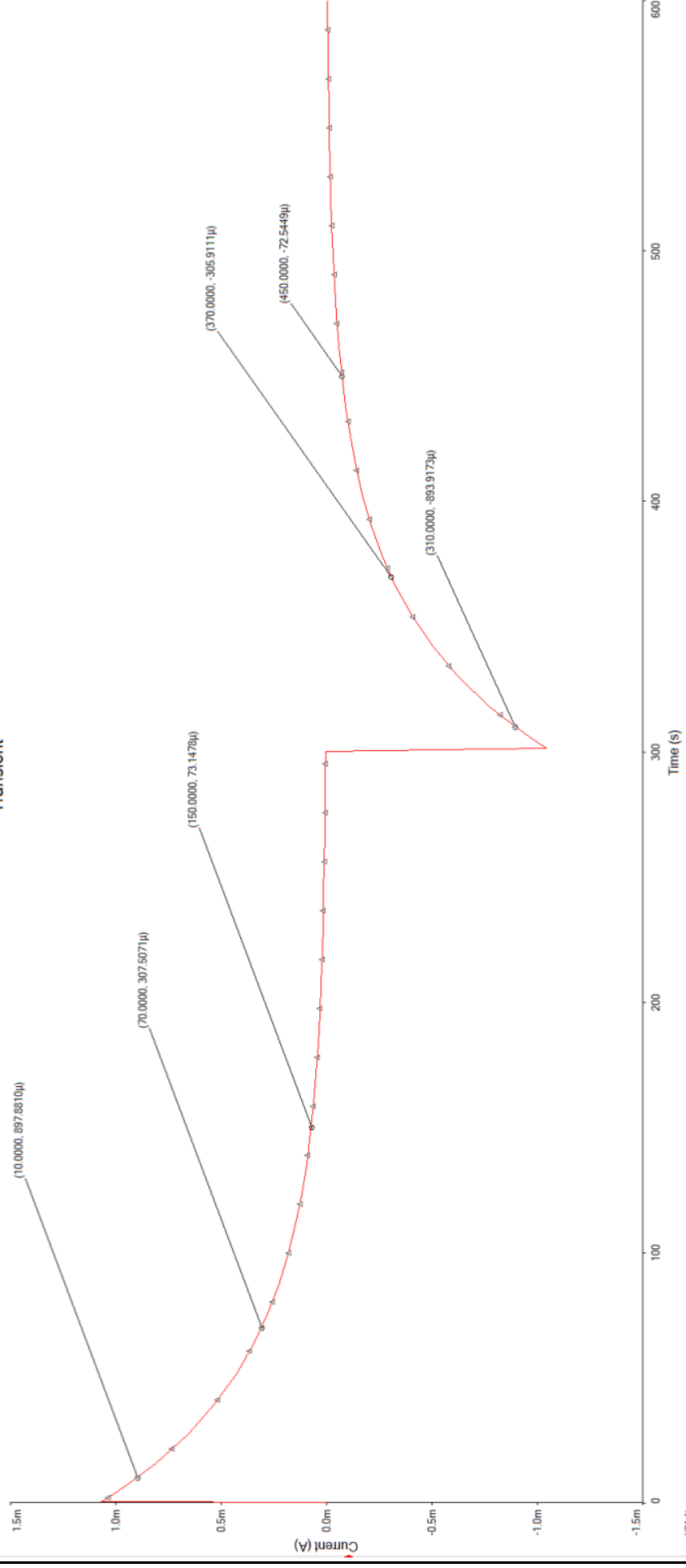


Figure 12 - Chosen Time Values Multisim Voltage

Current

Task 1
Transient



IC1.1
IPRT1

Figure 13 - Chosen Time Values Multisim Current

Above are two graphs showing my chosen time values on my mutism circuit. They are presented in a table of results below;

Charging		
Time (s)	Voltage (v)	Current (mA)
10	1.4	0.89
70	4.2	0.30
150	5.5	0.07
Discharging		
10	5	-0.89
70	1.7	-0.35
150	0.41	-0.07

Table 3 - Chosen Time Values Multisim Results

Practical

Charge

Time	Current	Voltage
0	1.07	0
5	0.92	0.54
10	0.84	1.04
15	0.77	1.49
20	0.7	1.86
25	0.64	2.21
30	0.59	2.55
35	0.54	2.84
40	0.49	3.13
45	0.45	3.39
50	0.41	3.61
55	0.38	3.82
56	0.37	3.85
60	0.35	4
70	0.29	4.34
80	0.24	4.62
90	0.21	4.85
100	0.17	5.05
110	0.15	5.21
120	0.12	5.35
150	0.07	5.65
180	0.04	5.83
210	0.03	5.93
240	0.02	5.95
270	0.01	6.03
300	0.01	6.06

Figure 14 - Chosen Time Values
Practical Charge

Discharge

Time	Current	Voltage
0	-1.07	6.06
5	-0.92	5.52
10	-0.84	5.07
15	-0.77	4.65
20	-0.7	4.24
25	-0.64	3.9
30	-0.59	3.56
35	-0.54	3.27
40	-0.49	2.98
45	-0.45	2.74
50	-0.41	2.5
55	-0.38	2.44
56	-0.37	2.25
60	-0.33	2.1
70	-0.29	1.76
80	-0.24	1.48
90	-0.2	1.24
100	-0.17	1.05
110	-0.14	0.88
120	-0.12	0.74
150	-0.07	0.44
180	-0.04	0.27
210	-0.02	0.16
240	-0.01	0.1
270	0	0.06
300	0	0.04

Figure 15- Chosen Time Values
Practical Discharge

Chosen Values Comparison

Time (s)	Multisim		Practical		Calculations	
<u>Charge</u>						
10	1.4V	0.89mA	1.04V	0.84mA	1.4V	0.81mA
70	4.2V	0.3mA	4.34V	0.29mA	4.2V	0.30mA
150	5.5V	0.07mA	5.65V	0.07mA	5.5V	0.07mA
<u>Discharge</u>						
10	5V	- 0.89mA	5.07V	-0.84mA	4.59V	0.25mA
70	1.7V	- 0.35mA	1.76V	-0.29mA	1.71V	0.76mA
150	0.41V	- 0.07mA	0.44V	-0.07mA	0.41V	0.99mA

Table 4 - Chosen Time Values Comparison

As you can see from the table of results above, all results are relatively similar. The calculated and multisim values should be very similar as they're calculated and simulated values. This is the case as shown in the comparison table above. With the practical values, the results may be ever so slightly out due to multiple things such as obtaining the results at the exact second. This is difficult to do, due to the speed of the human recording the result. Also, the power supply used may not be 100% accurate due to it may not be calibrated etc..

Task 3

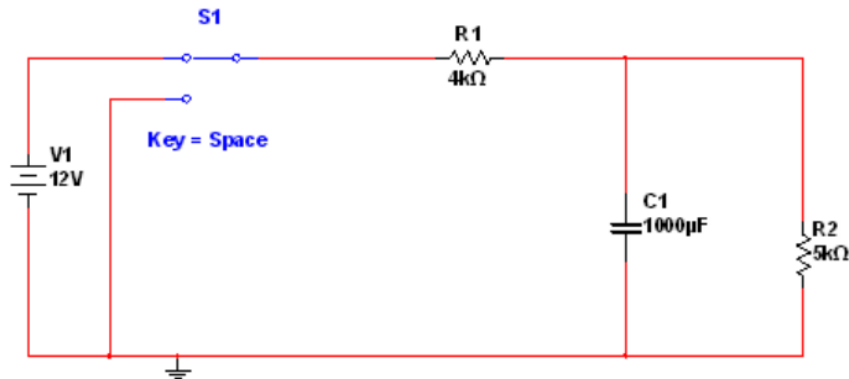


Figure 16 - Task 3 Circuit

Parallel Resistors/Equivalent Circuit

Above is the RC circuit for Task 3. In any RC circuit, the total resistance needs to be calculated in order to find out the time constant. To work out the total resistance of the circuit, the product over sum rule is used as shown below.

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{4 \times 10^3 \times 5 \times 10^3}{4 \times 10^3 + 5 \times 10^3} = 2.2 \text{ k}\Omega$$

By working out R_t , this can now replace both the resistors to create an equivalent circuit. This is seen below;

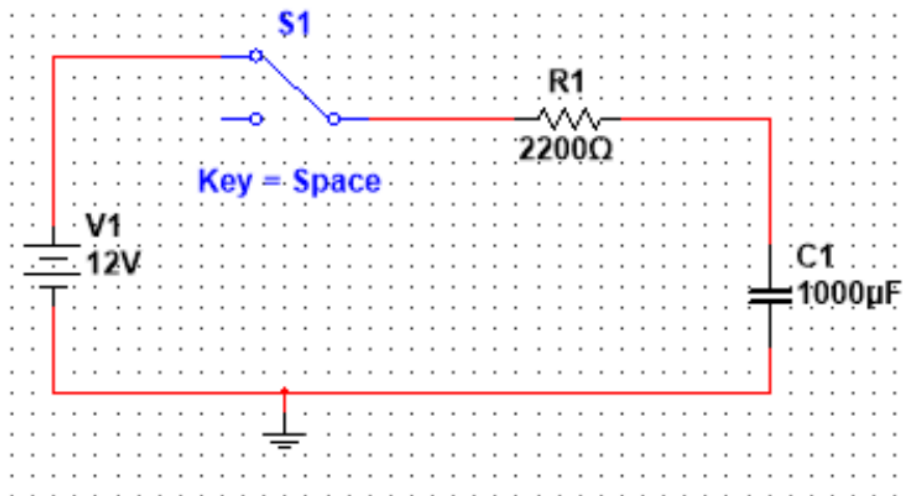


Figure 17 - Equivalent Circuit

Time Constant

With regards to the time constant, this can be found with the following equation;

$$\tau = R t \times C = 2.2 \times 10^3 \times 1000 \times 10^{-6} = 2.2s$$

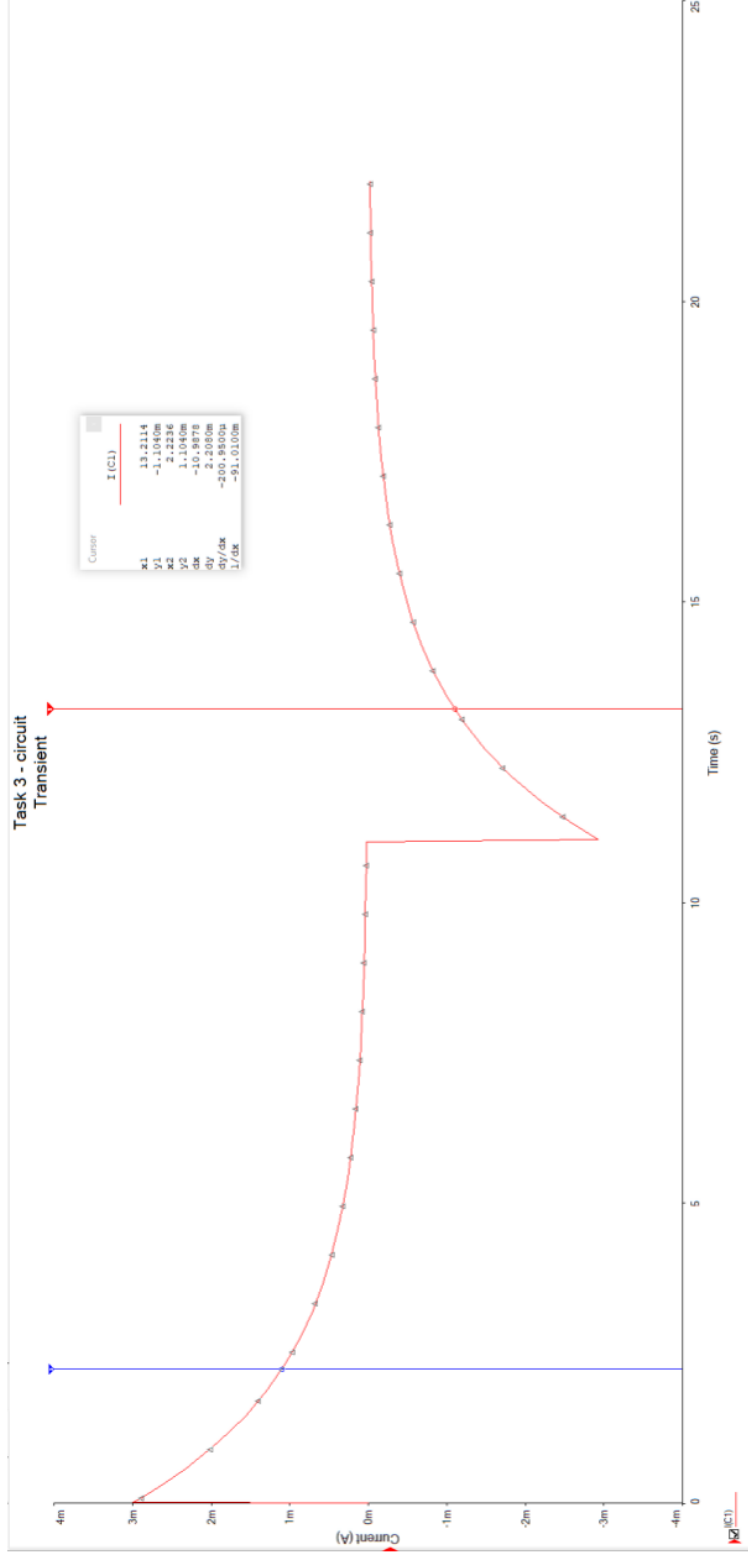


Figure 18 – Time Constant proof

Time Constant Proof

Calculations for Time Constant for charge and discharge

$0.632 \times 3 \times 10^{-3} = 1.896\text{ms}$ – This gives me a time constant of

$0.368 \times 3 \times 10^{-3} = 1.104\text{ms}$ – This gives me a time constant of

	Multisim	Calculations
Charge	2.21	2.2
Discharge	2.22	2.2

Table 5- Time Constant

As you can see from table 5, my calculations and simulation results are very similar. This is down to the fact there's not much human error.

Initial and Final Currents

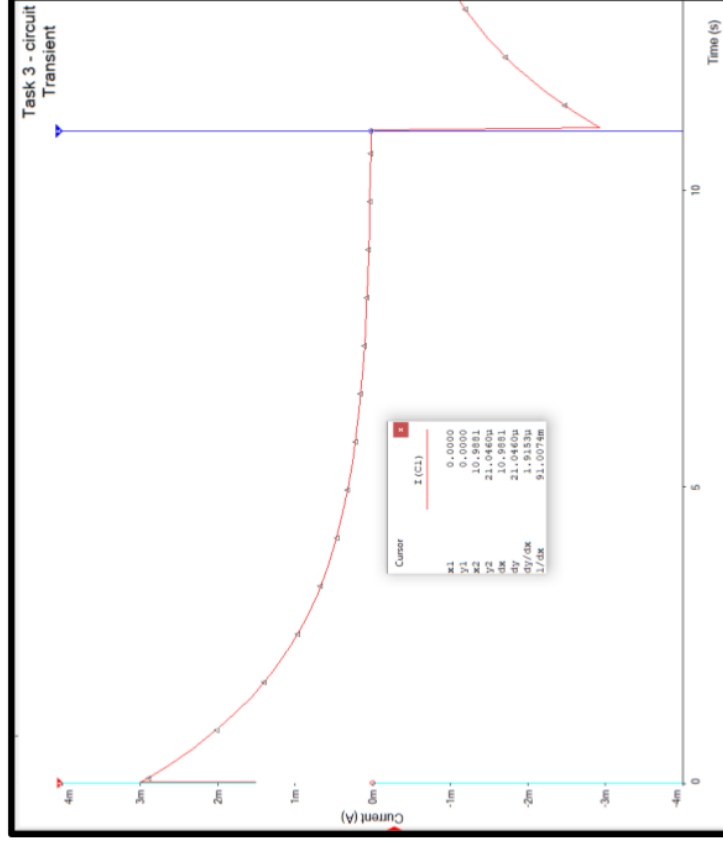


Figure 20- Charge

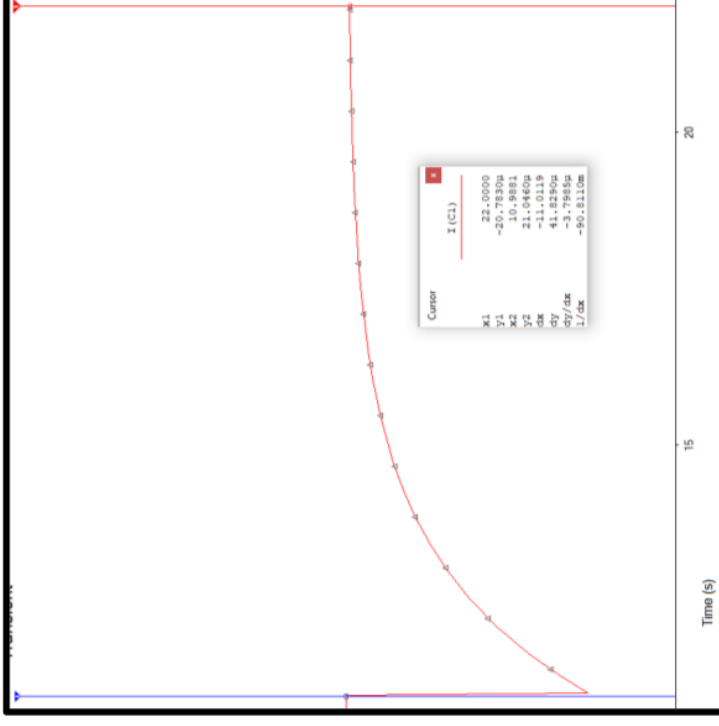


Figure 19 - Discharge

As seen in Figure 19 and 20 it shows the initial and Final Currents. The current starts at an initial value of 3mA and charges upto 0A. With regards to the discharge, the initial current is -3mA and rises to 0A.

Figure 18 shows both time constants for both the Charging and Discharging phases of the circuit. From the calculations, the time constant was calculated to be 2.2s. This can be seen in Figure 19 below.

Cursor		✕
		I (R1)
x1	2.2000	
y1	1.9554m	
x2	17.2000	
y2	-621.4995μ	
dx	15.0000	
dy	-2.5769m	
dy/dx	-171.7904μ	
1/dx	66.6667m	

Figure 21 - Time Constant Evidence

This figure shows a close up of the cursor shown in Figure 18. As shown, the time constant for the charging period is 17.2s with a current value of 0.62mA. With regards to discharge, the time constant is 2.2s with a current value of 1.95mA.

Transient Period

Now the time constant has been calculated, this means the total capacitor charging time can be worked out as its equivalent to 5-time constants;
 $5 \times 2.2 = 11$

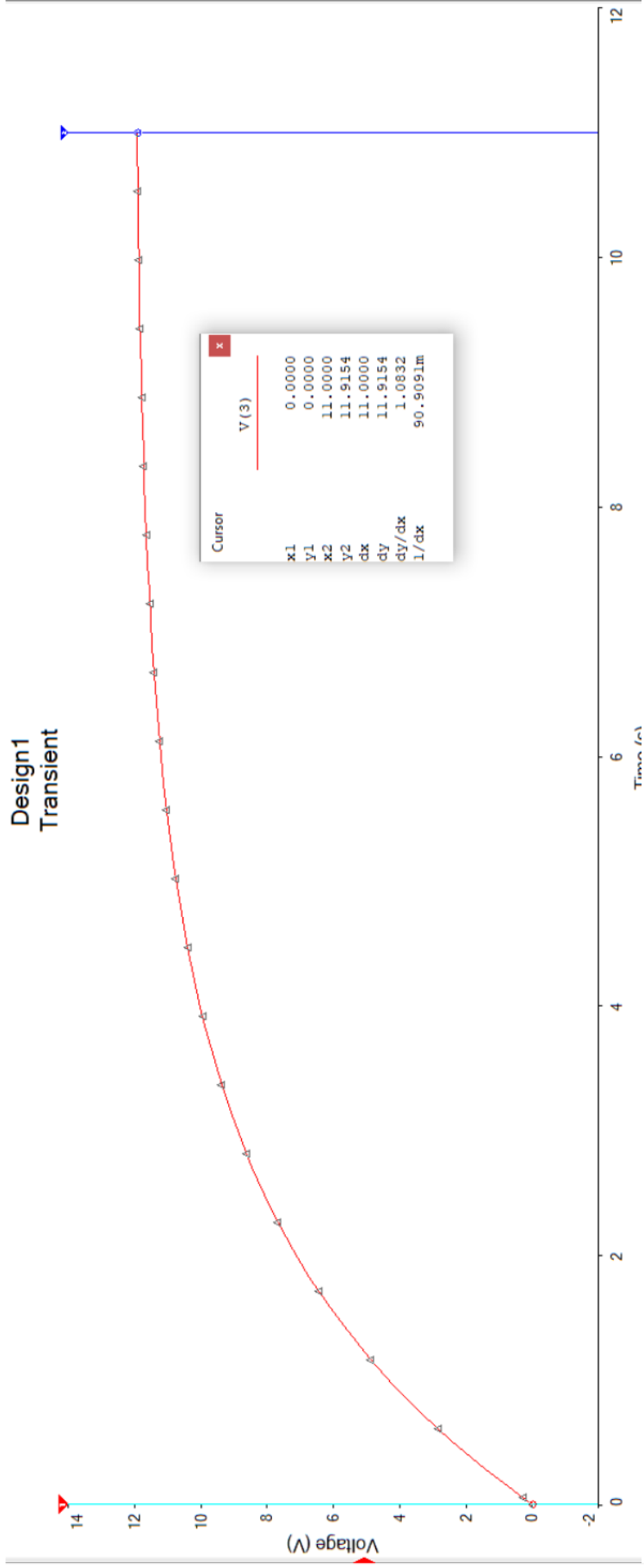


Figure 22 - Capacitor Charge

Equivalent Voltage

To work out the max current, the Equivalent voltage needs to be calculated. this can be calculated by the following formula;

$$V_{OUT} = \frac{R_2}{R_1 + R_2} \times V_s$$

$$V_{OUT} = \frac{5000}{(4000 + 5000)} \times 12 = 6.66V$$

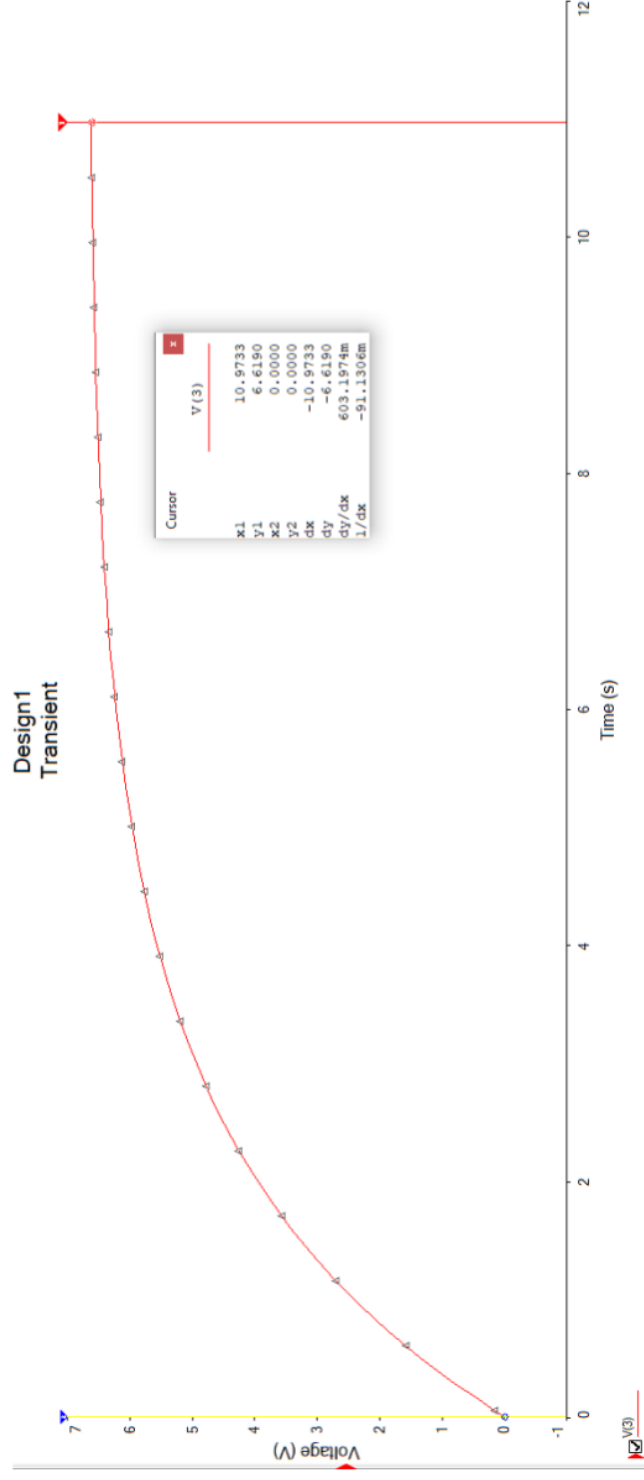


Figure 23 - Equivalent Voltage

Cursor	
	V(3)
x1	10.9733
y1	6.6190
x2	0.0000
y2	0.0000
dx	-10.9733
dy	-6.6190
dy/dx	603.1974m
1/dx	-91.1306m

Figure 24 - Equivalent Voltage Cursor Readings

As you can see from Figure 22, the transient analysis shows Vout to be 6.61V. This is very close compared to our calculated value of 6.66V with only a difference of 0.05V which is hardly nothing.

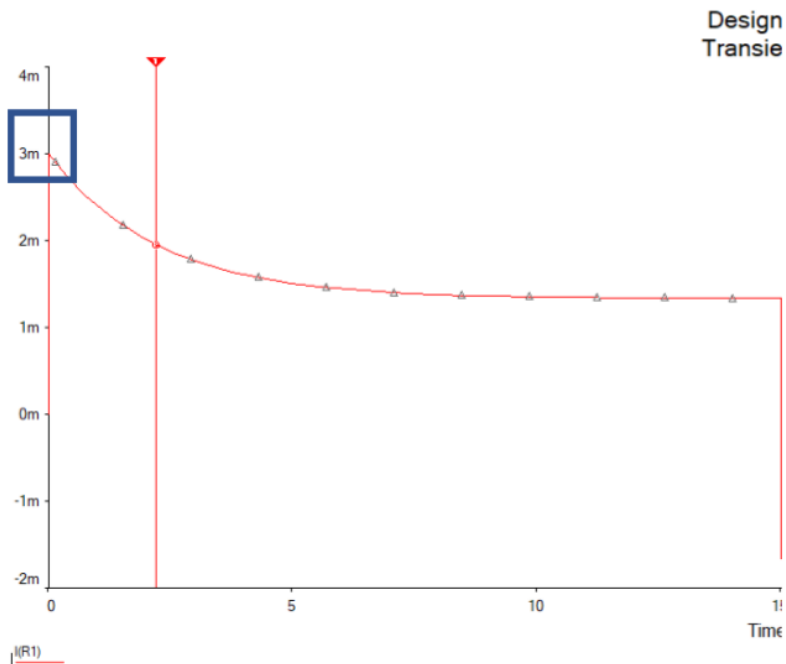
Maximum Current

With regards to current, the maximum current can be derived from using Ohm's Law (Shown Below)

$$I = \frac{V_{OUT}}{R_T}$$

$$I = \frac{6.66}{2200} = 3.027mA$$

This is shown in the transient analysis below;



Task 4

The circuit below is an RL circuit (Inductive) using a 15Ω resistor as well as a 3H inductor.

With an RL circuit, the time constant can be calculated using the following formula;

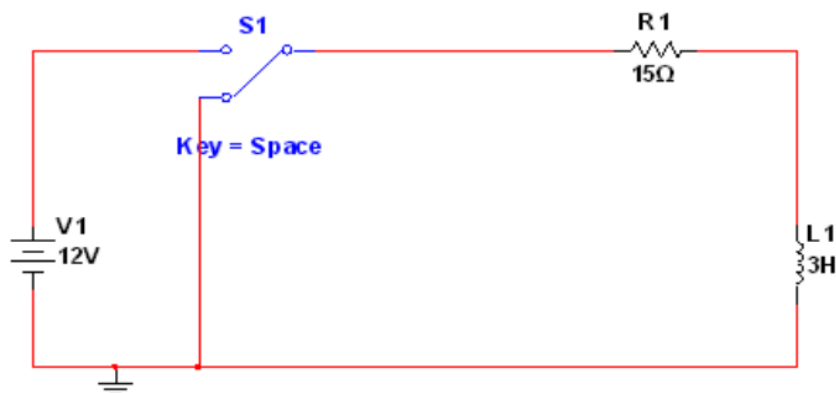


Figure 3

Figure 25 - Task 4 Circuit

$$T = \frac{L}{R}$$

Using this formula, the time constant is;

$$\tau = \frac{3}{15}$$

$$\tau = 0.2s$$

As shown in Figure 24, two cursors have been placed to show the time constants for both the charging and discharging phases. The cursors also display the current at the time constant. Table 6, shows the comparison between the calculated and simulated time constants with their matching currents.

	Calculation Time Constant	Calculation Current (mA)	Simulated Current (mA)
Charging	0.2s	294.30	291.97
Discharging	0.2s	505.69	505.68

Table 6- Time Constant Evidence

As seen from table 6, the calculated and simulation's result have very similar currents whilst discharging. However, during the charging phase, there is a slight difference of around 3mA. This may be down to a rounding error with the calculations. The simulated result tends to be more accurate as there's less human error involved. We can use this to prove that 0.2s is indeed the time constant for the inductor.

Time Constant

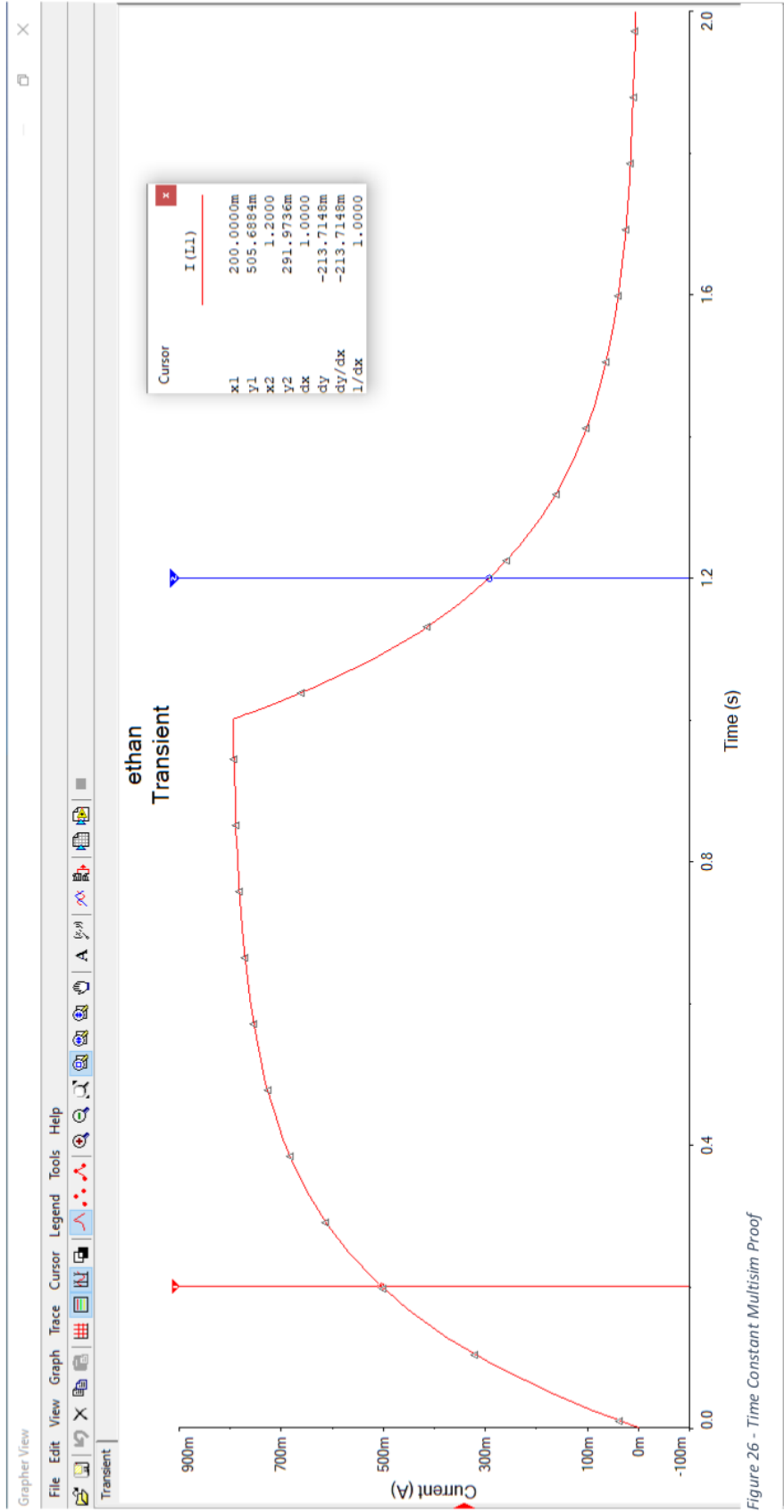


Figure 26 - Time Constant Multisim Proof

Figure 24 shows the time constants during the charging and discharging phase. The results can be seen from the cursor readings and Table 5 above.

With the time constant calculated, the inductor is fully charged after 5-time constants (1 second).

$$\text{Transient Period} = 5 \times T = 1s$$

Maximum Current before Switch Activates

Once the inductor has fully charged, the circuits current will be at the maximum, this current can be calculated with the following equation;

$$I_{MAX} = \frac{V_S}{R} = \frac{12v}{15\Omega} = 0.8A$$

To calculate the current growth across the inductor, intervals of 0.2s will be used up until 1s to show the shape of the current growth. Calculations will also be made to use as a method of comparison. The formula can be shown in Table 5 below whilst Figure 29 shows the Calculated current growth graph. Figures 24-28 show the Multisim values for the current at each time interval whilst a comparison table is shown in Table 6 on page 33.

Current Growth Analysis

Time (s)	Equation	Current (A)
0.2	$I_L = 0.8(1 - e^{\frac{-15}{3} \times 0.2})$	0.50569
0.4	$I_L = 0.8(1 - e^{\frac{-15}{3} \times 0.4})$	0.6917A
0.6	$I_L = 0.8(1 - e^{\frac{-15}{3} \times 0.6})$	0.7601A
0.8	$I_L = 0.8(1 - e^{\frac{-15}{3} \times 0.8})$	0.78534A
1.0	$I_L = 0.8(1 - e^{\frac{-15}{3} \times 1.0})$	0.7946

Table 7 - Current Growth

Figure 27 below, shows the current growth of up to 0.79A (800mA) before the switch switches. This matches the calculated result of 0.8A seen above.

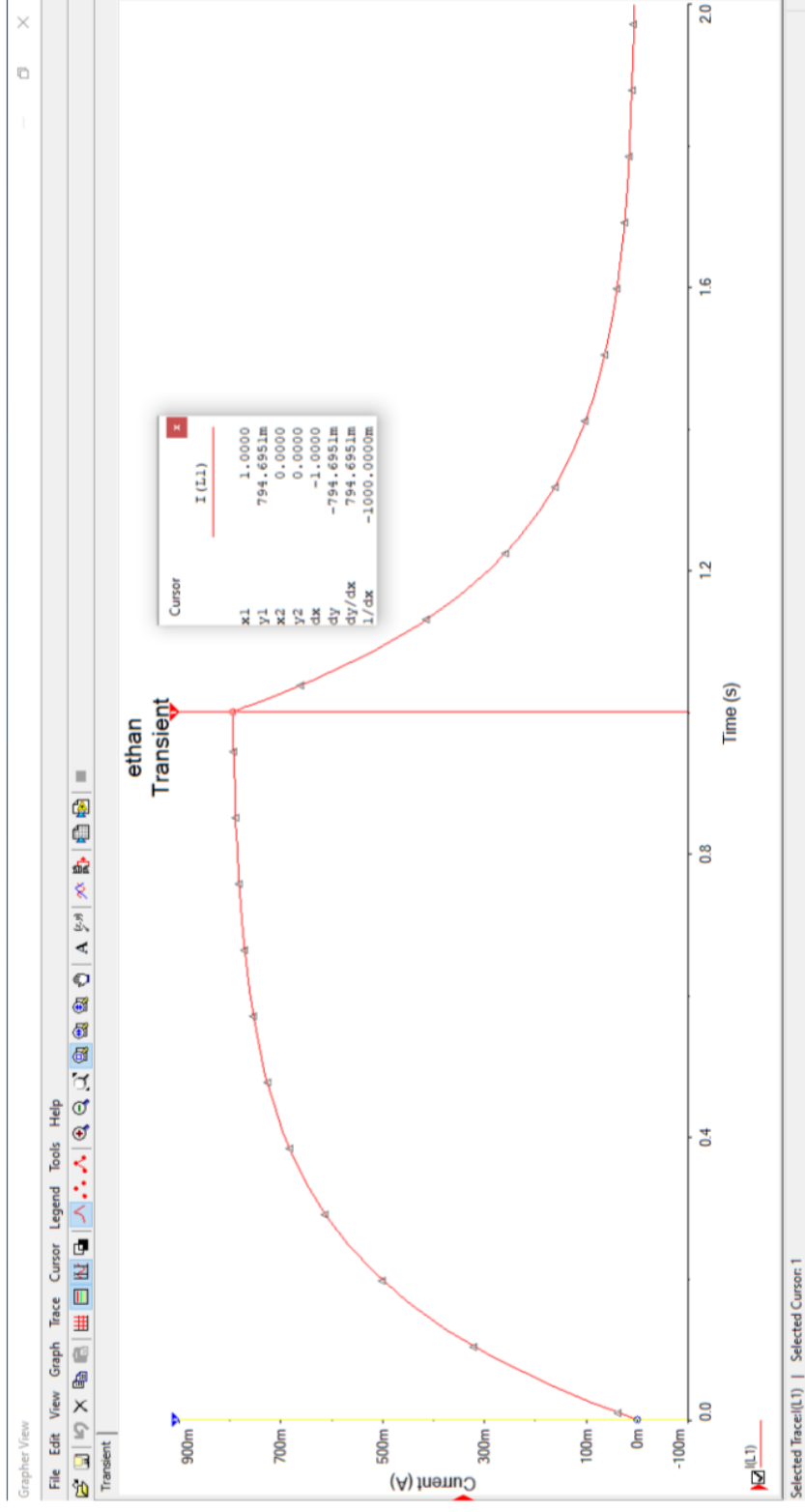


Figure 27 - Current Growth before switch turns

0.2s

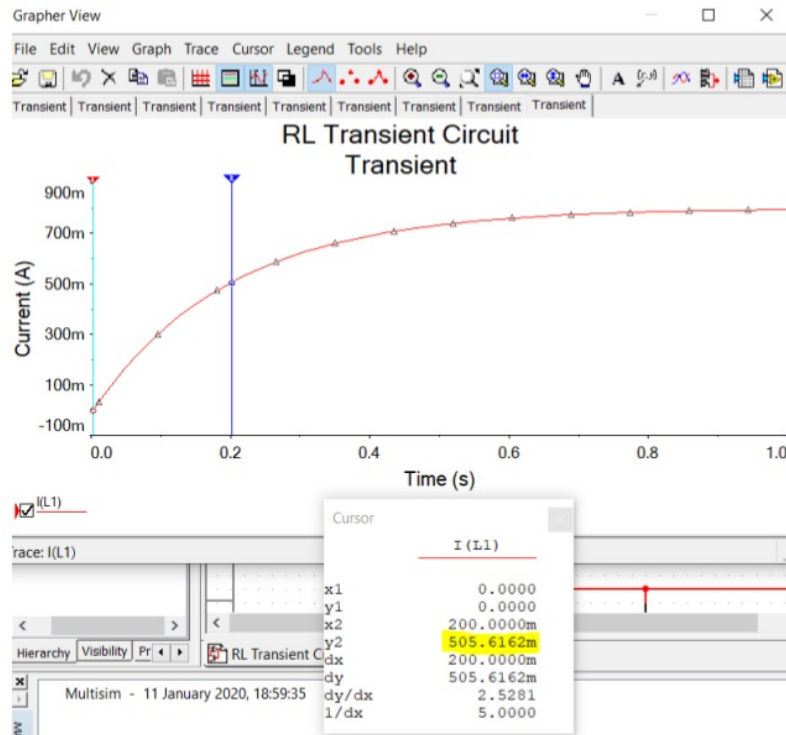


Figure 28 - Current Growth (0.2)

0.4s

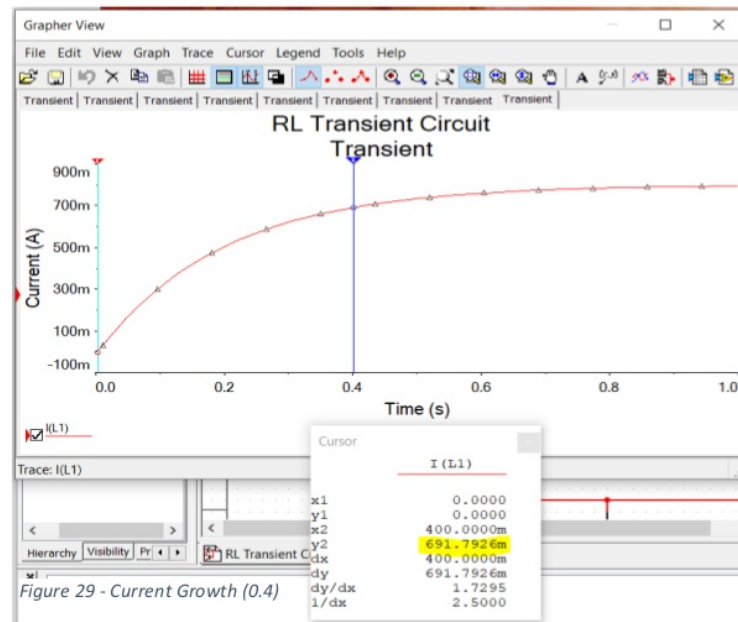


Figure 29 - Current Growth (0.4)

0.6s

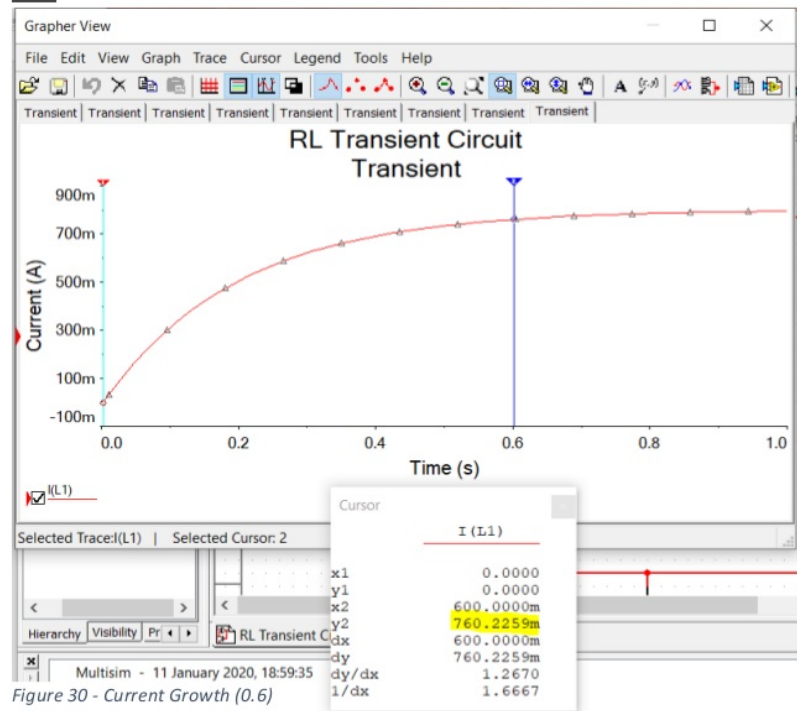


Figure 30 - Current Growth (0.6)

0.8s

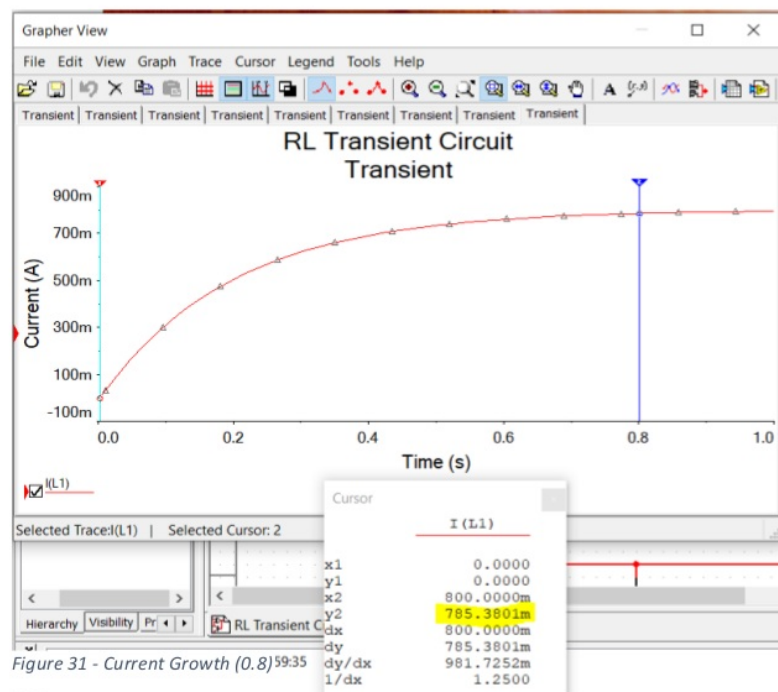


Figure 31 - Current Growth (0.8)

1.0s

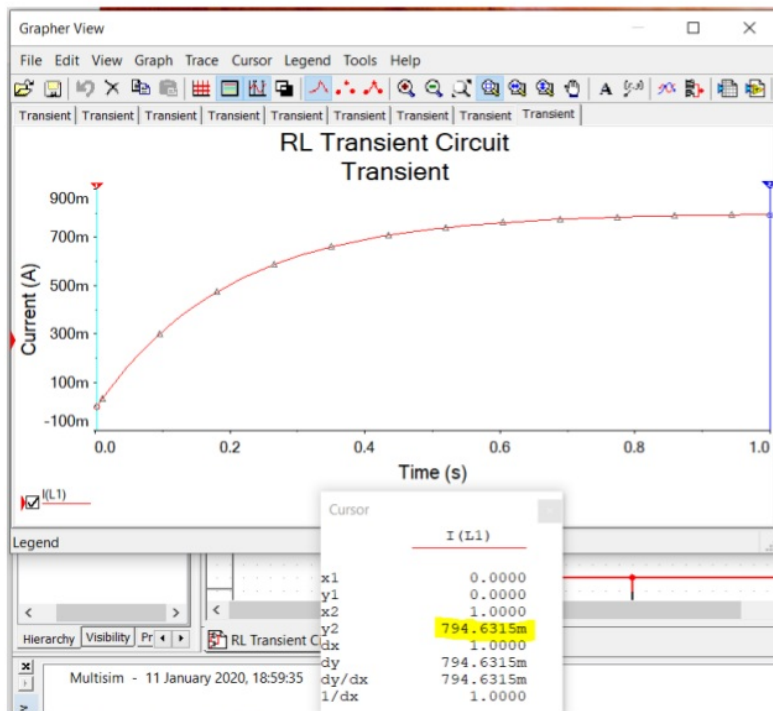


Figure 32 - Current Growth (1.0)

Below is a graph showing the current growth across the inductor whilst charging. As you can see it has a relatively quick increase before slowing down and hitting the steady state period.

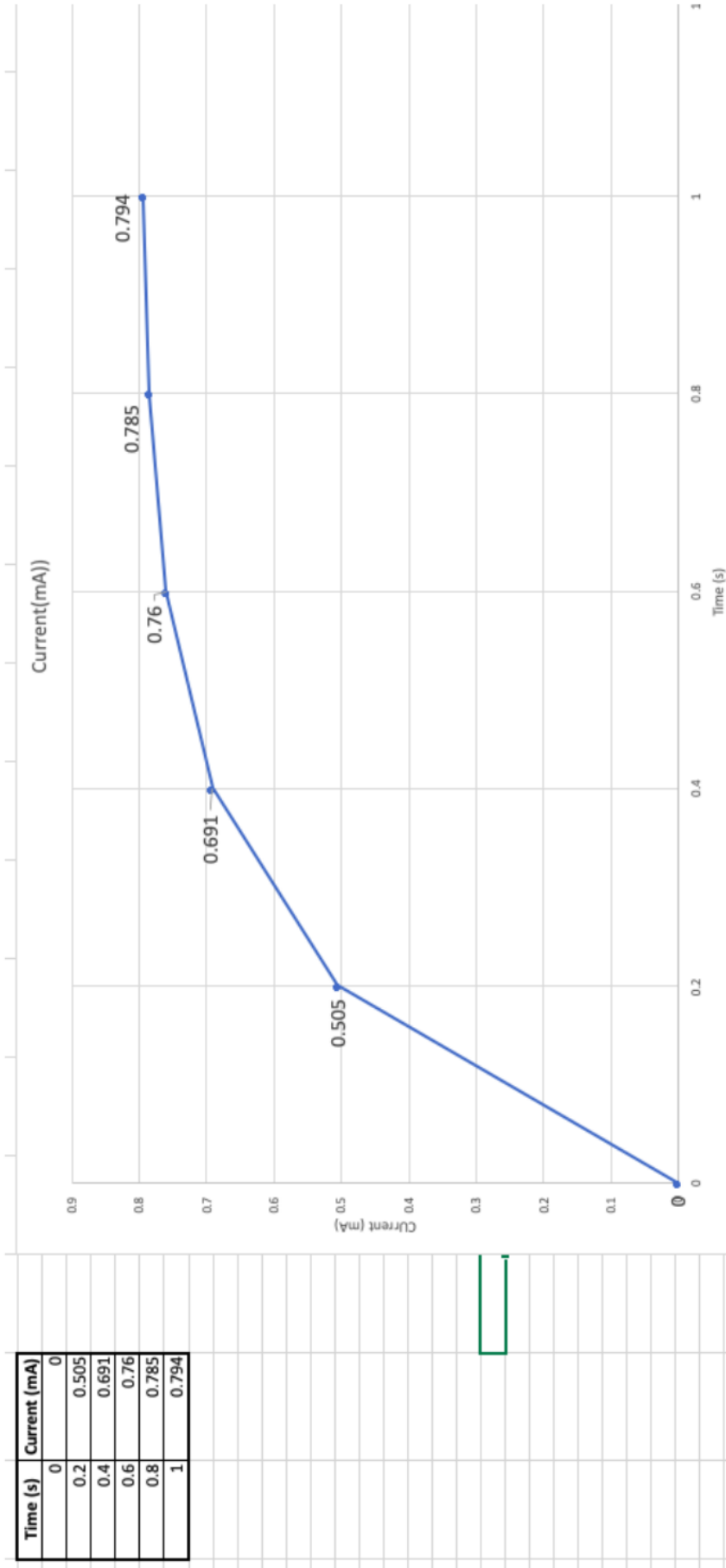


Figure 33 - Current Growth Graph

As the current growth was manually calculated as well as through Multisim. These results can be compared, and a conclusion can be made. (See Table Below)

Time (s)	Multisim	Calculations
0.2	505.61	0.505
0.4	691.72	0.691
0.6	760.22	0.76
0.8	785.38	0.785
1.0	794.63	0.794

Table 8 - Current Growth Comparison Table

As seen in Table 7, both the simulation and calculations have pretty much the exact same results. This is due to the lack of discrepancies involved with calculations and a computer-based simulation.

In order to calculate the time that it takes for the current to fall to a certain time the following equation is used:

$$I_L = I_{MAX}(e^{\frac{-t}{T}})$$

However, this equation has to be rearranged in order to make the equations subject 't', this is done by replacing 'e' with log rules:

$$\frac{I_L}{I_{MAX}} = (e^{\frac{-t}{T}})$$

$$\ln\left(\frac{I_L}{I_{MAX}}\right) = \frac{-t}{T}$$

$$-t = T \left[\ln\left(\frac{I_L}{I_{MAX}}\right) \right]$$

10mA/100mA Fall Times

In order to find the time taken for the circuit to elapse to 100mA and 10mA these figures and the values of I_L and I_{MAX} are substituted into the equation;

100mA;

$$t = T \left[\ln\left(\frac{I_L}{I_{MAX}}\right) \right]$$

$$t = 0.2 \left[\ln\left(\frac{100 \times 10^{-3}}{0.8}\right) \right] = -0.415888s$$

$$t = 0.416s$$

10mA;

$$t = 0.2 \left[\ln\left(\frac{100 \times 10^{-3}}{1.2}\right) \right] = -0.876405s$$

$$t = 0.876s$$

These equations can now be found on Multisim to help compare and make a comparison.

10mA;

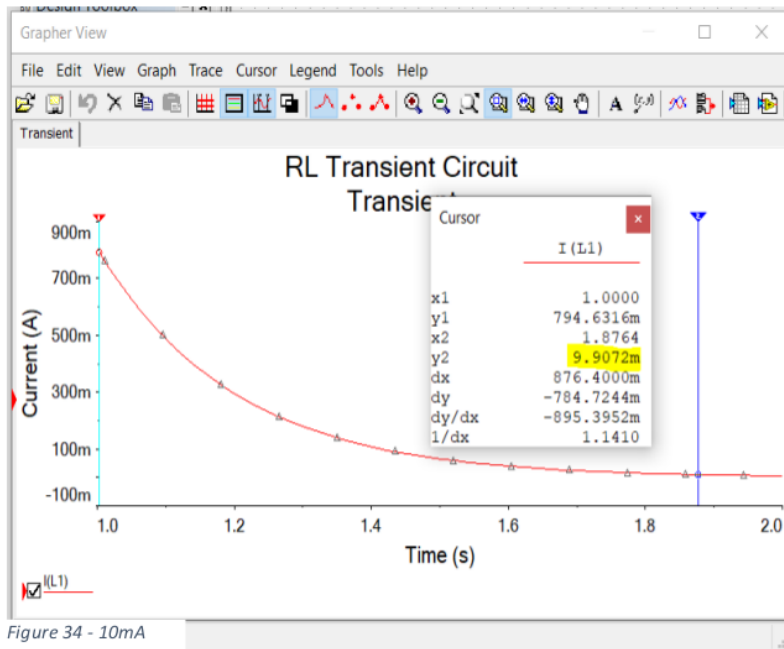


Figure 34 - 10mA

As seen in Figure 30 above, the simulation software gives a time value of 0.876s

100mA;

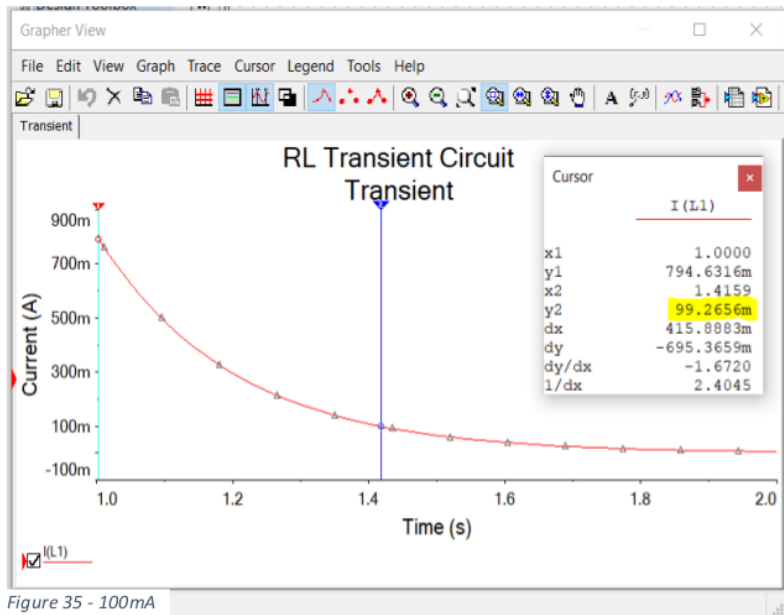


Figure 35 - 100mA

As seen in Figure 31 above, the simulation software gives a time value of 0.4158s

Comparison

Current mA	Multisim Time	Calculations Time
10	0.8764s	0.876405s
100	0.4158s	0.415888s

Table 9 - Comparison Table

As seen from Table 7, the results from both Multisim and manually via calculations, are pretty much exactly the same. The ever so slight difference may be down to a slight rounding error during the calculations.

Conclusion

Throughout this report, transient analysis was researched for different types of electrical circuits including RL, RC and a complex RC. These three circuits were analysed and tested during the charging and discharging phases by calculations, simulations and practical tests. Different characteristics were analysed including current, voltage and time constants. Three methods of testing were used as a means of comparison to verify the validity of the results. Each set of readings was analysed and a verdict was given with regards to their accuracy and any errors were pinpointed.

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FINAL GRADE

GENERAL COMMENTS

70/100

Instructor

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ETHAN JOEL

70

1. ENGAGEMENT WITH LITERATURE



NA

2. KNOWLEDGE AND UNDERSTANDING



2. Good level of knowledge, lacks key equations in some areas. 18/25

18

3. COGNITIVE AND INTELLECTUAL



3. Test results are tabulated and proof of results given in graphical analysis, it is not always evident where the calculated results are, consider placing at point of use. 22/30

22

4. PRACTICAL APPLICATION



4. Good application of basic methods, although not all your equations are present and correct 16/25

16

5. TRANSFERABLE SKILLS



5. Structure is ok, graphs are good, written communication is good. Conclusion could be improved by insertion of key images/tables and an account directly below. 14/20

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