

# 1909751

*by* Alex Williams

---

|                |                                                           |                 |       |
|----------------|-----------------------------------------------------------|-----------------|-------|
| FILE           | 11778_ALEX_WILLIAMS_1909751_175211_1032207550.PDF (1.65M) |                 |       |
| TIME SUBMITTED | 13-JAN-2020 12:15PM (UTC+0000)                            | WORD COUNT      | 3345  |
| SUBMISSION ID  | 118147626                                                 | CHARACTER COUNT | 18537 |

|                    |                                                 |
|--------------------|-------------------------------------------------|
| Course:            | HNC Electrical and Electronic Engineering       |
| Module:            | SGEE4000 – Electrical and Electronic Principles |
| Assignment Title:  | Investigation into DC Transients                |
| Name:              | Alex Williams                                   |
| University Number: | 1909751                                         |
| Date Submitted:    | 11/01/2020                                      |
| Word Count:        | 2136 words                                      |

## Contents

|                                                         |    |
|---------------------------------------------------------|----|
| Table of Figures.....                                   | 1  |
| Executive Summary.....                                  | 2  |
| Practical Task, Circuit analysis and Calculations ..... | 3  |
| Series RC circuit.....                                  | 3  |
| Complex RC Circuit.....                                 | 9  |
| Inductive Circuit .....                                 | 12 |
| Testing, result and analysis .....                      | 18 |
| RC Circuit.....                                         | 18 |
| Complex RC Circuit.....                                 | 18 |
| Inductive Circuit .....                                 | 19 |
| Conclusions and recommendations .....                   | 19 |
| References .....                                        | 21 |
| Appendix .....                                          | 21 |

## Table of Figures

|                                                                         |    |
|-------------------------------------------------------------------------|----|
| Figure 1: Circuit 1 – Series RC circuit.....                            | 3  |
| Figure 2: Voltage across capacitor while charging.....                  | 5  |
| Figure 3: Current flowing while capacitor is charging .....             | 6  |
| Figure 4: Voltage across capacitor while discharging .....              | 7  |
| Figure 5: Current flowing while capacitor is discharging.....           | 8  |
| Figure 6: Circuit 2 – Complex RC circuit .....                          | 9  |
| Figure 7: Complex RC Circuit Transient.....                             | 10 |
| Figure 8: Time constant estimation .....                                | 11 |
| Figure 9: Circuit 3 – Inductive circuit .....                           | 12 |
| Figure 10: Circuit 3 current growth.....                                | 13 |
| Figure 11: Circuit 3 time constant estimate.....                        | 15 |
| Figure 12: Circuit 3 at 100mA & 10mA .....                              | 17 |
| Figure 13: Series RC Circuit Practical Setup .....                      | 21 |
| Figure 14: Series RC Circuit Practical Result - Charge Voltage.....     | 22 |
| Figure 15: Series RC Circuit 1 Practical Result - Charge Current .....  | 22 |
| Figure 16: Series RC Circuit Practical Result - Discharge Voltage ..... | 23 |
| Figure 17: Series RC Circuit Practical Result - Discharge Current ..... | 23 |
| Figure 18: Current Transient Complex RC Circuit .....                   | 24 |
| Figure 19: Manual current plots - inductive circuit .....               | 25 |
| Figure 20: Simulated current – inductive circuit.....                   | 26 |
| <br>                                                                    |    |
| Table 1: Circuit 1 voltage results.....                                 | 18 |
| Table 2: Circuit 1 current results.....                                 | 18 |
| Table 3: Estimated and calculated time constant.....                    | 18 |
| Table 4: Circuit 3 current results.....                                 | 19 |

## Executive Summary

Three different circuits have been investigated for their transient behaviour. Circuit one is a series RC circuit which has been analysed for the transient behaviour for both the charging and discharging of the capacitor. The transient behaviour is known as the state of when the capacitor is charging or discharging until it has reached five time constants then it is classed that has reached its steady state. Both the current and voltage has been analysed and the practical results have been compared with both simulated and theoretical calculations. Circuit two is a complex RC circuit with one resistor in is series with the capacitor and a second in parallel. The aim was to investigate the parallel network to show the resistance is the parallel combination of both the resistors. In this circuit time constant ( $\tau$ ) had to be calculated theoretically.

All electrical circuits have a time delay between its input and output. This delay is generally known as the Time Constant of the circuit and it is the time response of the circuit when a voltage is firstly applied. (Electronics Tutorials, 2014). In order to work out the time constant the circuit first had to be simplified so to simplify out the parallel network. This was able to be done by applying the product over the sum rule.  $R_T = \frac{R_1 \times R_2}{R_1 + R_2}$ . Then the time constant could then be calculated by using  $\tau = C \times R$ .

Circuit 3 was an inductive circuit where the circuit was simulated to see the growth after one seconds. A manual plot was then carried out and compared with the simulated one and a comparison was made between the two with the graph on the simulation graph being more accurate to collect data from as the graph is constructed on more data points. Another estimation of the time constant was taken for circuit 3 with the results being near identical to the simulated and manual plots. Calculations were then carried out to find out the time elapsed before the current drops to 100mA and 10mA.

## Practical Task, Circuit analysis and Calculations

### Series RC circuit

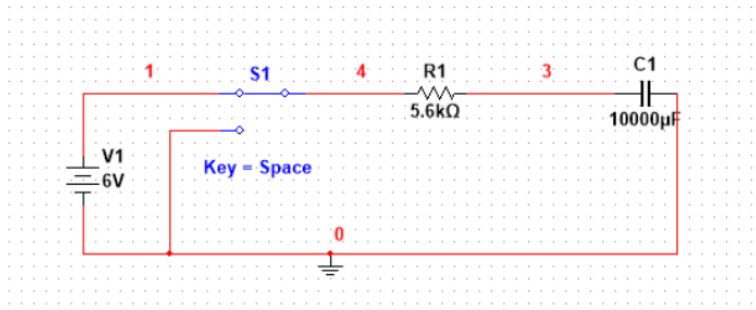


Figure 1: Circuit 1 – Series RC circuit

Figure 1 shows the circuit diagram and values for circuit 1 which is a series RC circuit. This is where a resistor and capacitor are connected in series.

### Practical Testing

The circuit shown in Figure 1 was built and can be seen in Figure 13 in the Appendix. The circuit was made up of a 6v dc supply, a 5.6kΩ resistor and a 10,000μF. The voltage and current were measured for both the charging and discharging of the capacitor. The results were recorded in 5 second intervals and a graph were plotted from these results. The graphs can be found in Figure 14, Figure 15, Figure 16 and Figure 17 in the appendix.

### Theoretical calculations for charging a capacitor

Time Constant,  $\tau = C \times R$

$$\tau = (10,000 \times 10^{-6}) \times (5.6 \times 10^3) = 56 \text{ Seconds}$$

Voltage across Capacitor after 25, 56 and 100 seconds:

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

- At 25 seconds,  $VC = 6 \left(1 - e^{-\frac{25}{56}}\right) = 2.16v$
- At 56 seconds,  $VC = 6 \left(1 - e^{-\frac{56}{56}}\right) = 3.79v$
- At 100 seconds,  $VC = 6 \left(1 - e^{-\frac{100}{56}}\right) = 4.99v$

$$\text{Maximum current in the circuit, } I_{max} = \frac{V}{R} = \frac{6}{5.6 \times 10^3} = 1.07mA$$

Current flowing after 25, 56 and 100 seconds:

$$I = I_{max} \times e^{-\frac{t}{\tau}}$$

- At 25 seconds,  $I = (1.07 \times 10^{-3}) \times e^{-\frac{25}{56}} = 0.68mA$
- At 56 seconds,  $I = (1.07 \times 10^{-3}) \times e^{-\frac{56}{56}} = 0.39mA$
- At 100 seconds,  $I = (1.07 \times 10^{-3}) \times e^{-\frac{100}{56}} = 0.179mA$

Figure 2 shows the simulated results of the voltage across the capacitor in circuit 1 while the capacitor is charging and Figure 3 shows the current flowing while the capacitor is charging.

Theoretical calculations for discharging a capacitor

Voltage across Capacitor after 25, 56 and 100 seconds:

$$VC = V_{max} \times e^{-\frac{t}{\tau}}$$

- At 25 seconds,  $VC = 6 \times e^{-\frac{25}{56}} = 3.84v$
- At 56 seconds,  $VC = 6 \times e^{-\frac{56}{56}} = 2.21v$
- At 100 seconds,  $VC = 6 \times e^{-\frac{100}{56}} = 1.01v$

Current flowing when the capacitor has been discharging for 25, 56 and 100 seconds:

$$\text{Initial current flowing, } I_{max} = \frac{V}{R}$$

$$I_{max} = \frac{6}{5.6 \times 10^3} = 1.07mA$$

$$\text{Current flowing, } I = -I_{max}(e^{-\frac{t}{\tau}})$$

- At 25 seconds,  $I = (-1.07 \times 10^3) \times e^{-\frac{25}{56}} = -0.68mA$
- At 56 seconds,  $I = (-1.07 \times 10^3) \times e^{-\frac{56}{56}} = -0.39mA$
- At 100 seconds,  $I = (-1.07 \times 10^3) \times e^{-\frac{100}{56}} = -0.18mA$

## Voltage across capacitor on charging

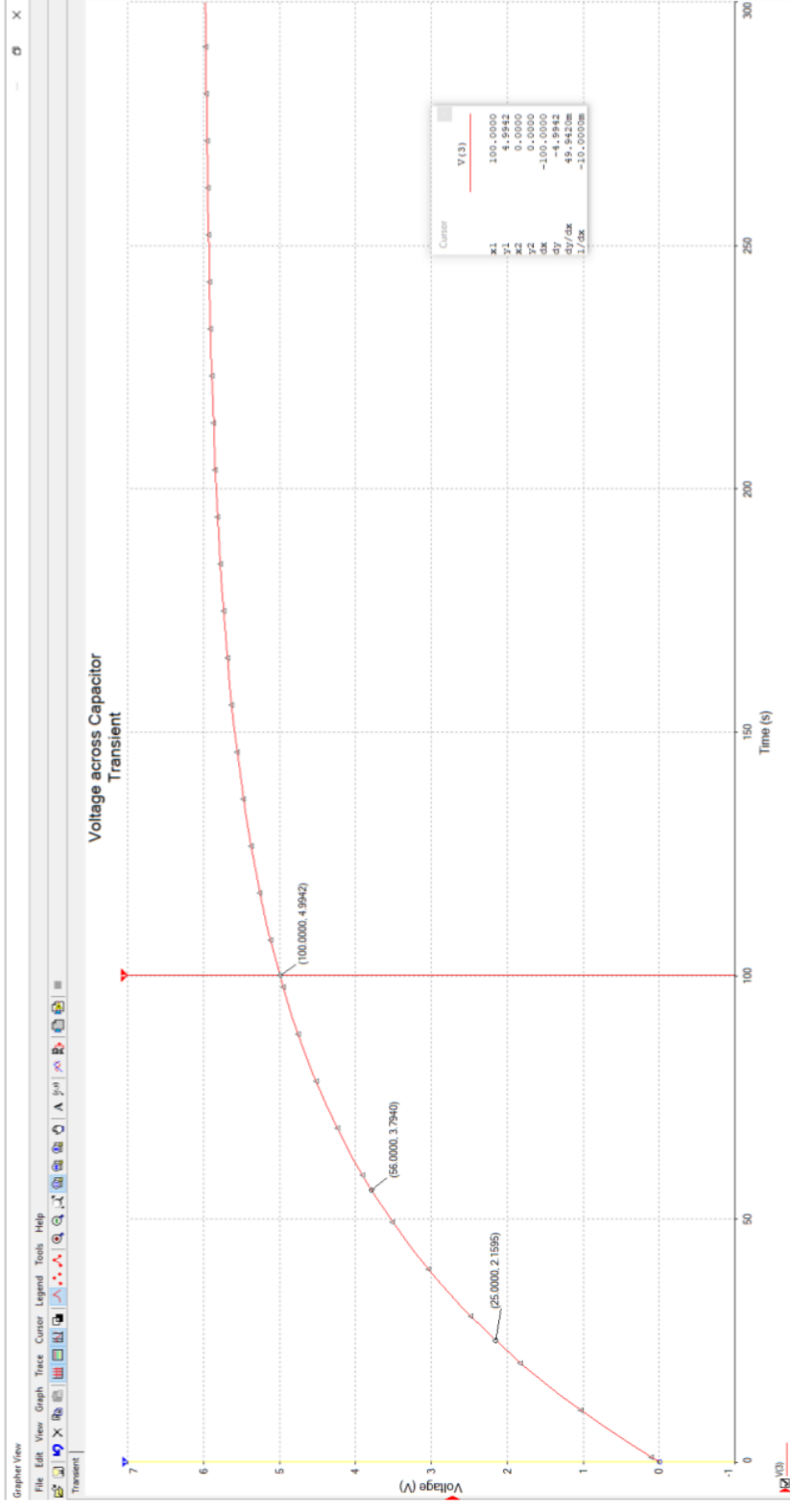


Figure 2: Voltage across capacitor while charging

## Current while charging capacitor

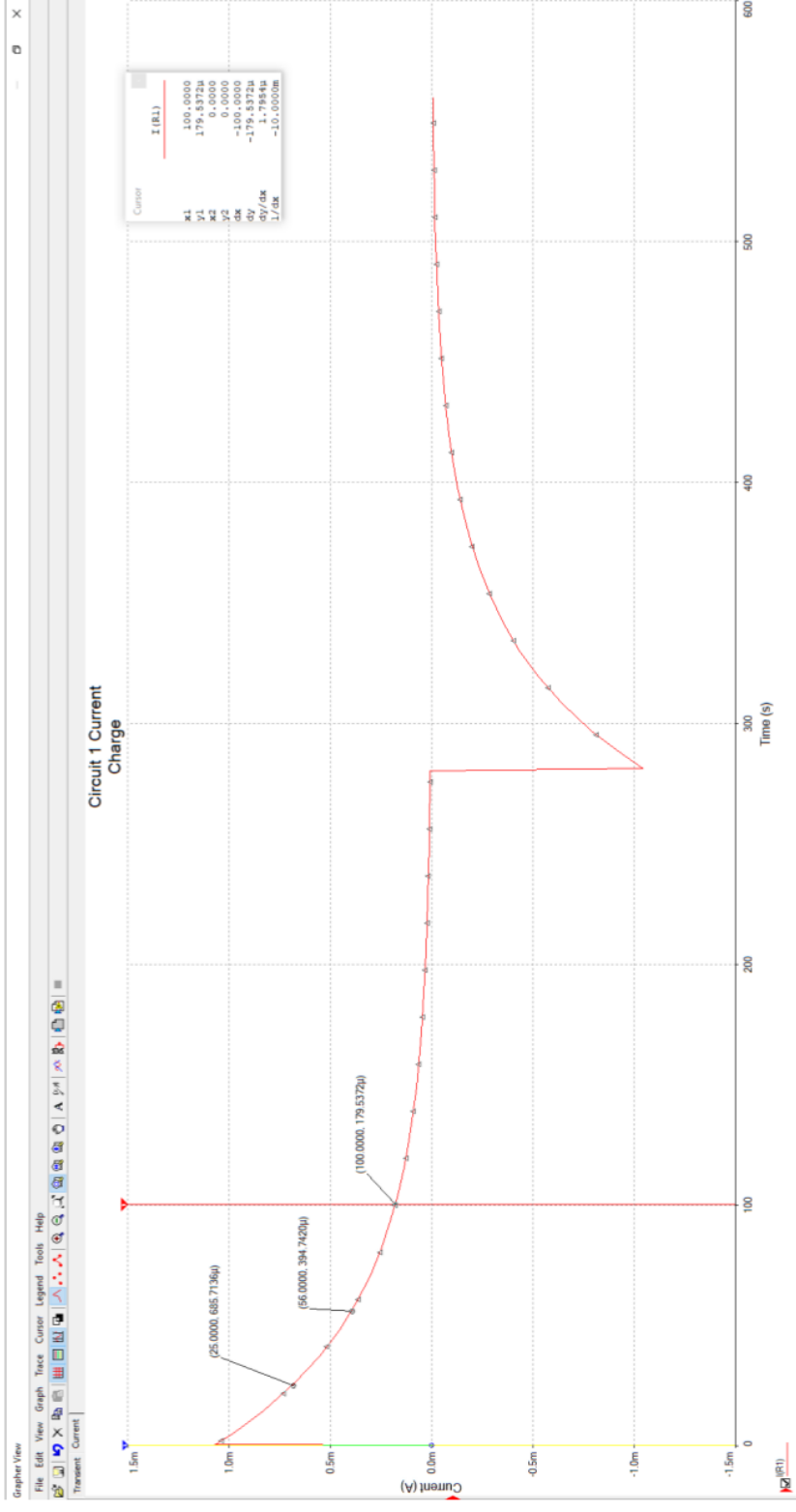


Figure 3: Current flowing while capacitor is charging

## Voltage across capacitor on discharge

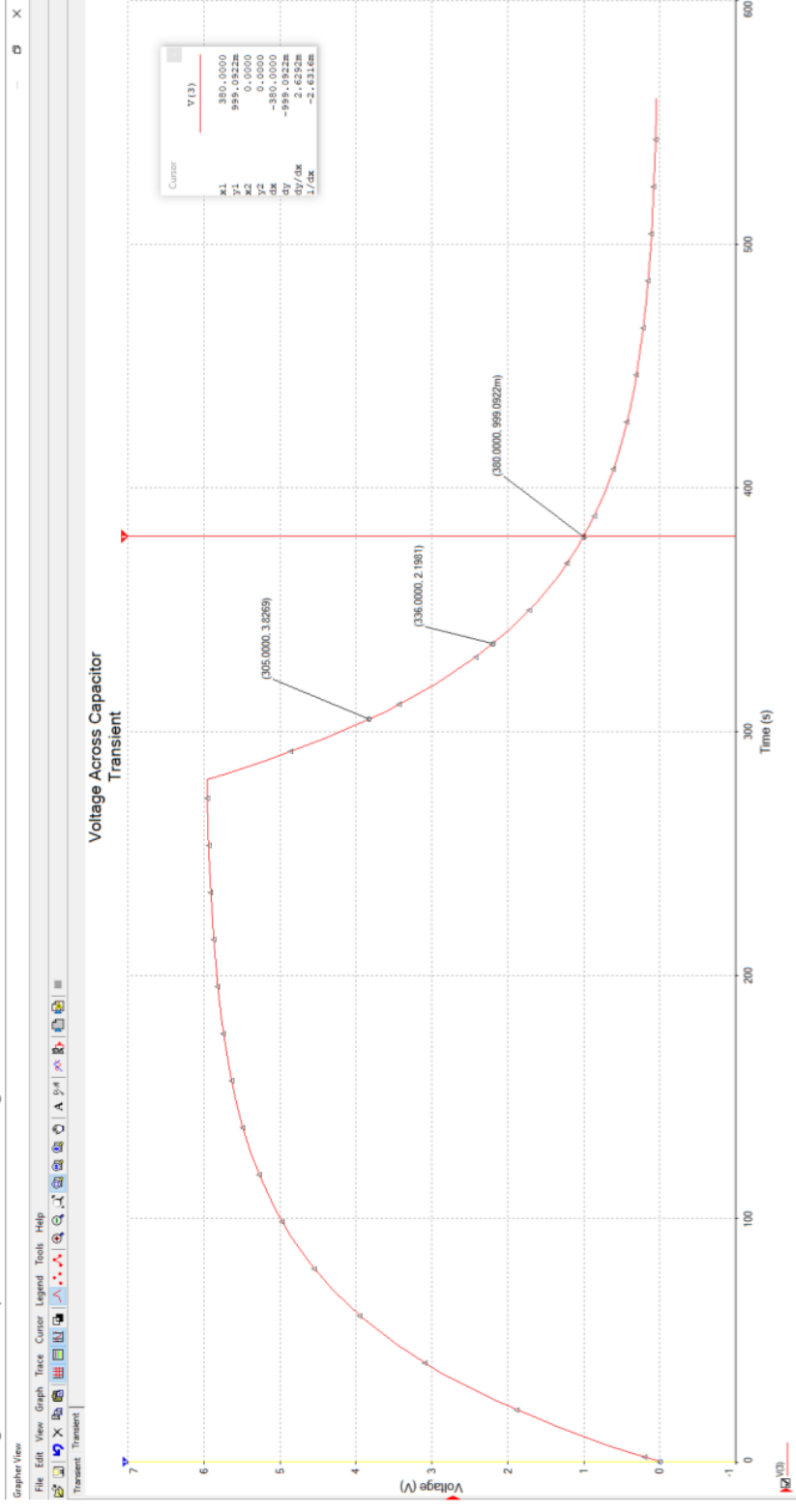


Figure 4: Voltage across capacitor while discharging

## Current while discharging capacitor

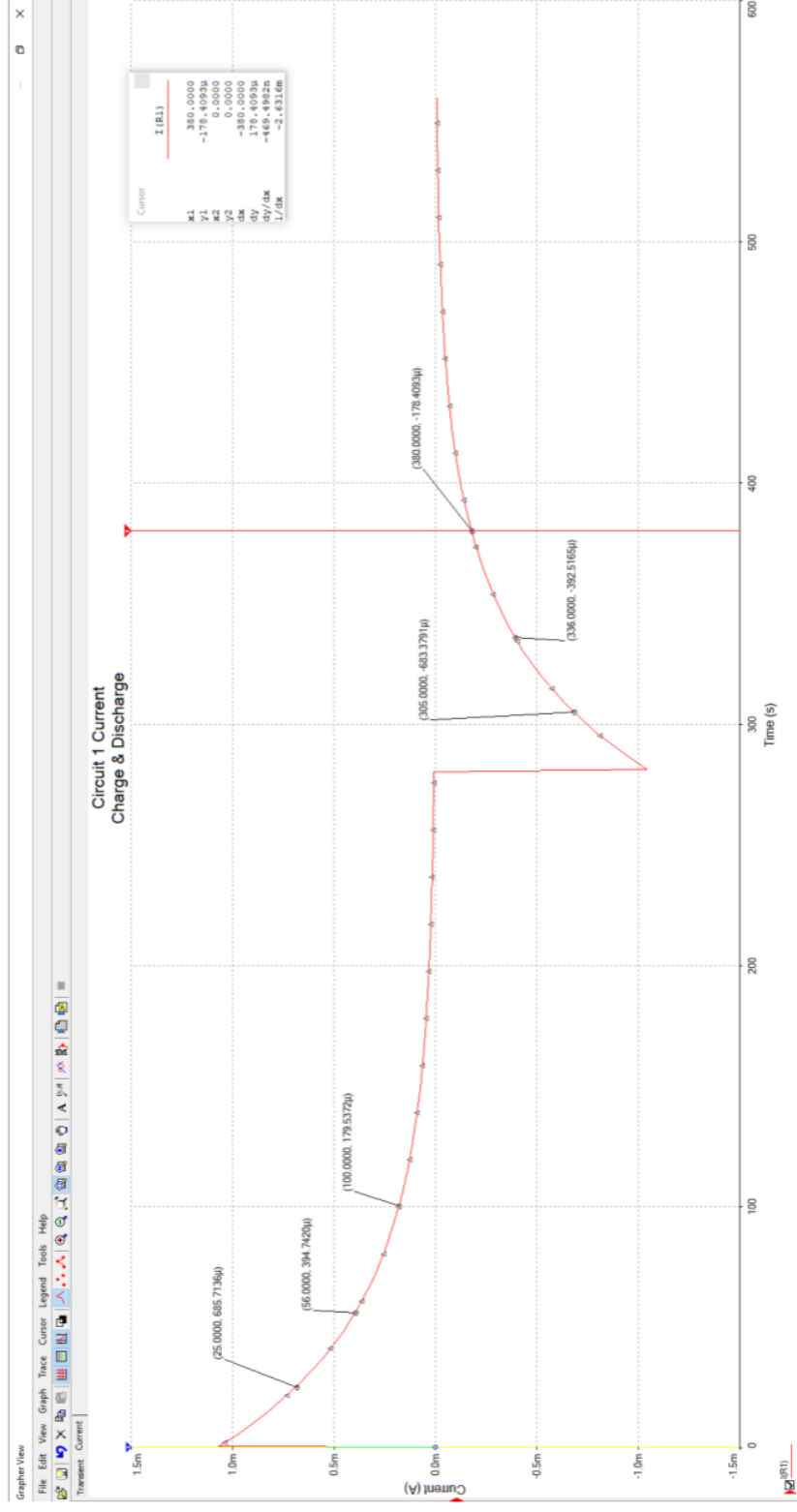


Figure 5: Current flowing while capacitor is discharging

### Complex RC Circuit

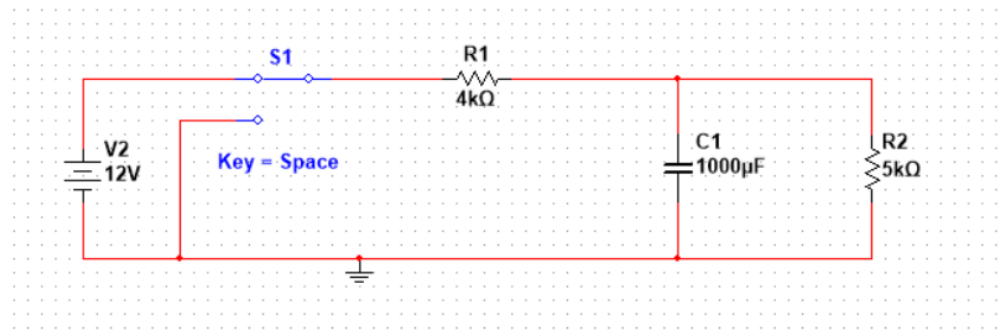


Figure 6: Circuit 2 – Complex RC circuit

Circuit 2 is a complex RC circuit as a resistor is also connected in parallel to the capacitor. In order for theoretical values to be calculated the circuit needs to be simplified down. The resistors are in parallel so can be calculated using the product over the sum rule and then new the new supply voltage can be calculated from a voltage divider.

$$R = \frac{(4 \times 10^3) \times (5 \times 10^3)}{(4 \times 10^3) + (5 \times 10^3)} = \frac{20 \times 10^3}{9 \times 10^3} = 2.22 \text{ k}\Omega$$

The parallel combination of R1 and R2 should be smaller than the individual resistors. With the combined resistor from parallel network being 2.2kΩ, it is smaller than the individual resistors in the circuit.

$$VS = \frac{5}{5+4} \times 12 = 6.67 \text{ v}$$

Figure 7 shows the simulated graph for the transient in the complex RC circuit. The middle data label shows the maximum voltage in the circuit which is shown as 6.62v in the simulation.

Using the simulated plots an estimate for the time constant for charging the capacitor can be calculated by looking at the time elapsed after 63.2% of Vmax.

$$\frac{63.2}{100} \times 6.62 = 4.18 \text{ v}$$

When at 63.2% of the maximum voltage taken from the graph in Figure 8 which is 4.18. The time elapsed is 2.1982 seconds which is approximately one time constant. The maximum voltage is marked by the central data label at 6.62v. Cursor 1 is at 63.2% with the data of x1 showing the time elapsed.

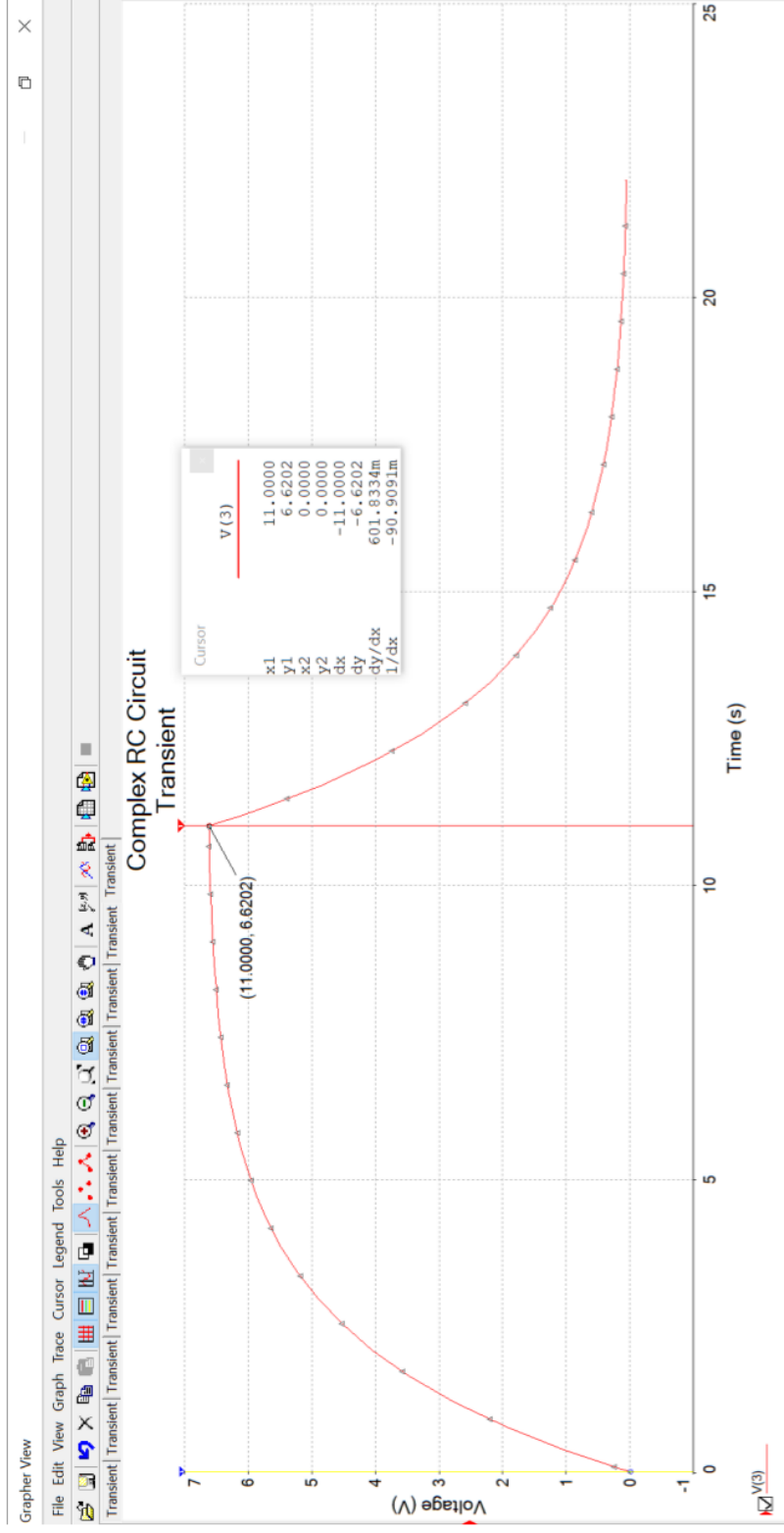
Estimate the time constant for discharging the capacitor, 36.82% of Vmax.

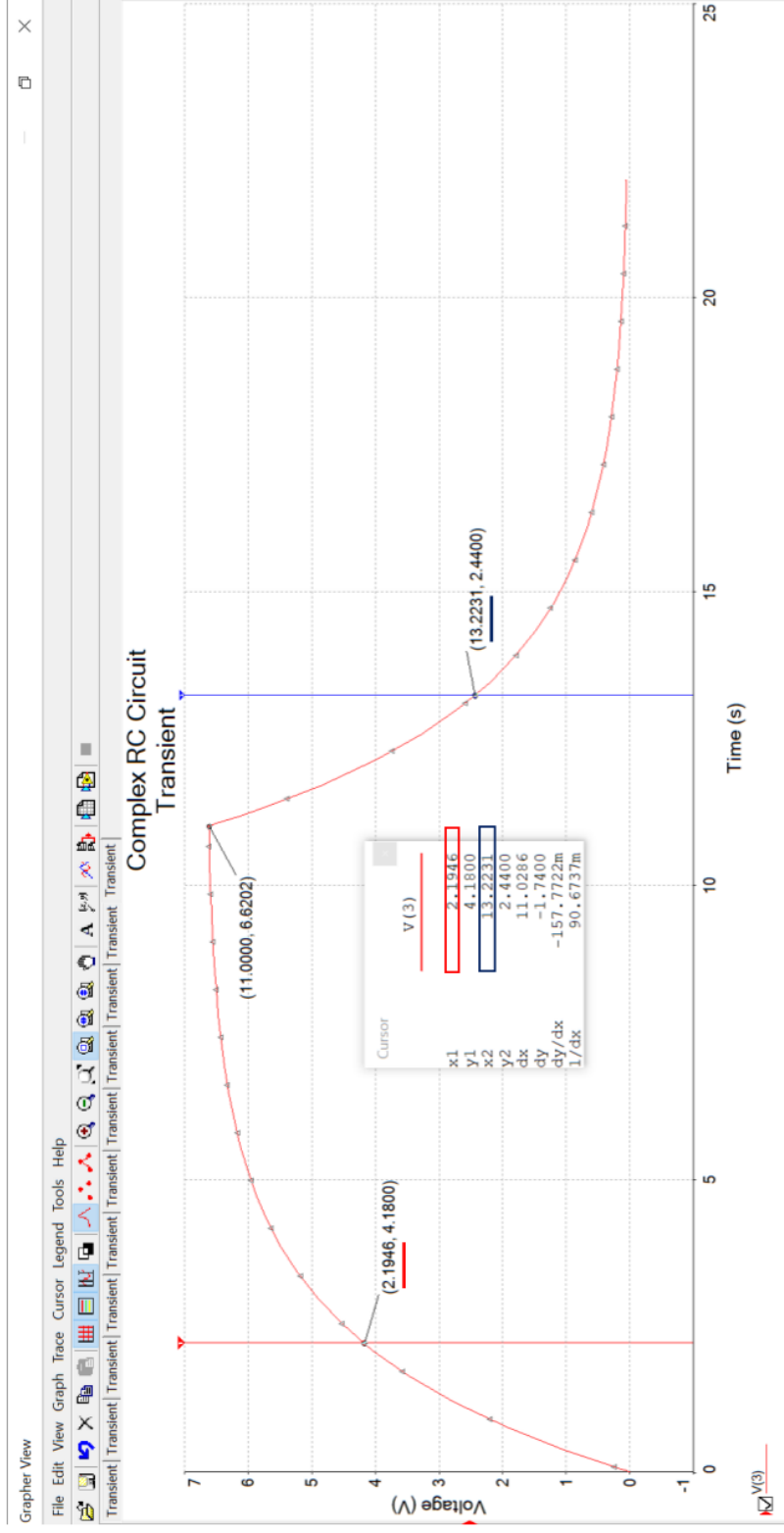
$$\frac{36.8}{100} \times 6.62 = 2.44 \text{ v}$$

Figure 8 also shows the simulated graph for the complex RC circuit but with the cursor 2 on the discharge curve. The time constant for discharging is at 36.8% of the maximum voltage. When the voltage on discharge is at 2.44v the time elapsed on the discharge is 2.223 seconds. (13.223 – 11 = 2.223 Seconds, 11 seconds is subtracted for the charge cycle). The maximum voltage is still marked by the central data label and then cursor 2 is at 36.8% with the data of x2 showing the time elapsed.

The time constant can then also be calculated by the formula  $\tau = C \times R$  using the simplified circuit.

$$\tau = (1,000 \times 10^{-6}) \times (2.2 \times 10^3) = 2.2 \text{ Seconds}$$





The initial current from the circuit can be calculated by using the formula  $i = \frac{V}{R}$

$$i = \frac{6.67}{2.2 \times 10^3} = 3.03 \text{mA}$$

The final current would be when the capacitor has reached steady state which would be at  $5\tau$ .

$5\tau = 5 \times \tau = 5 \times 2.2 = 11 \text{ Seconds}$ . So, using the formula to calculate current  $i = I \times e^{-\frac{t}{\tau}}$

$$i = (3.03 \times 10^{-3}) \times e^{-\frac{11}{2.2}} = 20.42 \mu\text{A}$$

### Inductive Circuit

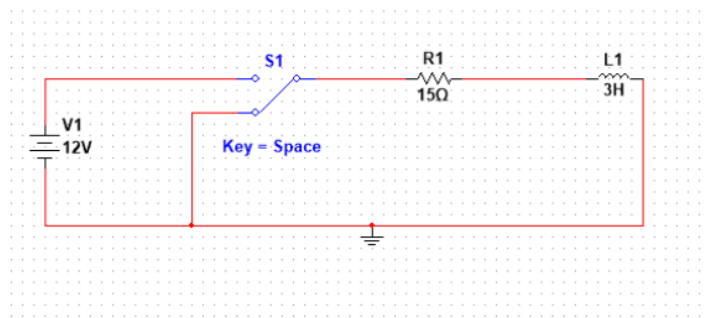


Figure 9: Circuit 3 – Inductive circuit

Figure 10 located below shows circuit simulated for current growth for one second.

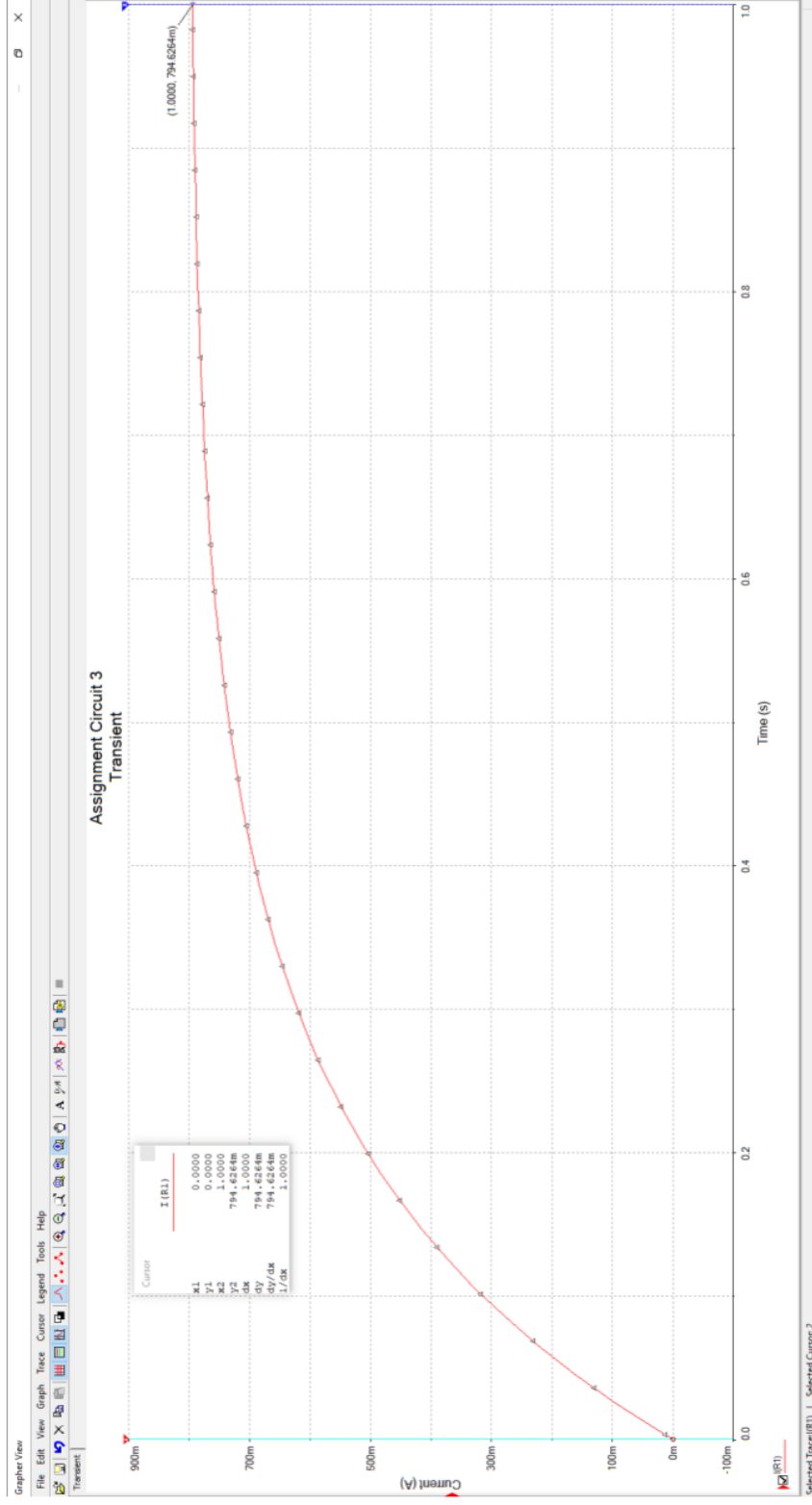


Figure 10: Circuit 3 current growth

Below are the calculations used in order to plot the current flowing in the inductive circuit.

$$\text{Time constant, } \tau = \frac{L}{R} = \frac{3}{15} = 0.2 \text{ Seconds}$$

$$I_{max} = \frac{V}{R} = \frac{12}{15} = 0.8A$$

$$\text{Current flowing, } i = I_{max} \left( 1 - e^{-\frac{Rt}{L}} \right)$$

$$1\tau, i = 0.8 \left( 1 - e^{-\frac{15 \times 0.2}{3}} \right) = 0.51A$$

$$2\tau, i = 0.8 \left( 1 - e^{-\frac{15 \times 0.4}{3}} \right) = 0.69A$$

$$3\tau, i = 0.8 \left( 1 - e^{-\frac{15 \times 0.6}{3}} \right) = 0.76A$$

$$4\tau, i = 0.8 \left( 1 - e^{-\frac{15 \times 0.8}{3}} \right) = 0.785A$$

$$5\tau, i = 0.8 \left( 1 - e^{-\frac{15 \times 1}{3}} \right) = 0.79A$$

$$\text{Calculate the initial current of the circuit, } i = \frac{V}{R} = \frac{12}{15} = 0.8A$$

The estimate time constant is 63.2% of the exponential curve for charging and 36.8% of the exponential curve for discharge.

$$\frac{63.2}{100} \times 0.8 = 0.5056A$$

$$\frac{36.8}{100} \times 0.8 = 0.2944A$$

Cursors 1 shows the charge current of 63.2% and cursor 2 shows the discharge current at 36.2%. The time elapsed is 0.2 seconds (rounded to 1 decimal place). This evidence can be seen in Figure 11 below.

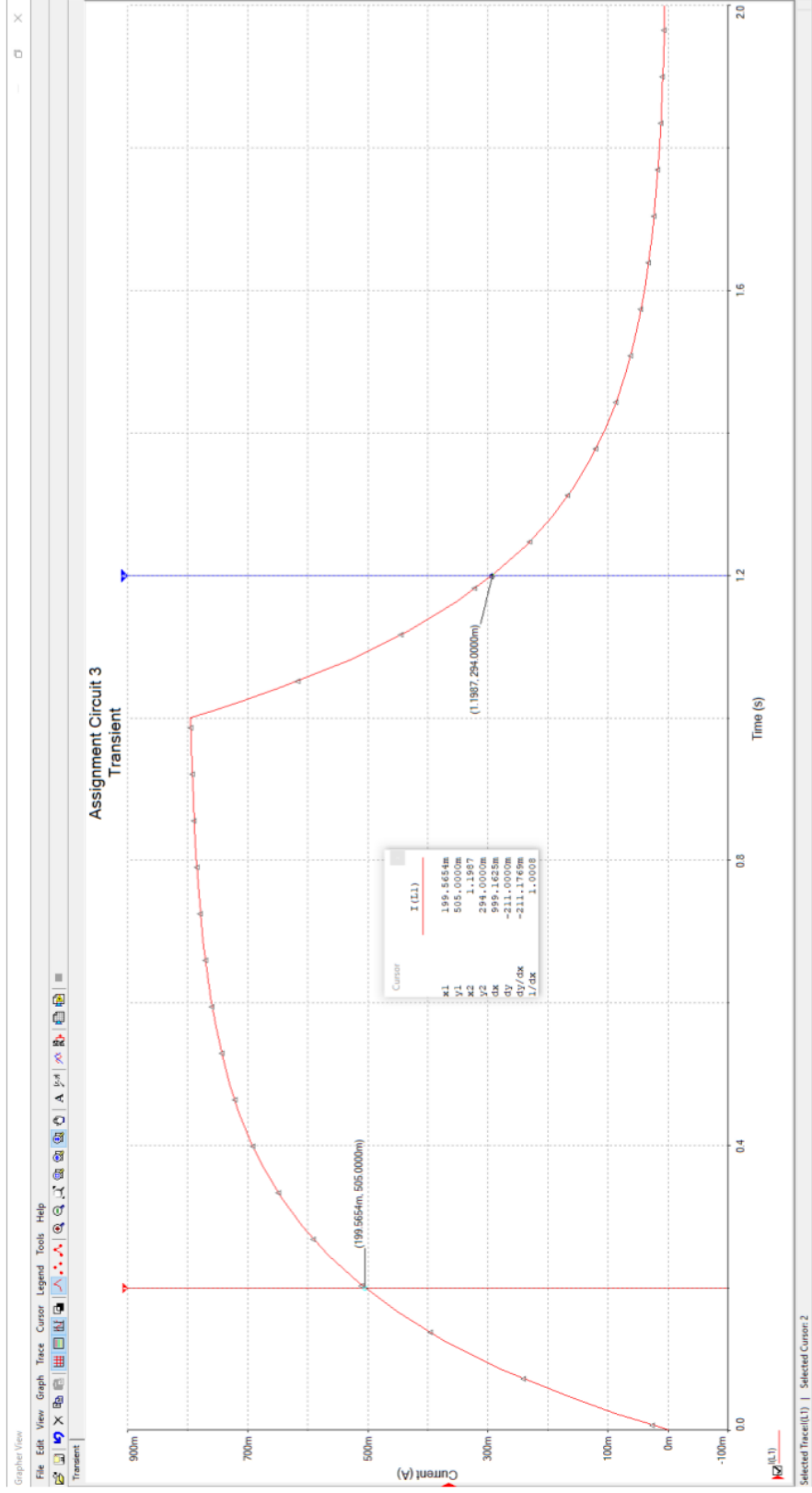


Figure 11: Circuit 3 time constant estimate

Time elapsed before the current has fallen to 100mA.

$$i = I_{max} \times e^{-\frac{t}{\tau}}$$

$$(100 \times 10^{-3}) = 0.8 \times e^{-\frac{t}{0.2}}$$

$$\frac{(100 \times 10^{-3})}{0.8} = e^{-\frac{t}{0.2}}$$

$$0.125 = e^{-\frac{t}{0.2}}$$

$$\text{Flip equation, } e^{-\frac{t}{0.2}} = 0.125$$

Take natural logarithm,  $\ln(e) = 1$

$$-\frac{t}{0.2} = \ln(0.125)$$

$$-\frac{t}{0.2} = -2.0794$$

$$t = -2.0794 \times -0.2$$

$$t = 0.42 \text{ seconds}$$

Time elapsed before the current has fallen to 10mA.

$$i = I_{max} \times e^{-\frac{t}{\tau}}$$

$$(10 \times 10^{-3}) = 0.8 \times e^{-\frac{t}{0.2}}$$

$$\frac{(10 \times 10^{-3})}{0.8} = e^{-\frac{t}{0.2}}$$

$$0.0125 = e^{-\frac{t}{0.2}}$$

$$\text{Flip equation, } e^{-\frac{t}{0.2}} = 0.0125$$

Take natural logarithm,  $\ln(e) = 1$

$$-\frac{t}{0.2} = \ln(0.0125)$$

$$-\frac{t}{0.2} = -4.3821$$

$$t = -4.3821 \times -0.2$$

$$t = 0.88 \text{ seconds}$$

The proof can be seen below in Figure 12 with cursor 1 in red showing the current at 100mA and cursor 2 in blue showing the current at 10mA.

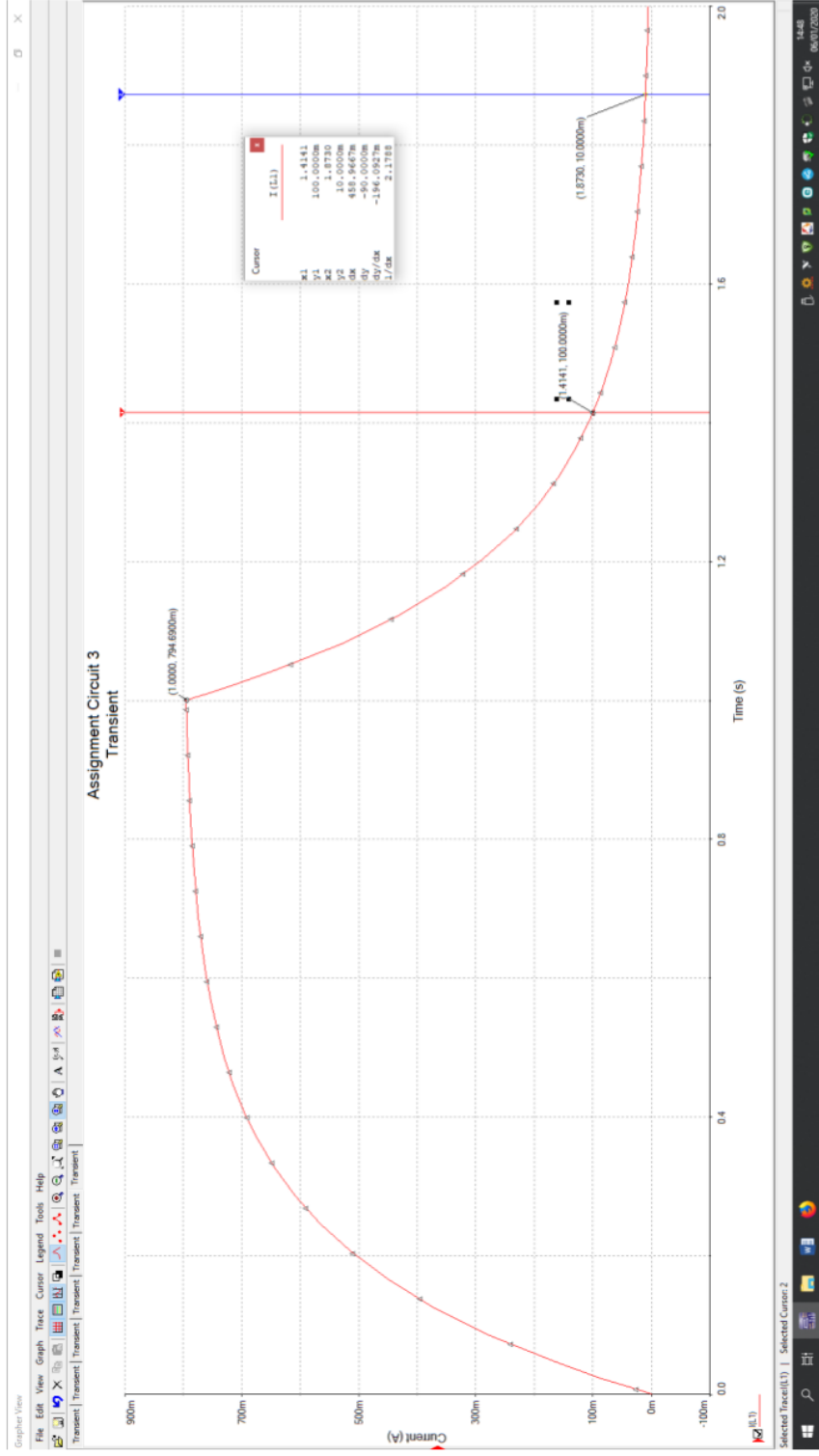


Figure 12: Circuit 3 at 100mA & 10mA

## Testing, result and analysis

### RC Circuit

| Voltage  |        |           |           |           |           |           |
|----------|--------|-----------|-----------|-----------|-----------|-----------|
| Time (s) | Charge |           |           | Discharge |           |           |
|          | Theory | Simulated | Practical | Theory    | Simulated | Practical |
| 25       | 2.16v  | 2.1595v   | 2.24v     | 3.84v     | 3.8269v   | 3.87v     |
| 56       | 3.79v  | 3.7940v   | 3.85v     | 2.21v     | 2.1981v   | 2.25v     |
| 100      | 4.99v  | 4.9942v   | 5.05v     | 1.01v     | 999.092mv | 1.05v     |

Table 1: Circuit 1 voltage results

| Current  |         |           |           |           |           |           |
|----------|---------|-----------|-----------|-----------|-----------|-----------|
| Time (s) | Charge  |           |           | Discharge |           |           |
|          | Theory  | Simulated | Practical | Theory    | Simulated | Practical |
| 25       | 0.68mA  | 0.685mA   | 0.64mA    | -0.68mA   | -0.683mA  | -0.64mA   |
| 56       | 0.39mA  | 0.394mA   | 0.37mA    | -0.39mA   | -0.393mA  | -0.37mA   |
| 100      | 0.179mA | 0.179mA   | 0.17mA    | -0.18mA   | -0.178mA  | -0.17mA   |

Table 2: Circuit 1 current results

Table 1 and Table 2 shows the results of the charging and discharging of the capacitor in circuit 1 for voltage and current. There is a slight variation in the results. This was to be expected. The theory results are the 'expected' results as this is what the calculations have worked out the answers to be. However, it is near impossible to reflect this perfectly in real life due to a different amount of variables. The simulated results for example, Multisim was used to simulate the circuit and to collect data. The components are preloaded into the software and the simulation will run the circuit with resistance in the components used so this will automatically give you a slight variation. The variation between simulated and theory is very minute, as shown in the table the difference is millivolts when comparing voltage with the biggest difference being 13 millivolts and while comparing current the difference is micro amps. The errors can be seen more in the practical to theory results. The variation again is still relatively small but on a bigger scale practical it could make much more of a difference. Human error can take part in practical tasks some of which can be hard to control. An example of this being the stop watch being started simultaneously to when the supply is connected to the circuit. It is near impossible to start the time at the exact same moment of which the supply is energised. Likewise stopping the time to record the data of the voltage and the current for both charge and discharge. All of these variation can affect the results of the task.

### Complex RC Circuit

The maximum voltage in the circuit is not equal to the supply voltage. This is because the resistors act as a voltage divider. The new calculated supply voltage from the voltage divider was calculated to be 6.67v. This is proven by the transient graph in Figure 7 as the maximum voltage is shown to be 6.62v

The time constant was estimated by using 63.2% of the exponential curve for charging of the capacitor and then 36.8% of the exponential curve for the discharging of the capacitor.

| Estimated Time |                | Calculated  |
|----------------|----------------|-------------|
| Charge         | Discharge      | Charge      |
| 2.1982 Seconds | 2.2231 Seconds | 2.2 seconds |

Table 3: Estimated and calculated time constant

Table 3 show the estimated time constant against the calculated time constant. The estimated time is the same when rounded to 1 decimal place. This shows that taking an estimate from the output voltage will provide a strong estimated time constant.

#### Inductive Circuit

The current was calculated and manually plotted for circuit 3 with the graph shown in Figure 19 found in the appendix. This can be compared with the simulated graph found in the Figure 20. The graph produced by the simulation would be more accurate as it has more information to be produced from compared to the manual plot which only has information of  $1\tau$  to  $5\tau$ . The values from each can be seen in Table 4 below. The results are the same but as previously stated the graph is more accurate and smoother in the simulated plot. If the graph was to be used to collect other information from the graph the simulated plot would be far more accurate as it was created against more data plots. The manual plot can be used to give an estimation and guideline but as the graph is only created off 5 data points being  $1\tau$  to  $5\tau$  it is not as accurate as the simulate result which uses much more data points. When simulating the circuit the simulation software automatically applies a small resistance to the components where when working out the calculations the assumed resistance is zero so this adds a small variations/discrepancy between the two.

| Time    | Current     |                |
|---------|-------------|----------------|
|         | Manual plot | Simulated plot |
| $1\tau$ | 0.51A       | 0.505A         |
| $2\tau$ | 0.69A       | 0.691A         |
| $3\tau$ | 0.76A       | 0.76A          |
| $4\tau$ | 0.785A      | 0.785A         |
| $5\tau$ | 0.79A       | 0.794A         |

Table 4: Circuit 3 current results

## Conclusions and recommendations

The series RC circuit which was in circuit 1 was carried out practically. In order to collect data to a degree of accuracy the time constant had to be large enough in order collect the data from. If the time constant was smaller, such as 0.2 seconds as seen in the inductive circuit, practical data would be much harder to collect as the data would have to be collected every twenty milliseconds. With the time constant at 56 seconds, there is still errors in the collecting of practical data as it is communicated and done visually with the human eye. The response time of watching the stop watch to then reading the measurement will never be exact making the reading slightly off. In order to reduce the chances of this, the test could be carried out three times to record an average voltage and current reading to try to reduce the chance of human error but this still will not give an exact result. This is also because all components have a tolerance. An example of this would be the  $5.6k\Omega$  resistor used in the series RC circuit may not be exactly  $5.6k\Omega$  it could be ever so slightly out where in the calculations exactly  $5.6k\Omega$  is used. As with the human error, a way to try make the circuit a fair practical test with the slight tolerance in resistors would be to build the identical circuits to average out any tolerance. However, the tolerance will be very small and trying to eliminate every variable and human error becomes impractical and not cost or time worth. As seen in the results in Table 1

and Table 2 the results are extremely close which goes to show the accuracy and possibly a reason to rule out averaging and retesting.

The both the series RC and complex RC circuits both charge a capacitor, when it reaches its steady state at  $5\tau$ , it can then be discharged and can release its stored energy into the circuit like a small battery. When this happens, the current then flows the opposite way in the circuit. This is shown as a negative current which then grows to zero from a negative start. Figure 18 in the appendix shows the transient of the capacitor charging and discharging in the complex RC circuit. You can see in from the data labels in the graph the point at which the capacitor starts to discharge as the current has dropped from zero to a negative current.

## References

Electronics Tutorials, 2014. *RC Charging Circuit*. [Online]  
Available at: [https://www.electronics-tutorials.ws/rc/rc\\_1.html](https://www.electronics-tutorials.ws/rc/rc_1.html)  
[Accessed 08 January 2020].

## Appendix

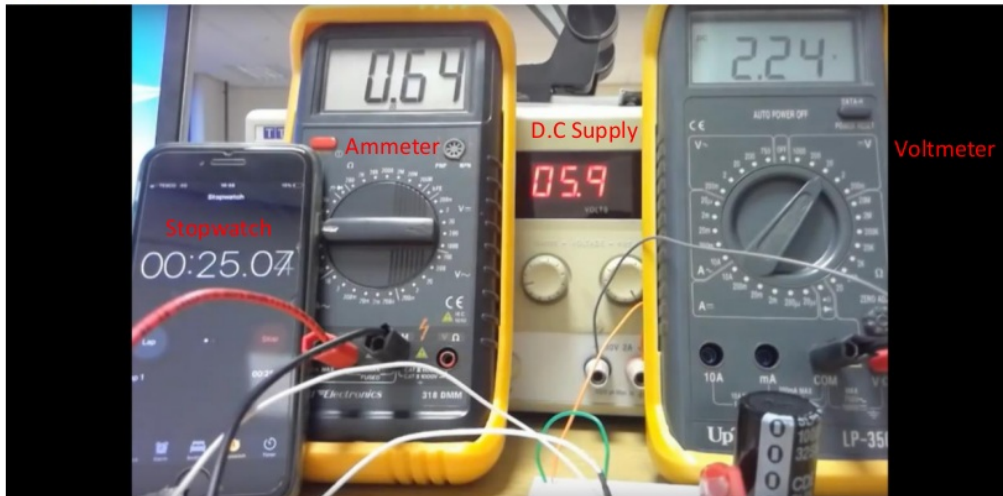


Figure 13: Series RC Circuit Practical Setup

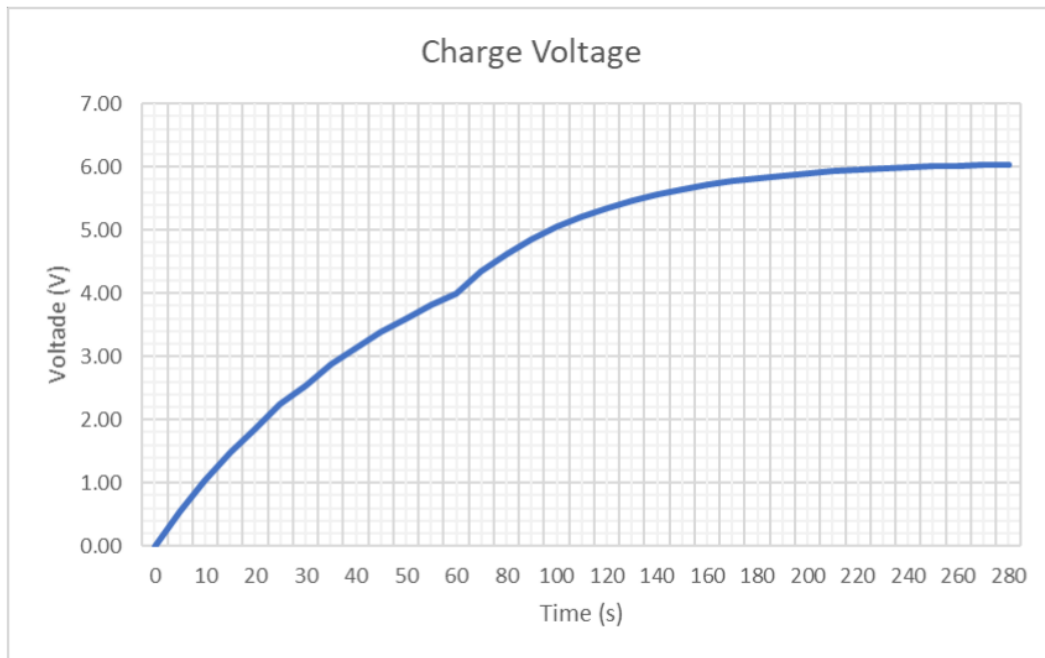


Figure 14: Series RC Circuit Practical Result - Charge Voltage

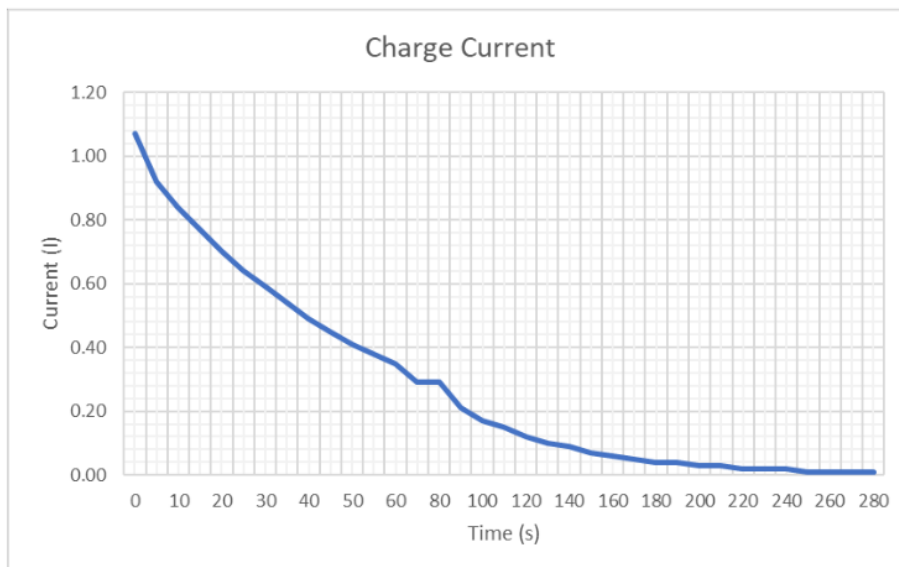


Figure 15: Series RC Circuit 1 Practical Result - Charge Current

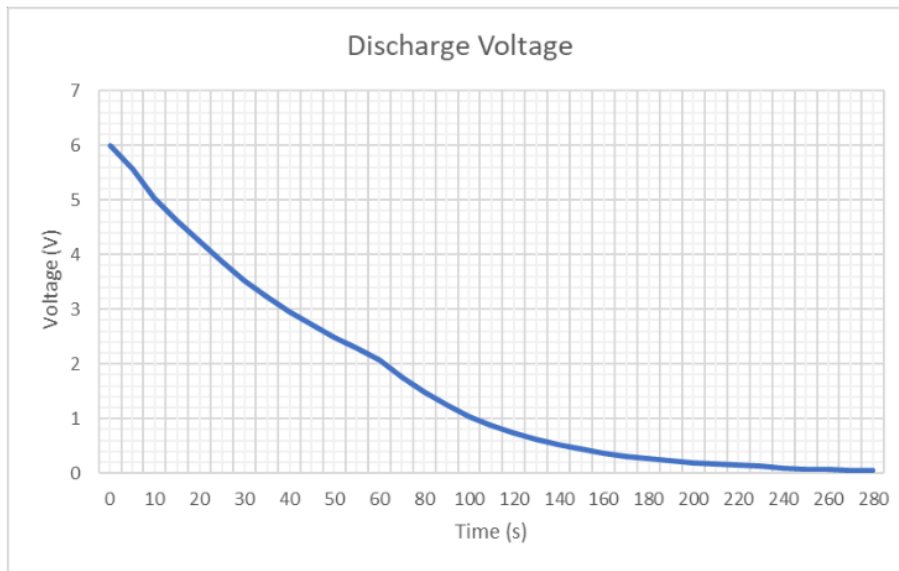


Figure 16: Series RC Circuit Practical Result - Discharge Voltage

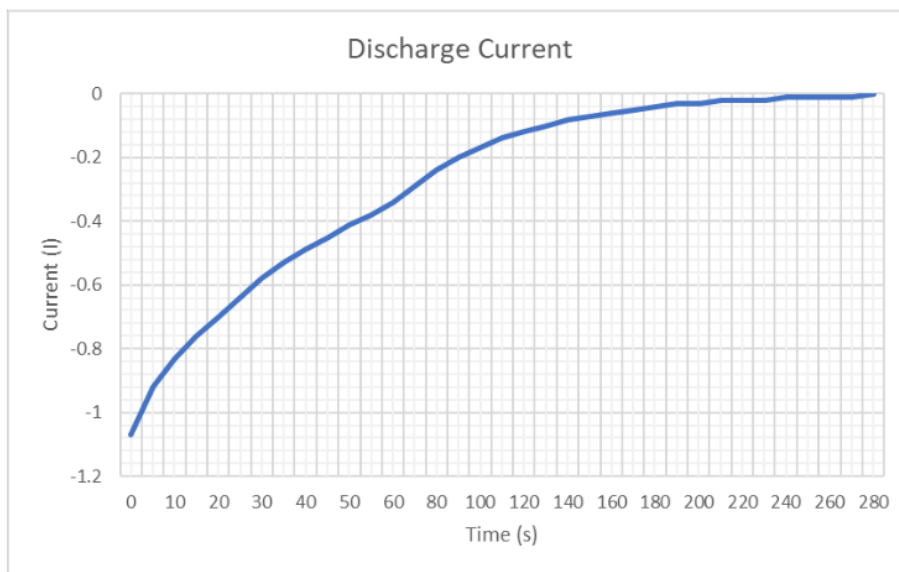
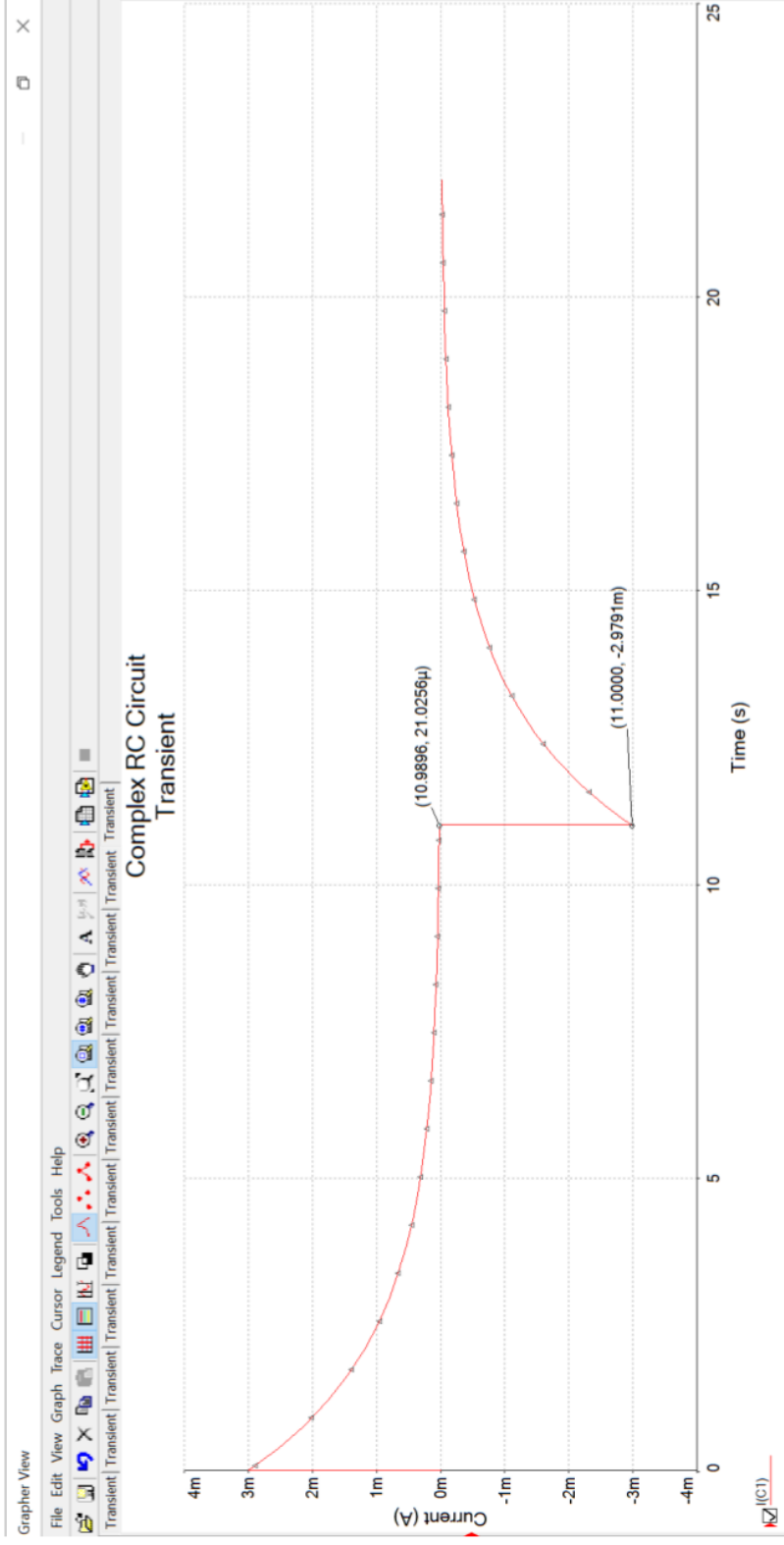


Figure 17: Series RC Circuit Practical Result - Discharge Current



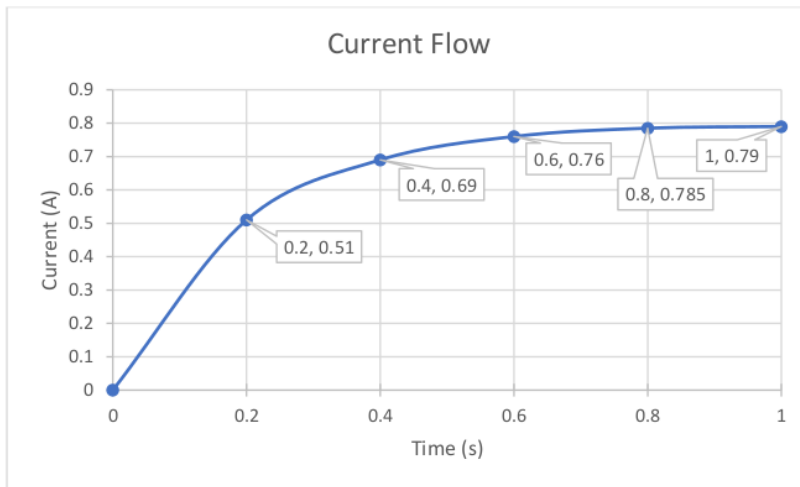


Figure 19: Manual current plots - inductive circuit

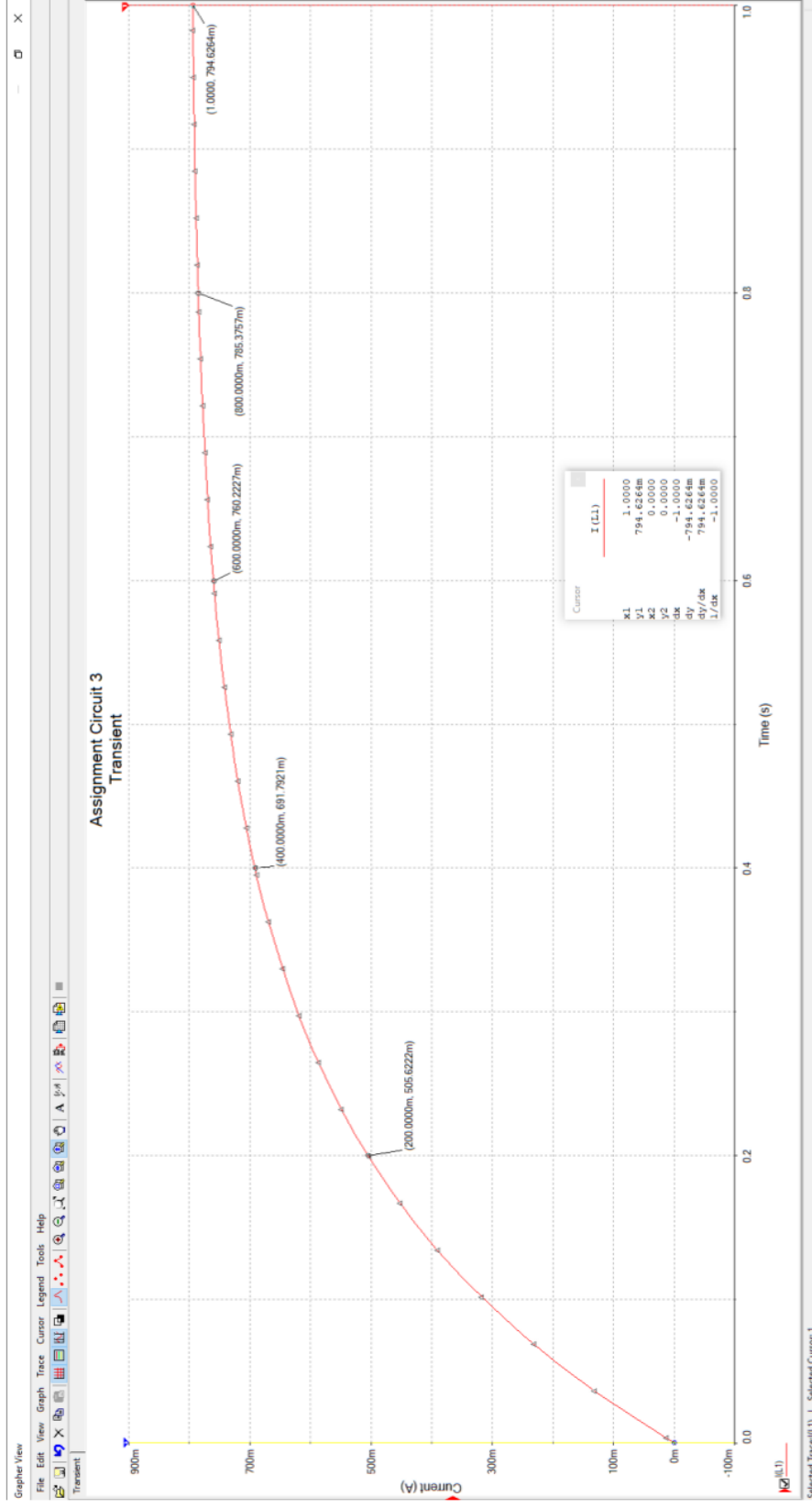


Figure 20: Simulated current – inductive circuit

FINAL GRADE

GENERAL COMMENTS

**Instructor**

81 / 100

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11

PAGE 12

PAGE 13

PAGE 14

PAGE 15

PAGE 16

PAGE 17

PAGE 18

PAGE 19

PAGE 20

PAGE 21

PAGE 22

PAGE 23

PAGE 24

PAGE 25

PAGE 26

PAGE 27

GRADING FORM: NEW CSG-RUBRIC

**ALEX  
WILLIAMS**

**81**

### 1. ENGAGEMENT WITH LITERATURE



n/a

### 2. KNOWLEDGE AND UNDERSTANDING



Generally excellent knowledge and understanding, you could have been more clear in your introduction by numbering each circuit and applying consistency

**20**

in the report

### 3. COGNITIVE AND INTELLECTUAL

 Sound evaluation and interpretation of results, few minor areas for improvement as marked. **22**

### 4. PRACTICAL APPLICATION

 Advanced application of testing skills. Test results are of good quality, you could have included errors in your tables **22**

### 5. TRANSFERABLE SKILLS

 Coherent work which flows and presentation is of a high standard. see comments detailing improvement opportunities. **17**