

Investigating the Behavior of Charge, Voltage and Current During Charging and Discharging of Capacitor

Tsegaye Menberu Genzebu

Department of Physics, Wolkite University, Wolkite, Ethiopia

Email address:

menberutsegaye6@gmail.com

To cite this article:

Tsegaye Menberu Genzebu. Investigating the Behavior of Charge, Voltage and Current During Charging and Discharging of Capacitor. *World Journal of Applied Physics*. Vol. 7, No. 2, 2022, pp. 16-20. doi: 10.11648/j.wjap.20220702.11

Received: May 26, 2022; **Accepted:** July 9, 2022; **Published:** July 18, 2022

Abstract: Researchers were continuously working towards trade-off solutions to know the relationship between charge, voltage and current with time during charging and discharging of capacitor. But knowing the characteristics of charge, voltage and current during charging and discharging of capacitor using smaller values of capacitor is becoming increasingly challenging. The main objective of this paper is to investigate the behavior of voltage, current and charge during charging and discharging of capacitor by using smaller values of capacitors. In this paper the behavior of voltage, current and charge during charging and discharging capacitor was investigated experimentally. The experiment was done by using Electrolytic capacitor (100 μ F) and resistor (1M Ω). The graph was plotted by using origin soft ware. As the experimental result shows that, during charging capacitor at ($t = 0$) the voltage and charge are zero, and it increase exponentially with time. But current decrease exponentially. Whereas during discharging capacitor at ($t = 0$) the voltage and charge are maximum, it decreases exponentially with time. But current decrease exponentially. This shows that the experimental result match's with theoretical result. This work will support science students and researchers to know the detail knowledge about the relationship about voltage, current and charge with time even if the capacitor value is small.

Keywords: Capacitor, Charging Capacitor, Discharging Capacitor

1. Introduction

A Capacitor is a passive device that accumulates electric energy and feedback this energy to the circuit whenever required [1]. It is made up of two conducting plates with positive charge on one plate and an equally negative charge on the other, this are separated by a non-conducting material or (dielectric material) [2]. If a battery pumps charges on the plates, then a potential difference between them is created [2, 3].

We can characterize capacitors by their capacitance (C). Capacitance is defined as the ratio of the charge stored in the capacitor (Q) to the potential difference between its plates (V) [4, 5]. The SI unit of capacitance is farad (F). Mathematically capacitance is given by:

$$C = \frac{Q}{V} \quad (1)$$

Capacitance is a measure of storing a charge in a capacitor [6]. When a capacitance is high, more charge can be stored

using the same voltage V, i.e. capacitance is constant [6]. Two processes called "charging" and "discharging" are occurred in specific conditions, when a capacitor is connected to direct current source circuit [7].

1.1. During the Charging of a Capacitor

Figure 1 shows the characteristics of capacitor during charging capacitor and it relates voltage difference across the capacitor, Current and Charge with time.

Initially no charge can be accumulated on the capacitor as we seen in figure 1c [7]. In charging when capacitor starts charging the charge starts at zero and no voltage on the capacitor [7].

Figure 1b shows current versus time as the capacitor charges [10]. In this figure we understand that current initially flows at its maximum rate [11]. But, as the moving electric current charges the capacitor, the change in voltage on the capacitor increases exponentially with time as we see the figure 1a [10-12]. In the same manner the charge increases exponentially with time as we see figure 1c. The

increase of voltage opposes the flow of charge which leads the decreases in current exponentially with time as we see in

figure 1b; for larger voltage on the capacitor and as time goes up, current asymptotically goes to almost zero value [13].

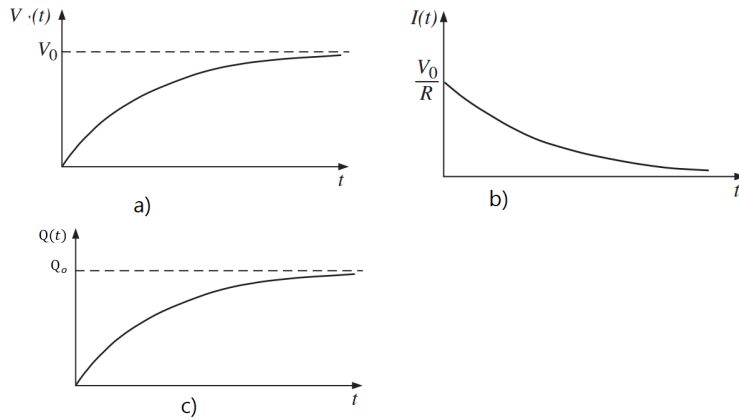


Figure 1. a) Voltage difference across the capacitor versus time as the capacitor charges b) Current versus time as the capacitor charges c) Charge on the capacitor versus time as the capacitor charges [7-9].

The general formulas that expresses voltage across the capacitor, the charge and the current can be given in eqns (2, 3 and 4) respectively [1, 2, 12].

$$V(t) = V_0(1 - e^{-\frac{t}{\tau}}) \quad (2)$$

$$Q(t) = Q_0(1 - e^{-\frac{t}{\tau}}) \quad (3)$$

$$I(t) = I_0 e^{-\frac{t}{\tau}} \quad (4)$$

Where:

$e = 2.718$ is Euler's number.

V_0 is applied voltage in volt.

$V(t)$ is voltage across the capacitor in volt at any time.

$I(t)$ is the current as function of time in ampere.

$Q(t)$ is the charge as function of time in coulomb.

R is resistor in ohm.

C is capacitance of capacitor in farad.

The characteristic time called the time constant is a measure of fastens or slowness of a capacitor as it charges and discharges [12]. It is dependent on the values of the capacitance as well as the resistance found in the circuit [8]. It is measured in seconds which is the same as the unit of time [10]. During charging capacitor the time constant is the time required to increase the potential difference or the charge from zero to 0.632 or 63.2% of its maximum value [10].

1.2. Discharging the Capacitor

Figure 2 shows the characteristics of capacitor during discharging case and also it shows the behavior of voltage difference across the capacitor, charge and current on the capacitor with time.

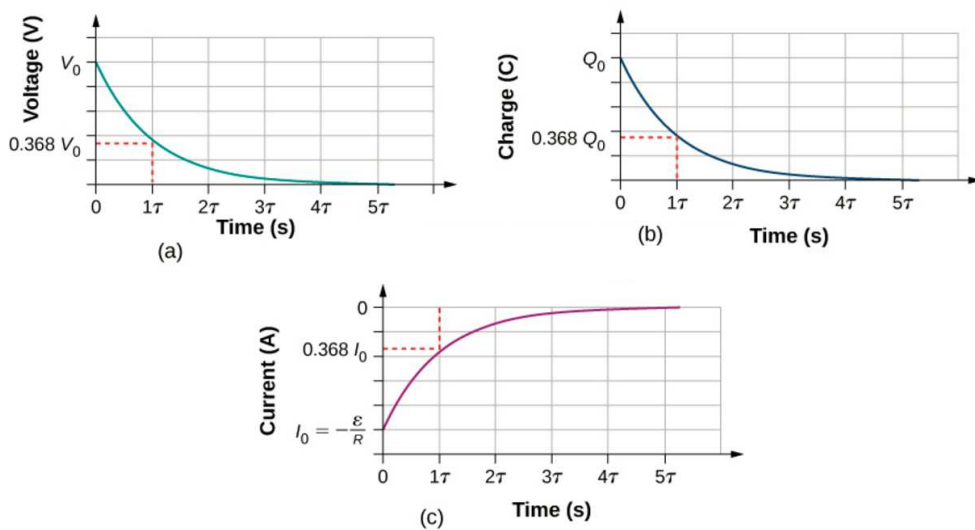


Figure 2. a) Voltage difference across the capacitor versus time as the capacitor discharges. b) Charge versus time as the capacitor discharges. c) Current on the capacitor versus time as the capacitor discharges [3, 6].

When time is equal to zero second, the current is almost zero, whereas the voltage on the capacitor is almost equal to

the applied voltage [1-3]. In addition to this its charge is maximum as we see in figure 2 [14]. The voltage applied to the capacitor used to "push" the current which lead to discharge capacitor and decrease in current [3]. So as time goes on the rate of discharge slows down [14]. When the capacitor is discharged by a resistor the current, as well as voltage across the capacitor and charge on the capacitor slows down exponentially as we see in figure 2 [1-3, 14-16].

The general formulas for voltage across the capacitor, the charge and the current can be given in eqns (5, 6 and 7) respectively as follow as [12, 17]:

$$V(t) = V_o e^{-\frac{t}{\tau}} \quad (5)$$

$$Q(t) = Q_o e^{-\frac{t}{\tau}} \quad (6)$$

$$I(t) = -I_o e^{-\frac{t}{\tau}} \quad (7)$$

Similar time constant is applicable to show the behavior of discharging cycle [13]. However in this case it shows the time it will require the charge and voltage to slow down by 0.368 or 36.8% times from its initial value [6].

Objectives:

1) Main objective:-

The main objective of this paper is to investigate the behavior of voltage, current and charge during charging and discharging of capacitor.

2) Specific objectives are:-

- To know the characteristic of capacitor.
- To know the effect of resistor during charging and discharging capacitor.
- To understand advantages of capacitor.
- To understand the relationship between voltage and time.
- To understand time constant of capacitor during charging and discharging process.

2. Materials and Methods

2.1. Materials

Materials which were used to conduct this paper were listed in the following table with its specification and quantity.

Table 1. Materials used to conduct the experiment.

Number	Device Name	Specification	Quantity
1	Multimeter	0-20V	1
2	Electrolytic capacitor	100 μ F	1
3	Resistor	1M Ω	1
4	DC power supply	0-18V	1
5	Crocodile clip		2
6	Probe wire		6
7	Stop watch		1

2.2. Method

In this paper the data were collected by conducting experiment. To conduct the experiment I had followed the following procedures.

Step 1: I set the circuit as shown in figure 3: that is I connect the negative end of a DC power supply with negative end of a capacitor, then I connect the positive end of a capacitor with one end of the resistor, then I connect the capacitor's negative end to the negative of DC power supply, then I connect the capacitor's positive end to the positive of DC power supply. After this, In order to measure the voltage and current I connected the voltmeter parallel to the capacitor and ammeter series to capacitor respectively.

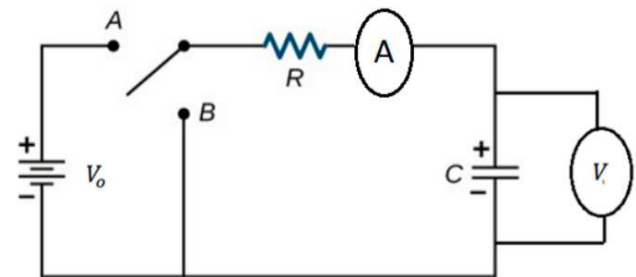


Figure 3. The circuit diagram for charging and discharging capacitor.

Step 2: I set the probe wire from position B to position A to start charging and, I had checked stopwatch, ammeter and voltmeter ought to read zero before capacitor starts charging, is witch on the DC power supply, at the same time I started my stopwatch, and I recorded the voltage across the capacitor and current across capacitor at each 20 second interval for 280 seconds. Immediately when time is equal to 280 seconds, I turn the probe wire from position A to position B, to discharge capacitor, and I recorded voltage and current at each 20 second interval for 280 seconds.

3. Data, Result and Dissection

3.1. Data

The recorded voltage for charging and discharging capacitor that I had got from my experiment is given in the table 2.

Table 2. Experimentally recorded voltage during charging and discharging capacitor.

Time (S)	Voltage of charging capacitor (Volt)	Voltage of discharging capacitor (Volt)
0	0	19.2
20	4.4	15.3
40	7.5	13.0
60	10	10.8
80	11.9	9.0
100	13.3	7.4
120	14.5	6.1
140	15.5	5.0
160	16.3	3.8
180	16.9	2.9
200	17.5	2.4
220	18	2.0
240	18.5	1.7
260	18.8	1.3
280	19.2	0.9

The recorded current for charging and discharging capacitor that I had got from my experiment is given in the table 3.

Table 3. Experimentally recorded current during charging and discharging capacitor.

Time (s)	Current for charging capacitor (Ampere)	Current for discharging capacitor (Ampere)
0	2.3	1.8
20	1.8	1.5
40	1.3	1.3
60	0.9	1.1
80	0.7	0.9
100	0.6	0.7
120	0.5	0.5
140	0.4	0.4
160	0.3	0.3
180	0.2	0.2
200	0.09	0.1
220	0.08	0.05
240	0.06	0.04
260	0.04	0.03
280	0.02	0.02

By using the general formula we had also calculated the charge during charging and discharging process by using the recorded values of voltage given in the table 2 is given in the table 4.

Table 4. Experimentally recorded Charge during charging and discharging capacitor.

Time (S)	Charge during charging capacitor (μC)	Charge during discharging capacitor (μC)
0	0	1920
20	319.6	1020
40	546	800
60	751	593
80	954	444
100	1071	271
120	1215	183
140	1347	110
160	1430	68.3
180	1510	47.9
200	1610	32.4
220	1700	22
240	1780	15.3
260	1840	9.62
280	1860	5.4

3.2. Result and Dissection

Figure 4 shows voltage verses time graph for charging and discharging capacitor.

Figure 4 shows the relationship between voltage and time during charging and discharging capacitor. As seen from the graph, it is evident that in the case of charging capacitor initially ($t = 0$) the voltage across the capacitor is zero, but it increases exponentially as time increases. While in the case of discharging capacitor initially ($t = 0$) the voltage across the capacitor is maximum, but it decreases exponentially as time increases.

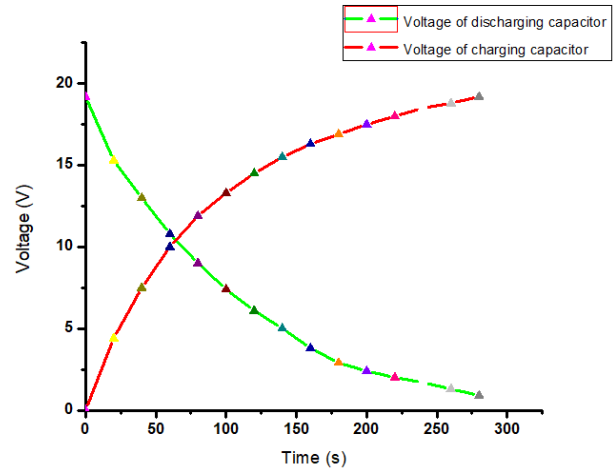


Figure 4. Voltage-time graph for charging and discharging capacitor.

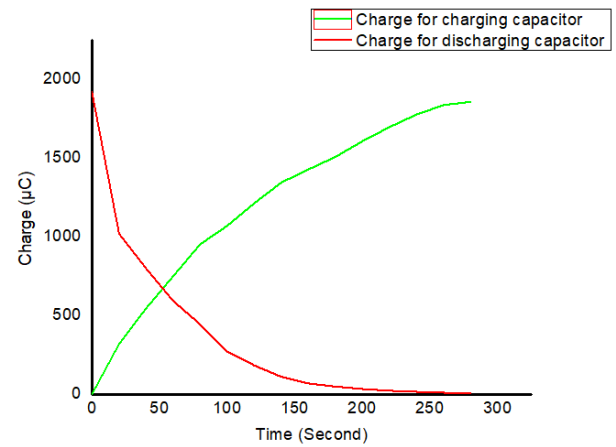


Figure 5. Charge-time graph for charging and discharging capacitor.

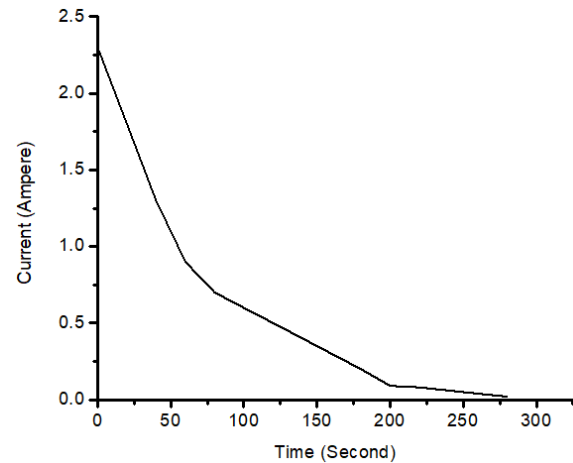


Figure 6. Current-time graph for charging capacitor.

Figure 5 shows the relationship between charge and time during charging and discharging capacitor. As we seen from the graph, it is evident that in the case of charging capacitor initially ($t = 0$) the charge across the capacitor is zero, but it increases exponentially as time increases. While in the case of discharging capacitor initially ($t = 0$) the charge across the capacitor is maximum, but it decreases exponentially as time increases.

Figure 6 provides the relationship between current and time during charging capacitor. As seen from the graph, it is evident that in the case of charging capacitor initially ($t = 0$) the current across the capacitor is maximum, but it decreases exponentially as time increases.

Figure 7 shows the relationship between current and time during discharging capacitor. As seen from the graph, it is evident that in the case of discharging capacitor initially the current across the capacitor is maximum, but it decreases exponentially as time increases.

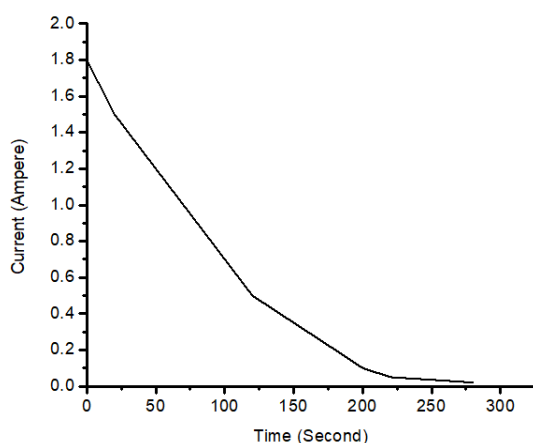


Figure 7. Current-time graph for discharging capacitor.

4. Conclusion

In this paper we were tried to show the relationship between voltages, current and charge with time in detail by using smaller values of capacitance. Since studying the behaviors of voltage, current and charge with time by using smaller values of capacitance is challenging due to the reason that reading their values is difficult due to smaller time. Whatever the case from this paper we would conclude that the following points:

- 1) In the case of charging capacitor initially i.e. when time is equal to zero the voltage and charge across the capacitor is almost zero, however it goes up exponentially as time goes up, while current goes down exponentially with time.
- 2) In the case of discharging capacitor initially ($t = 0$) the voltage and charge across the capacitor is maximum, where as it goes down exponentially as time goes up. In addition current goes down exponentially with time.

Abbreviations Used

Abbreviation	Expanded form
μC	Micro-coulomb
C	Capacitance
Q	charge stored in the capacitor
V	potential difference between its plates
DC	Direct Current
V(t)	voltage across the capacitor in volt at any time,

I(t)	current as function of time in ampere,
Q(t)	charge as function of time in coulomb, R
R	is resistor
T	Resistor
Eqns	time constant
	Equations

References

- [1] Al-Jaber, S. and Saadeddin, I. (2020) Theoretical and Experimental Analysis of Energy in Charging a Capacitor by Step-Wise Potential. *Journal of Applied Mathematics and Physics*, 8, 38-52. doi: 10.4236/jamp.2020.81004.
- [2] Shockley, William (1950). Electrons and holes in semiconductors: with applications to transistor electronics. R. E. Krieger Pub. Co. ISBN 0882753827.
- [3] Asnawi, R., Nurhadiyanto, A. Z. and Asmara, A. (2018) The Characteristic of Supercapacitors Circuit as a Future Energy Storage Media. *Journal of Physics: Conference Series*, 1140, Article ID: 012001. Robert Boylestad "Electronic devices and circuit theory", 7th edition.
- [4] Robert Boylestad "Electronic devices and circuit theory", 7th edition.
- [5] R. A. Serway and J. W. Jewett (2014). *Physics for scientists and Engineers*, second edition, Boston, USA.
- [6] Tran, C. D., Vu, A. Q. and Van, L. T. (2018) Uniform Coating of Polyaniline on Porous Carbon Nanofibers as Efficient Electrodes for Supercapacitors. *Journal of Physics: Conference Series*, 1082, Article ID: 012081.
- [7] D. Halliday and R. Resnick, *Fundamentals of Physics*, 4th edition.
- [8] Makihara, K., Onoda, J. and Miyakawa, A. (2006) Low Energy Dissipation Electric Circuit for Energy Harvesting. *Smart Materials and Structures*, 15, 1493-1498.
- [9] Feynman, Richard (1963). *Feynman Lectures on Physics*. Basic Books.
- [10] Young university physics with modern physics twelve edition.
- [11] Y. Moon and D.-K. Jeong, "An efficient charge recovery logic circuit," *IEEE J. Solid-State Circuits*, vol. 31, pp. 514-522, Apr. 1996.
- [12] Senamaw Mequanent Zegeye. A Review Paper on the Study of Charging and Discharging the Capacitor. *American Journal of Quantum Chemistry and Molecular Spectroscopy*. Vol. 3, No. 2, 2019, pp. 48-55. doi: 10.11648/j.ajqcms.20190302.14.
- [13] S. M. Sze, *Physics of Semiconductor Devices*. New York: Wiley, 1981.
- [14] J. P. Uyemura, *Fundamentals of MOS Digital Integrated Circuits*. Reading, MA: Addison-Wesley, 1988.
- [15] Tayal D. C. *Basic Electronics*, 2nd edition. Himalaya Publishing House Mumbai, (1998).
- [16] J. J. Brophy, *Basic Electronics for scientists*.
- [17] Bernard Grob, *Basic Electronics*, 4th ed., McGraw Hill International Book Company, London, (1983).