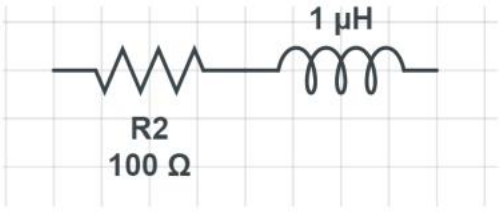
Mathematical Fundamentals for Electrochemical Energy Storage Systems

Exercise 3

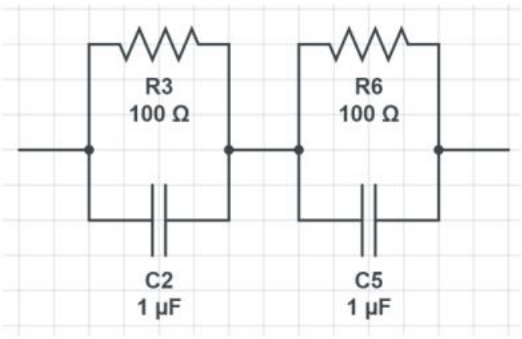
Task 1: Plotting Complex Numbers

a. The cmath library in python can be used to perform complex number calculations. Use it to plot the real and imaginary values of impedances of the following circuits

i)



ii)

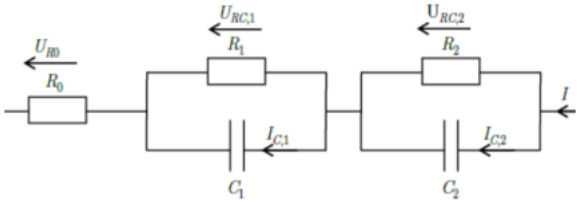


Task 2: EIS of Batteries

b. Electrochemical impedance spectroscopy is a characterization method for batteries that can offer information about different processes that occur inside it. By probing the battery at different frequencies, the 'statuses' of different processes in the battery can be tracked. Usually, the impedance spectroscopy data is in the following format. The first column represents the frequency of the probing signal in Hz, the second column represents the real part of the impedance, and the third column represents the imaginary part of the impedance. To analyse this data, we assume that this data can be

represented by an equivalent circuit consisting of resistive and capacitive components. Finally, we derive the impedance equation of this circuit and fit this equation to our experimental data. The values of the individual circuit components are considered as an indicator of the internal state of the battery.

i. Download the file 'impedance_data.csv' from e learning and load it on python using the pandas library
ii. Plot the real and imaginary impedance value in the XY plane
iii. Assume that this data can be represented by the following circuit



Can you roughly estimate the values of the components from the graph?

iv. (Bonus) Download the file 'impedance_noisy_data.csv' from e learning and load it on python. Can you fit the circuit shown above to this dataset? (Note: Use scipy and nonlinear least squares)