1. Basic circuit for electronic load - Three basic operation mode
   A. Constant current mode B. Constant resistance mode C. Constant voltage mode
   For this project, only A&B are suitable operation mode for buck converter test load design.
   First approach: LM741 operational amplifier - amplification for current sense feedback control
   Problem: Has to set offset voltage to turn on MOSFET to designed operation point. Increase complexity in circuitry.
   Even worse in CR mode design, since the offset voltage varies due to the change in source voltage.
   Most importantly, this design will amplify the voltage and current ripple in the system, since there is small ripple in the source voltage, which is from the converter, and the voltage across the sense resistor inherits the ripple. The ripple is then amplified by the op-amp, producing bigger ripple in the output, therefore big ripple in the gate voltage to the power MOSFET results in big load current ripple, which increase the instability to the whole system.
   Second approach: LM324 single supply operational amplifier as a comparator in the system. LM324 has low input bias current 100nA maximum. By using a comparator to compare reference voltage and the voltage across the sense resistor, the right voltage can be provided to the power MOSFET to act as a resistive element in the circuit.
   This approach can be well designed for CC and CR mode operation.

2. Device selection and ordering - 0711
   Sense resistor is a problem - small value (10mΩ) cannot achieved since the track has resistance too. Too small resistance will be treated as short circuit. As the value of resistor increases, the power on the resistor increases linearly, exponentially with current.
   Solution: Pick power resistor with high precision + 4 stages of electronic load circuit => support max 1Ω sense resistor to achieve minimum overall resistance 0.25Ω (in reality, on-state MOSFET also has resistance, therefore, Rs < 1Ω)
   => 0.47Ω (7W), 0.68Ω (7W), 1Ω (5W) power resistors ordered
   Power MOSFET: When gate voltage ≤ 5V, Vds = [1, 5]; Id should at least achieve 4A
   Thermal design: Power MOSFET heat sink + fan + temp sensor = thermal calculation for heat sink + temp monitor to show current temp and turn on the fan when the temp exceed the set temp level (can be monitored and controlled by Arduino)
   Temp sensor: temp range (25~300°C) + Accuracy (5%) + Stability (cycles) + Cost => RTD temp sensor (low power & high accuracy)
   How to amount on the MOSFET - heat transfer mainly through metal, if it is made of plastic, heat mainly transfer by metal leads. (Put as close as to the measured device, common ground may needed - check documents)

3. The electronic load performance -
   a, Minimum overall resistance 0.25Ω - Extreme scenario 1: 1V source voltage with 4A load current
   Maximum overall resistance > 33Ω - Extreme scenario 2: continuous and discontinuous operation
   b, Under test, can it be treated as a resistive element (CC & CR mode)
   c, For the buckle converter, can it be viewed as a dummy load, having the same performance as the slide rheostat.

4. Control theory
   Since the voltage from the buck converter is not clear (with 1mV ripple inside, frequency from 320kHz to 2.25MHz), how to treat the buck converter and the electronic load as a whole system, obtain the transfer function, explore the poles and zeros of the system. Therefore, the stability over the frequency range can be verified.
   RC filters - where to add - which value should be picked - remain problem

Dissertation Outline:

Abstract (modification - wait for last minutes)

Chapter 1 Introduction, Aims and Overview
1.1 Introduction (introduction to the MSc project)
1.2 Background on Remote Lab (Educational Lab - history and other examples)
1.3 Motivation (Motivation of turning in-person lab experiment into remote operation experiment)
1.4 Scope (Only designed for the MSc course in power engineering of University of Edinburgh)
1.5 Aims and Objectives (check mission statement)
1.6 Thesis Organization and Outline (wait for last minutes)

Chapter 2 Introduction to Switch Mode Power Supply

Chapter 3 Introduction to the Buck Converter Laboratory Course
3.1 Curriculum and Educational Purpose (Curriculum, Target, Education Purpose, Outcomes)
3.2 Laboratory Setting (Buck converter board, Adjustable components, Designed parameters - Vout, Iout etc)
3.3 Buck Converter Board Design (Main Components, Working principle, Operation modes, Circuitry for adjustable components, etc)
3.4 Main Observation Results on the Buck Converter Laboratory Course (Questions and results from the lab course)

Each section should include methods evaluation, device selection, Arduino control, simulation or experimental results
Chapter 4 Digital Switches Design (Setpoint, Flyback, CapSelect, Switch bottom)

Chapter 5 Digital Potentiometers Design (Setpoint, Frequency)

Chapter 6 Controllable Load Design
6.1 Function Requirements (Minimum-0.25Ω, Maximum-33Ω, Short circuit)
6.2 Methods Explanation and Evaluation
- 6.2.1 Potentiometer with Motor
- 6.2.2 Electronic Load
- 6.2.3 Relay
- 6.2.4 Methods Evaluation (the last two methods remains)

Chapter 7 Electronic Load Design
- 6.3.1 Introduction to Electronic Load (CC, CV, CR - basic operation mode for commercial device)
  - 6.3.1.1 Basic Operation Mode and Principle
  - 6.3.1.2 Modern Electronic Load Devices (Commercial devices and data sheet explanation or even patents)
  - 6.3.1.3 Electronic Load Circuit Design
- 6.3.2 Circuit Design and Evaluation (CC&CR&Voltage divider&Arduino control)
- 6.3.3 Constant Current Mode - Electronic Load Design, Development and Test
- 6.3.4 Constant Resistance Mode - Electronic Load Design, Development and Test

Chapter 8 Short Circuit Design
- 6.4.1 Introduction to Relay
- 6.4.2 Short Circuit Design, Development and Test

Chapter 8 Measurement and Display (Power supply, Oscilloscope)

Chapter 9 Complete Working Prototype of Remote Laboratory