Hysteric Boost Controller

Introduction

- So far, we have covered:
  - IPT
  - Full bridge rectifiers
  - Connecting boost converters onto a parallel tuned secondary
- This section discusses how to turn the energy that the IPT system receives into a controlled dc voltage

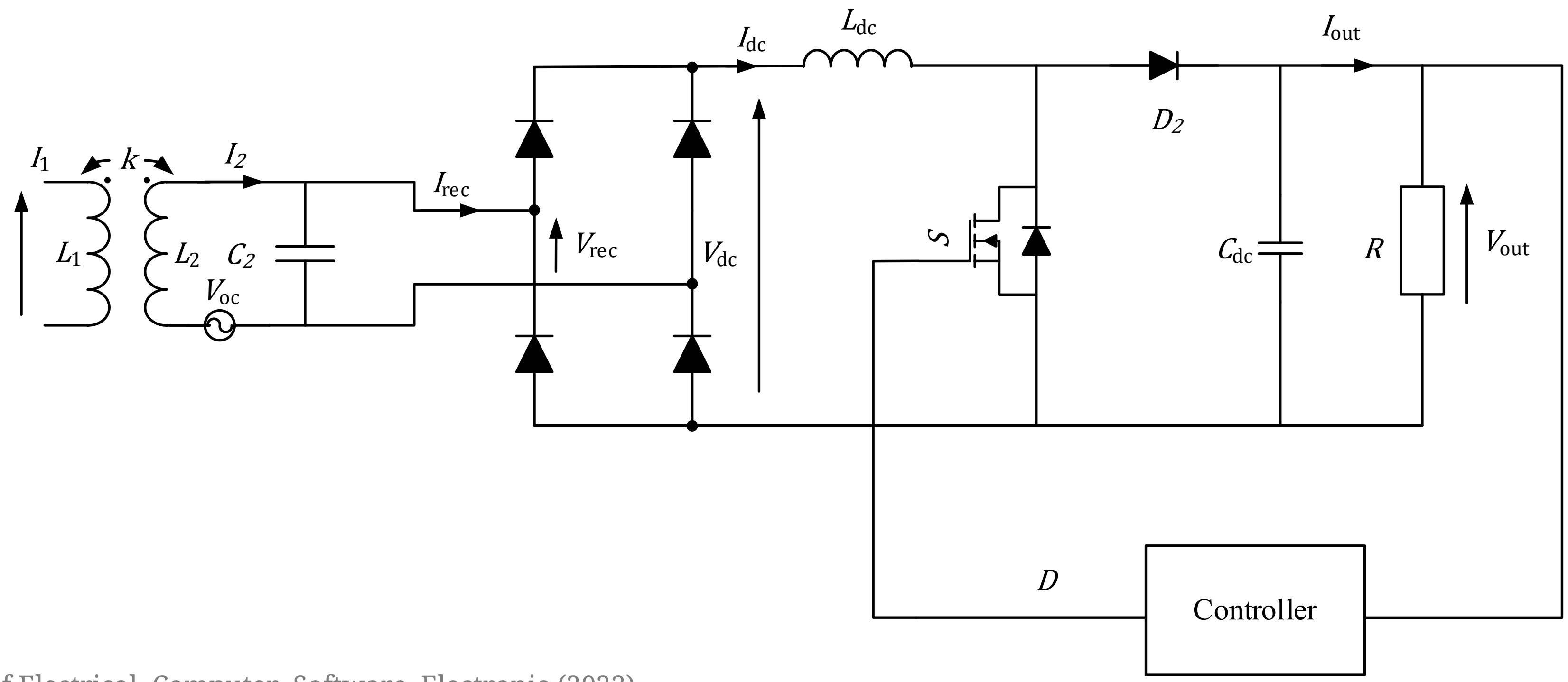
Learning Objectives

- Understand the operating principles of hysteretic (slow switched) controllers

- How you will be assessed:
    - Lab 1 task 3
    - Test
    - Practical build

A short circuit controller

- A short circuit (boost) controller is typically used to regulate the output of a parallel tuned pick-up
  - Rectifier converts AC to DC
  - DC inductor (L_{dc}) decouples AC from DC side and maintains a continuous current through rectifier
  - Switch duty cycle controlled to regulate output current (I_{out}) to maintain V_{out}
  - Diode (D_2) avoids discharge of (C_{dc}) through switch when ‘on’
  - Output capacitor (C_{dc}) minimizes output voltage ripple (ΔV_{out})



A short circuit controller

- From the rectifier slides:
  - $I_{dc} = \frac{\pi}{2\sqrt{2}} I_{sc} = I_{out}$ if the secondary network is well tuned
- RMS pick-up coil voltage can be calculated assuming 100% efficiency

$$V_{rec} = \frac{\pi}{2\sqrt{2}} V_{out} \text{ or } V_{out} = \frac{2\sqrt{2}}{\pi} V_{rec}$$

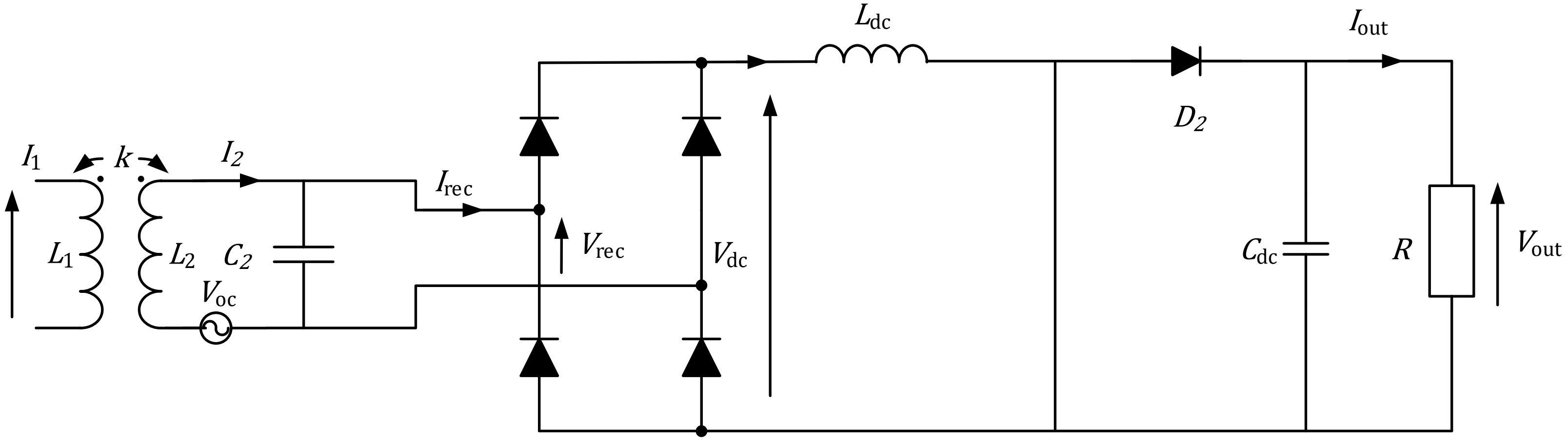
- The loaded quality factor (voltage boost), Q, of the pick-up coil is given by:

$$Q = \frac{V_{rec}}{V_{oc}} = \frac{\pi}{2\sqrt{2}} \frac{V_{out}}{V_{oc}}$$

- The maximum Q of the pick-up is 1.1 times the ratio between V_{out} and V_{oc}
- In practice, due to non ideal operating conditions, relationship between I_{sc} and I_{out} as well as V_{rec} and V_{out} will be different
  - As a result of losses, imperfect tuning, current ripple in I dc , diode switching,

Slow switching analysis

- When S is on I_{dc} is shunted through the switch collapsing the resonance and decoupling the pick-up
- $V_{out} = 0\ V \ \rightarrow V_{rec} = 0\ V \ \rightarrow I_2 = I_{sc}$
- D_2 blocks current from flowing backwards
- C_{dc} discharges through R
- V_{out} will ramp downwards



Slow switching analysis

- When S is off I_{dc} (1.1 times I_{sc}) is fed to the load through D_2
  - There is now a duty cycle (D) which controls the boost converter
- Output current is the average current through D_2

$$I_{out} = (1-D)I_{dc} = \frac{\pi}{2\sqrt{2}}(1-D)I_{sc}$$

- If V_{out} is regulated (S is operating at $0 < D < 1$), the output power is:

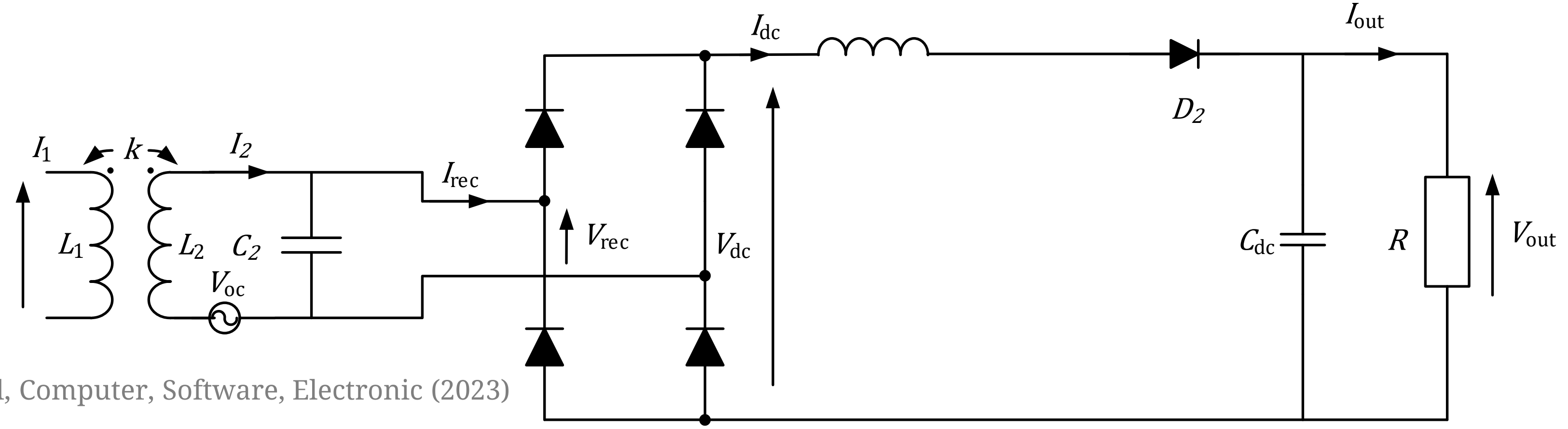
$$P_{out} = I_{out}V_{out} = \frac{\pi}{2\sqrt{2}}(1-D)I_{sc}V_{out} = (1-D)P_{max}$$

- If V_{out} is unregulated (S is off), output voltage is:

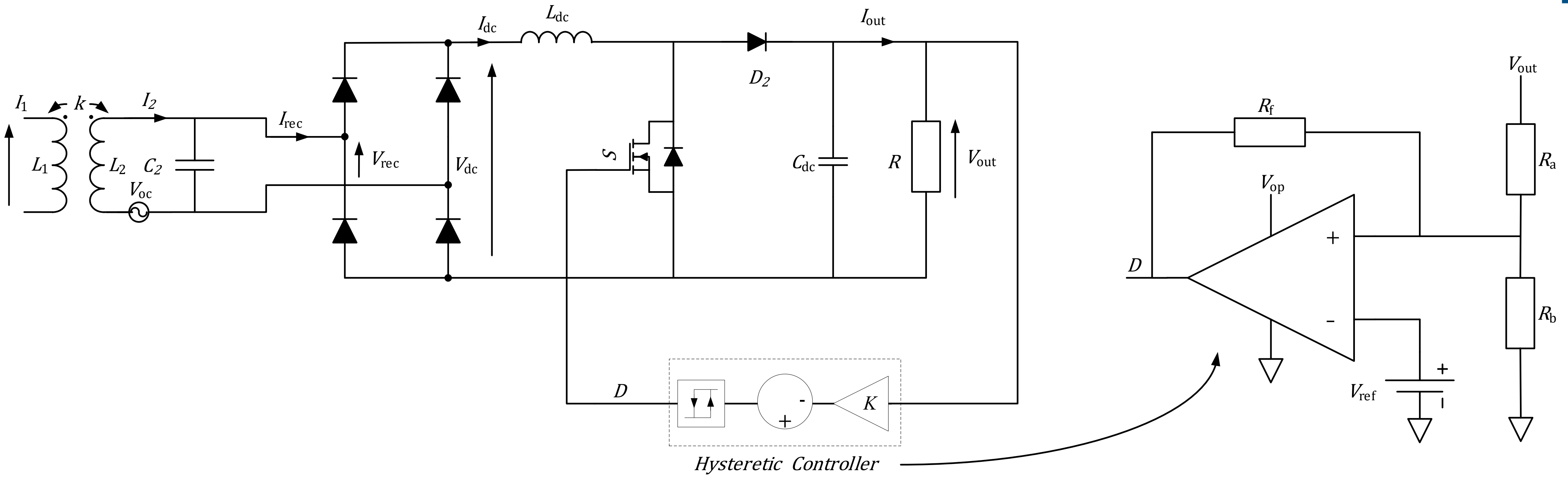
$$V_{out} = I_{out}R_2 = \frac{\pi}{2\sqrt{2}}I_{sc}R_2$$

- Pick up operates at maximum Q (when S is off) independent of load

$$Q_{max} = \frac{\pi}{2\sqrt{2}}\frac{V_{out}}{V_{oc}}$$



Slow switching implementation



- Controller turn off/turn on S when V_{out} is below/above a threshold
  - Can be implemented using a Schmitt trigger circuit
  - V_{op} is the output high voltage of the Op-amp whereas output low voltage is assumed to be 0

$$\Delta V_{out} = V_{op}\frac{R_a}{R_f}$$

$$V_{out,avg} = V_{ref}\frac{R_aR_b + R_f(R_a + R_b)}{R_fR_b} - V_{op}\frac{R_a}{2_{R_f}}$$

Slow switching analysis

- Switching frequency is a function of ΔV_{out}, C_{dc}, and R_2

$$f_s \approx \frac{\pi I_{sc}}{2\sqrt{2} C_{dc} \Delta V_{out}} (1 - D) D$$

- Maximum switching frequency occurs at $D = 0.5$

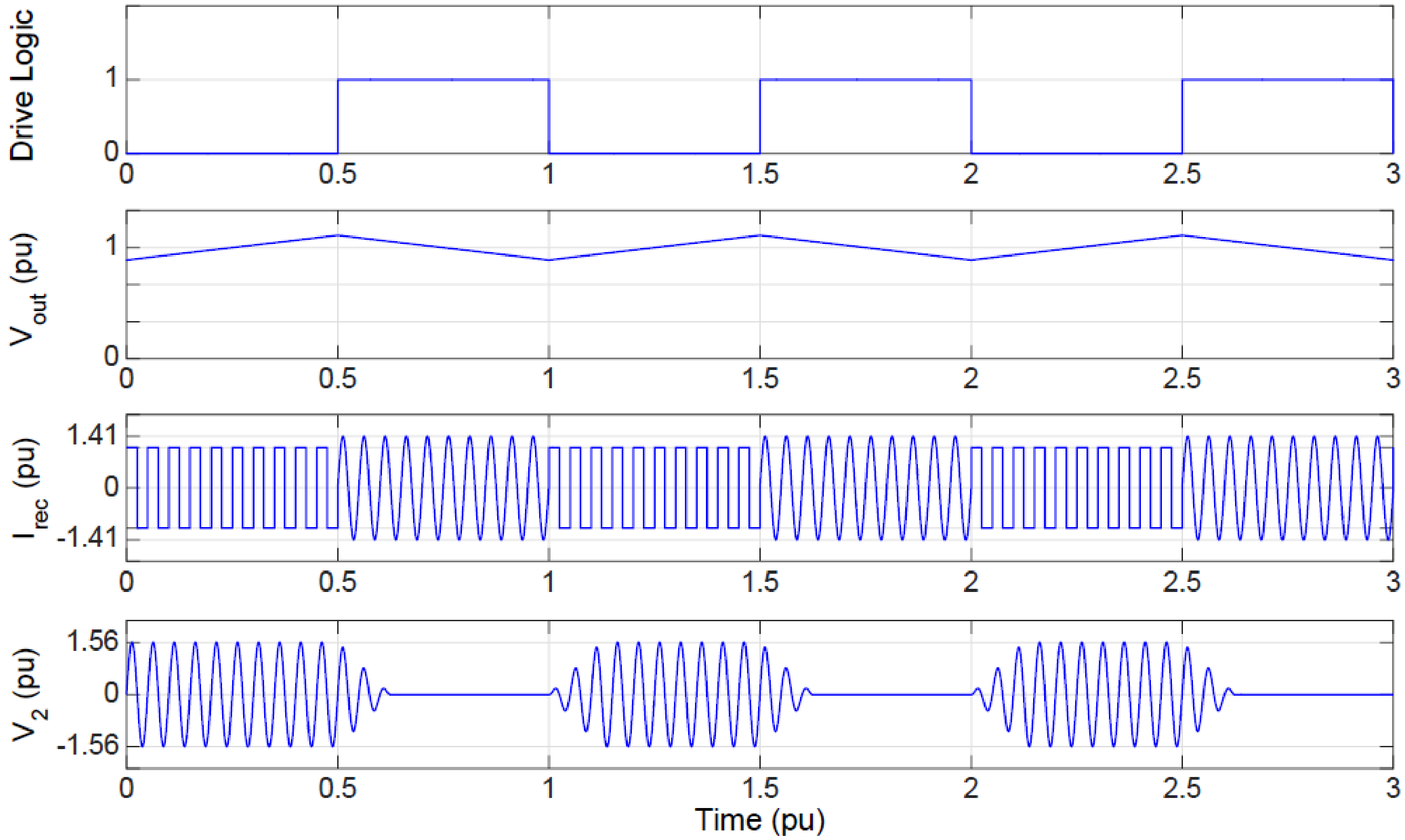
$$f_s \approx \frac{\pi I_{sc}}{8\sqrt{2} C_{dc} \Delta V_{out}}$$

- C_{dc} should be chosen to keep the switching frequency within an acceptable range

$$C_{dc} > \frac{\pi I_{sc}}{8\sqrt{2} f_{s,max} \Delta V_{out}}$$

  - Need to consider voltage ratings, RMS current ratings, ESRs, and capacitor lifetimes
  - Secondary resonance between C_{dc} and L_{dc} should be avoided
  - ESRs can lead to false triggering of the Schmitt trigger

Slow switching waveforms



Summary

- Discussed a simple way to control a short circuit controller
  - No microcontroller used
  - Slow switched
- The pick-up controller given to everyone in class will be based on these notes
- You will need to tune the resistor values as needed for this year’s project