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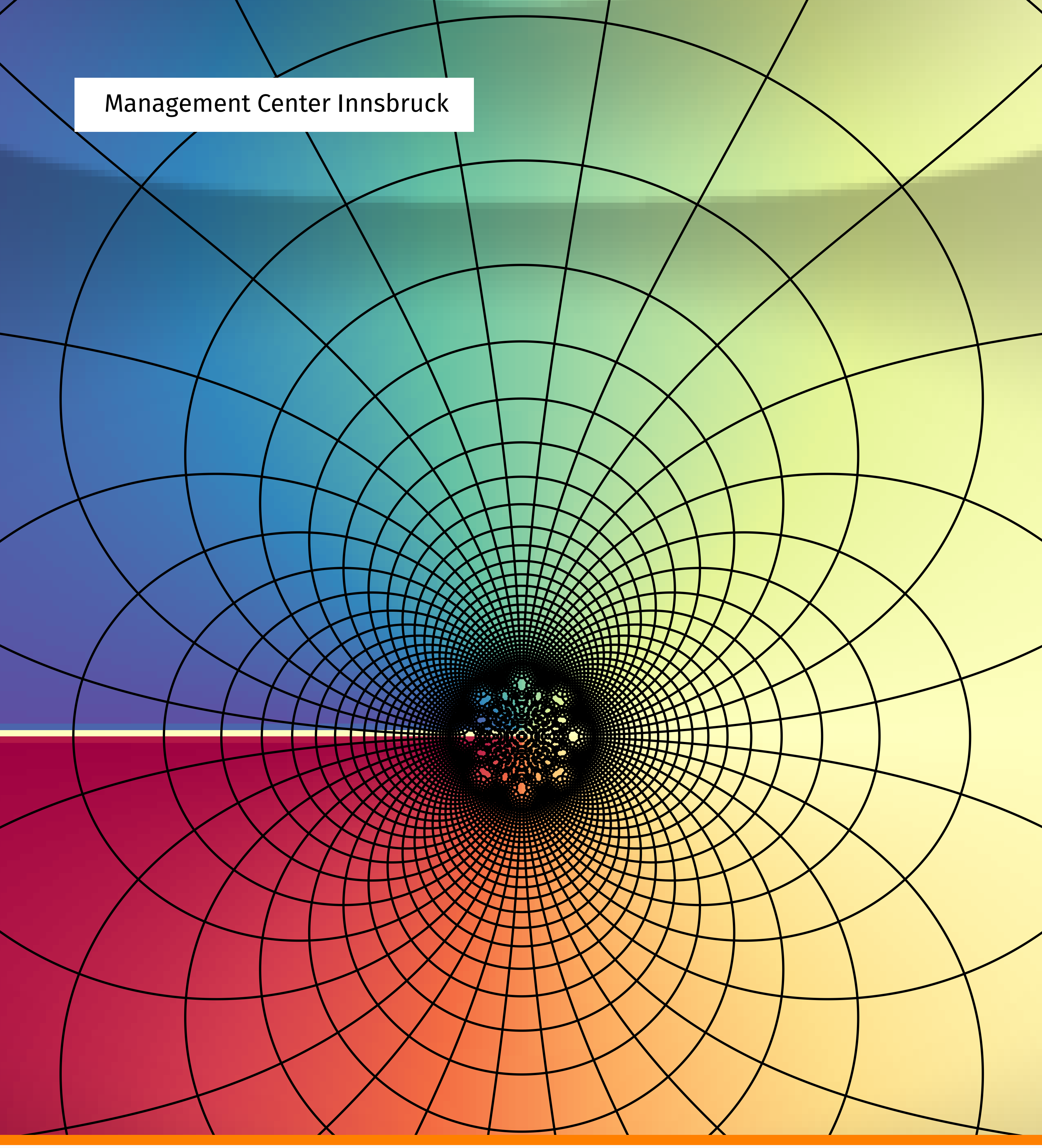

Drive Technology

Lab Script

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Semester 5

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Degree B.Sc

Contents

Chapter 1

Installation of a Drive System

1.1 Introduction

This lab exercise focuses on the installation and the application of a variable speed drive power train using a Programmable Logical Controller (PLC), an inverter and an induction drive.

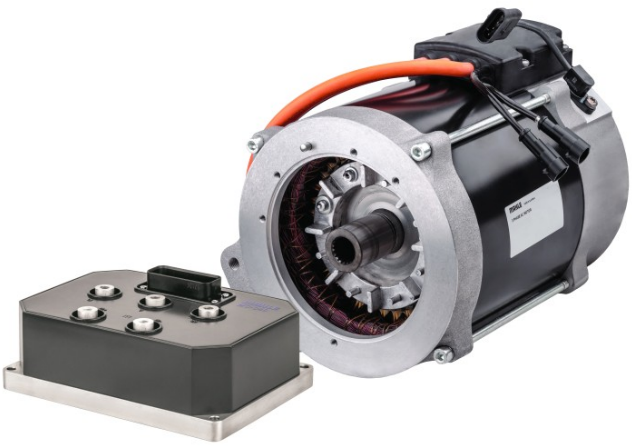


Figure 1.1: Electric drives are becoming more common in industry as converter efficiency and optimisation of manufacturing increases.

1.2 Learning Outcomes

During this exercise you will do all steps of the quick installation guide in given in ABB document. The goal is to have a fully working drive power train in a no load configuration, which is controllable by the inputs of the PLC.

You will be familiar with the following topics after the exercise:

(LO1) electrical installation of PLCs, inverters and induction machines,

(LO2) possible configurations for a drive power train with an induction machine,

(LO3) configuration of an inverter with parameters.

> For this lab you are to define subtasks for your groups to work efficiently during the time in the laboratory.

1.3 Literature Review

The following subsections cover information which may prove useful in understanding the underlying principles of this lab exercise.

> Prior to attending the lab it is highly recommend to get accustomed to the ABB manual.

1.3.1 Inverters

Inverters are also called AC Drives, or VFD (variable frequency drive), are electronic devices that can turn DC to AC. They are also responsible for controlling speed and torque for electric motors which are found in most devices we use to do work such as small electronics, transportation, and office appliances. These motors need electricity to run. Matching the motor's speed to the required process is essential to avoid wasting energy. In factories, wasted energy and materials could put the business at risk, and so inverters are used to control electric motors, boosting productivity and saving energy.
An AC drive works between a power supply and an electric motor where power goes into the AC drive and regulates it. The regulated power is then sent to the motor.
An AC drive consists of a rectifier unit, a DC intermediate circuit, and an inverse conversion circuit. The rectifier unit inside an AC drive can be unidirectional or bidirectional. The former can accelerate and run the motor by taking energy from the electrical network. A bidirectional rectifier can take the mechanical rotation energy from the motor and send it back to the electrical system. A DC circuit will store the electrical power for the inverse conversion unit to use.
Before the regulated power is received by the motor, it undergoes a process inside the AC drive. The input power runs into a rectifier unit and the AC voltage is converted to DC voltage. The DC intermediate circuit smoothens the DC voltage. It then flows through the inverse conversion circuit to convert the DC voltage back into AC voltage.
This process allows the AC drive to adjust the frequency and voltage supplied to the motor depending on the demands of process. The speed of the motor increases when the output voltage is at a higher frequency. This means that the speed of the motor can be controlled via the operator interface.

1.4 Tasks

- During the preparation every group has defined sub-tasks and now it is time to work on these subtasks.
- As there are many different ways to structure the task in subtasks, it is depending to the group, who is doing what.
- In general there has to be an electrical installation of all the different modules like the PLC and the inverter together with the communication interface (MODBUS).
- Cables have to be prepared for the connections (PLC-Inverter, Inverter-Machine, Inverter-Grid, etc.) and the machine itself has to be prepared as well.
- The materials and the tools for the exercise will be provided by the lecturer or the lab supervisor (Manuel Berger). Every group has its own kit to use.
- Make sure not to loose anything, since the modules will be used next year as well.

> Cables will be manufactured by the group, if necessary.

> Only the lecturer or the supervisor is allowed to run the drive power train, so only he is allowed to power the experiment.

1.4.1 Transient Behaviour

- If the setup of the drive power train is completed, use the analogous output of the inverter to get a step response of the speed.

> Find out how you can change the transient behaviour of the setup by changing parameters in the parameter list.

- Since there are many parameters, try to find out how they affect the transient response.
- Also think of possible scenarios, where certain parameter configurations could be reasonable.

1.5 Analysis and Report

No report has to be done for this exercise, but your performance during the exercise will be noted and contributes to the final grade.

Chapter 2

Building a Lathe

2.1 Introduction

The art of wood turning has become more and more popular for hobbyist carpenters over the last decades. The most common way to do wood turning is using a lathe. Below is an industrial scale lathe. A lathe is a machine tool which rotates a work piece (i.e., a woodwork)

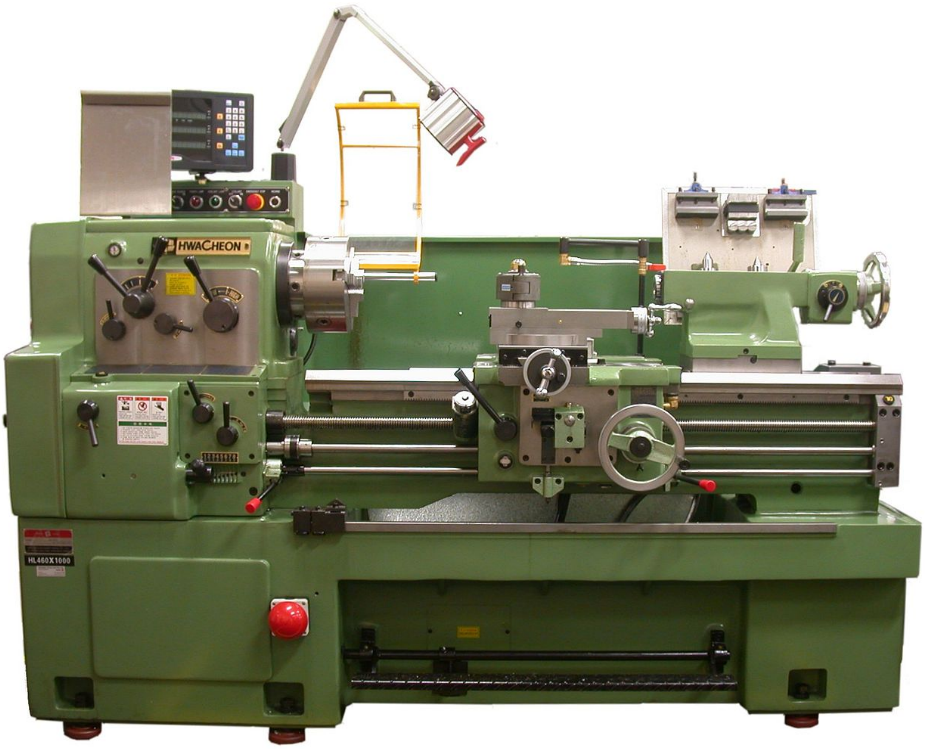


Figure 2.1: A Modern lathe used in industry [8].

about an axis of rotation to perform various operations such as cutting, sanding, knurling, drilling, deformation, facing, threading and turning, with tools that are applied to the work piece to create an object with symmetry about that axis.

The drive technology, which is often used in such lathes, is an inverter and an induction drive, especially for the ones which are on the more commercially affordable side. Sometimes also gearboxes are applied, but in this exercise the focus is on the drive power train without gearboxes.

> The purpose of gearboxes is to transfer the motor power to the wheels as well as to reduce this power in order to achieve more torque and less speed.

2.2 Learning Objectives

During this lab exercise you will develop a strategy to design the drive power train of a lathe. Then the realisation is the next step to take. The goal is to have a fully working drive power train for a lathe, which is manually controllable.
The learning outcomes of this lab exercises are:

(LO1) Developing strategies for easy application for inverters and induction drives,

(LO2) Using the input and output of an inverter to control via external methods,

(LO3) How to configure an inverter.

2.3 Preparation for the Lab

For this exercise the preparation does not require extensive literature review like the other lab sessions do and requires of you only the following research:

1. Investigate reasonable wood turning speeds with a diameter d between 130 mm to 500 mm.
2. How is the turning speed dependent to the diameter of the wood as a function $n(d)$,
3. How would you distribute six (6) discrete turning speeds in the range, which came from the investigations?

2.4 Tasks

During this lab exercise the first task will be to set up the inverter and the induction drive similar to what was done in Lab Exercise 1, but without the PLC.

> This configuration will be the starting point for this exercise.

Once this setup is attained there will be three (3) approaches to do.

2.4.1 First Task

The fist task is to build a drive power train which has all the fundamental features of a typical lathe. These features are:

- Seven (7) discrete turning speeds,

- Signalisation of errors and warnings of the inverter,
- An ON/OFF switch.

2.4.2 Second Approach

The second task should build on top of the first task with additional features with the additional features being:

- Three (3) discrete variable turning speed,
- Signalisation of errors and warning of the inverter,
- Additional analogous input to vary the turning speed continuously,
- An ON/OFF Switch
- As an Output the turning speed has to be provided as a current between 4 mA to 20 mA,
- With an input it should be possible to change between type sets of dynamic parameters for the drive system.

2.4.3 Third Approach

The third and the final approach is now up to the group and optional. At this point the drive power train can be changed based on the requirements of the group. For more information on what could be done, please check out [2] for inspiration.

2.4.4 Analysis and Report

As this exercise has a part which is about realising the given goals, this has to be part of the report. If your group was not able to achieve the goals, write about which part of the goals were achieved and which were not. Also include the reasons why your group failed. Make sure to state what you have done, and why you have done it.

2.5 What to Hand in

Your lab report, with your findings **must** be submitted to SAKAI no later than **2 weeks** after the experiment is concluded. Your lab report should roughly include the following points:

Topic	Description
Cover Page	The cover page needs to include: ▪ Title of the Experiment ▪ Student Name(s) ▪ Student Number(s) ▪ Module
Abstract	A short description of your work where you summarise your results in 100 - 200 words.
Introduction	The point in which you can hook the reader into reading your report. Start in with a broad picture and as you continue funnel the reader into what is relevant to your work. Here also include the literature research done for the lab preparation.
Materials and Methods	Explain to the reader what tools were used and give enough information for the work to be reproducible.
Results	Provide the reader with all the information gathered from the lab results and present them in a table of figure format.
Discussion and Conclusion	Considers whether the data you obtained support the hypothesis and discus the ramifications of your results.
References	Present all the relevant references for your work. As the work is carried out in the electrical engineering, it is recommended to use IEEE citation format.

Table 2.1: A brief look on the stages of writing a lab report.

If you need a refresher of would like to learn more about scientific lab report writing, please look at Chapter 5.

Chapter 3

Synchronous and Induction Drives

3.1 Introduction

This lab exercise will cover two (2) types of electrical drives used in industry:

1. Induction drive (also known as Asynchronous drive),
2. Synchronous generator

These machines' properties will be analysed on a typical test bench. In an industrial setting, machines have to be tested for specific applications, and depending on the application (i.e., lifts, linear motion, generator) specific tests would be conducted. Possible tests could be for life cycle of the machine, analysing its equivalent circuit, determining inrush current, etc..

The test bench for this exercise is a so called power test bench, with sensors to determine the parameters (torque, power factor, temperature, efficiency, rotation speed) for a machine operating in normal operation.

3.2 Learning Outcomes

During the lab exercises you will work on induction and synchronous machines. The learning outcomes are as follows:

(LO1) Understanding the induction drive behaviour,

(LO2) Working with induction drives and testing its parameters,

(LO3) Understanding synchronous drive behaviour,

(LO4) Working with synchronous drives and testing its parameters, The aim is to understand their working principle and to develop an understanding of their behaviour using graphs, which usually are provided in data sheets.

1. First task will focus on induction motor and determining its characteristics.
   - Once determined, a compensation network will be integrated to the system to re-evaluate its power factor ($\cos\phi$).
2. Second tasks will be study of a synchronous machine.
   - Operating in generator mode, you will feed DC current to the excitation windings to generate voltage across the windings and plot it (x: DC Excitation, y: Single Phase),
   - Once the curve is obtained, you will introduce a 3 load to the generator windings and under a constant DC excitation, plot winding voltage (x: Resistor value, y: Single Phase).

3.3 Literature Research

Before setting foot into the lab, it is important to know some fundamental knowledge on the drives you will be experimenting in.

Here are some topics you should have knowledge of:

1. Know the general working principle of an induction drive,
2. Understand how compensation networks work, and how can an induction drive work with a compensator to achieve a power factor of 1 (i.e., $\cos\phi = 1$).
3. Know the general working principle of a synchronous drive.

It is recommended to read the following sections prior to attending the lab session.

3.4 Literature Review

3.4.1 Induction Motor

In an induction drive, AC power supplied to drive's stator creates a magnetic field ($\mathbf{B}$) that rotates **in synch** with the AC grid. An induction motor's rotor rotates at a somewhat slower speed than the stator field. The induction motor stator's magnetic field is therefore *changing or rotating relative to the rotor*. This induces an opposing current in the rotor, in effect the motor's secondary winding. The rotating magnetic flux induces currents in the rotor windings, in a manner similar to currents induced in a transformer's secondary winding(s).

The induced currents in the rotor windings in turn create magnetic fields in the rotor that *react against the stator field*. The direction of the rotor magnetic field opposes the change in current through the rotor windings, following Lenz's Law. The cause of induced current in the rotor windings is the rotating stator magnetic field, so to oppose the change in rotor-winding, currents the rotor turns in the direction of the stator magnetic field.

The rotor accelerates until the magnitude of induced rotor current and torque balances the load on the rotor. Since rotation at synchronous speed does not induce rotor current, an induction motor always operates slightly slower than synchronous speed. The difference, or "*slip*" between actual and synchronous speed varies from about 0.5% to 5.0% for an average motor. The induction motor's essential character is that **torque is created solely by induction** instead of the rotor being separately excited as in synchronous or DC machines or being self-magnetised as in permanent magnet motors.

For rotor currents to be induced, the speed of the physical rotor must be lower than that of the stator's rotating magnetic field (n_s); otherwise the magnetic field would not be moving relative to the rotor conductors and no currents would be induced. As the speed of the rotor drops below synchronous speed, the rotation rate of the magnetic field in the rotor increases, inducing more current in the windings and creating more torque.

The ratio between the rotation rate of the magnetic field induced in the rotor and the rotation rate of the stator's rotating field is called slip. Under load, the speed drops and the slip increases enough to create sufficient torque to turn the load. For this reason, induction motors are sometimes referred to as asynchronous motors.

3.4.2 Synchronous Motors

A synchronous electric motor is an AC electric motor in which, at steady state, the rotation of the shaft is synchronised with the frequency of the supply current [4].

> The rotation period is exactly equal to an integral number of AC cycles.

Synchronous motors use electromagnets as the stator of the motor which create a magnetic field that rotates in time with the oscillations of the current. The rotor with permanent magnets or electromagnets turns in step with the stator field at the same rate and as a result, provides the second synchronised rotating magnet field.

> A synchronous motor is termed doubly fed if it is supplied with independently excited multi-phase AC electromagnets on both the rotor and stator.

3.4.3 Synchronous Speed

The synchronous speed of a synchronous motor is given:

$$n_s = 60\frac{f}{P} = 120\frac{f}{p}, \qquad \text{or} \qquad \omega_s = 2\pi\frac{f}{P} = 4\pi\frac{f}{p}.$$

where f is the frequency of the AC (Hz), p is the magnetic poles and P is the pole pair.

3.4.3.1 Starting Methods

Above a certain size, synchronous motors cannot self-start.

This property is due to rotor inertia as it cannot instantly follow the rotation of the stator's magnetic field.

Since a synchronous motor produces no inherent average torque at standstill, it cannot accelerate to synchronous speed without a supplemental mechanism.

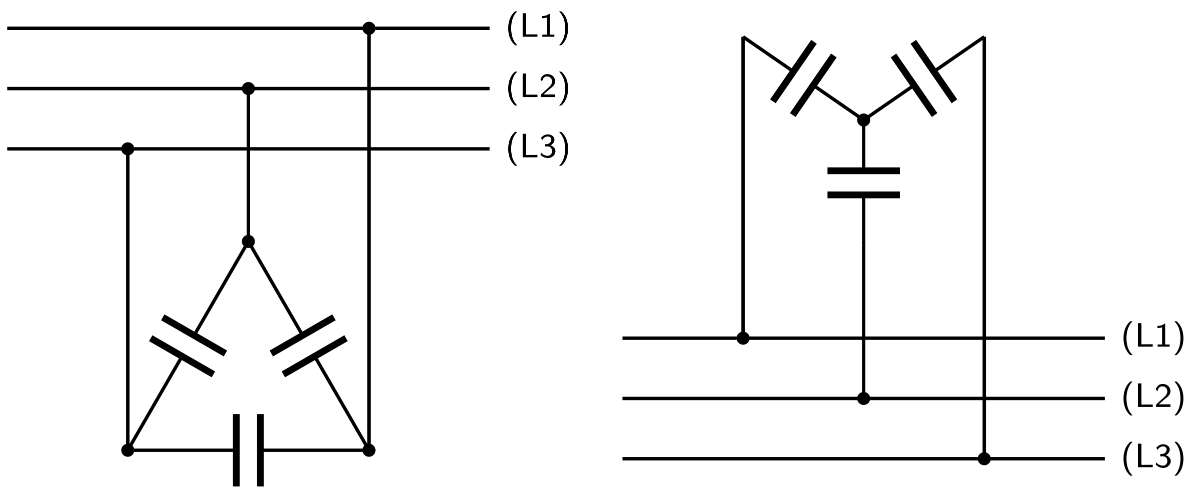
Large motors operating on commercial power include a squirrel-cage induction winding that provides sufficient torque for acceleration and also serves to damp motor speed oscillations.

Once the rotor nears the synchronous speed, the field winding becomes excited and the motor pulls into synchronisation. Very large motor systems may include a "pony" motor that accelerates the unloaded synchronous machine before load is applied. Electronically controlled motors can be accelerated from zero speed by changing the frequency of the stator current.

Small synchronous motors are commonly used in line-powered electric mechanical clocks or timers that use the power line frequency to run the gear mechanism at the correct speed. Such small synchronous motors are able to start without assistance if the moment of inertia of the rotor and its mechanical load are sufficiently small. The motor accelerates from

Figure 3.1: Synchronous condenser installation at Templestowe substation, Melbourne, Victoria, Australia. Built by ASEA in 1966, the unit is hydrogen cooled and capable of three phase power at 125 MVA [9].

slip speed to synchronous speed during an accelerating half cycle of the reluctance torque. Single-phase synchronous motors such as in electric wall clocks can freely rotate in either direction, unlike a shaded-pole type.



(a) Delta (Δ) configuration

(b) Star (Y) configuration

Figure 3.2: Types of compensation network connections.

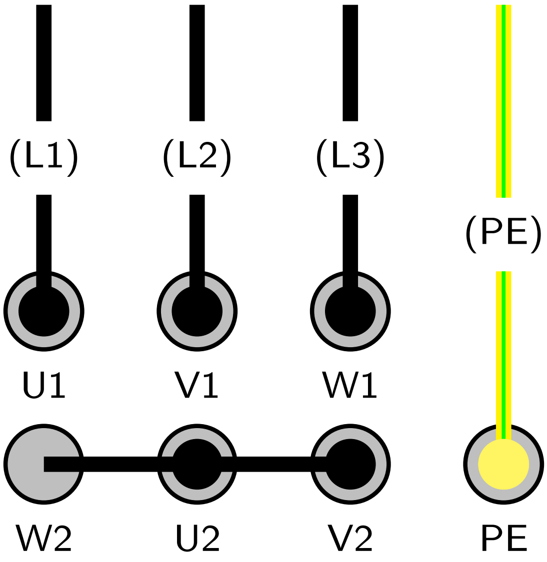
3.4.4 Static VAR Compensator (SVC)

A static VAR compensator (SVC) is a set of electrical devices for providing fast-acting reactive power on high-voltage electricity transmission networks [2]. SVCs are part of the flexible AC transmission system device family, regulating voltage, power factor, harmonics and stabilising the system. A static VAR compensator has no significant moving parts (other than internal switch-gear). Prior to the invention of the SVC, power factor compensation was the preserve of large rotating machines such as synchronous condensers or switched capacitor banks with an example shown in **Figure 3.1**.

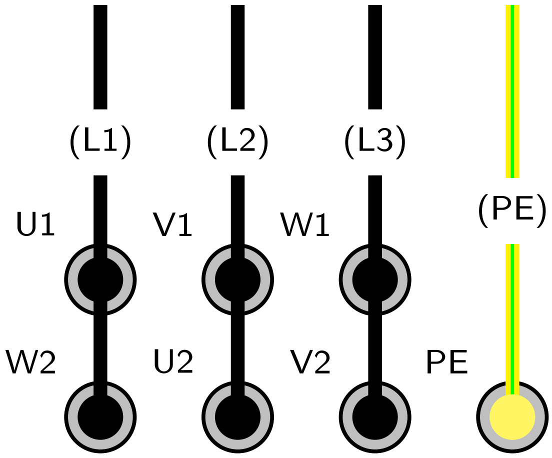
The SVC is an automated impedance matching device, designed to bring the system closer to unity power factor. SVCs are used in two (2) main situations:

1. Connected to the power system, to regulate the transmission voltage (”transmission SVC”),
2. Connected near large industrial loads, to improve power quality (”industrial SVC”)

In transmission applications, the SVC is used to regulate the grid voltage. If the power system’s reactive load is capacitive (leading), the SVC will use thyristor controlled reactors to consume VARs from the system, lowering the system voltage. Under inductive (lagging) conditions, the capacitor banks are automatically switched in, thus providing a higher system voltage. By connecting the thyristor-controlled reactor, which is continuously variable, along with a capacitor bank step, the net result is continuously variable leading or lagging power. In industrial applications, SVCs are typically placed near high and rapidly varying loads, such as arc furnaces, where they can smooth flicker voltage. You can see the possible 3-phase configuration of a compensation network in **Figure 3.2**.



(a) Star connection (Y) on a machine.



(b) Delta connection (Δ) on a machine.

Figure 3.3: Types of connections for electric motors.

3.5 Tasks

Below are the tasks for the two (2) lab sessions pertaining to electric drives.

3.5.1 Induction Motor

For the induction machine all the tasks should be done in both **Star** and **Delta** configuration.

> Only the supervisor or lecturer is allowed to operate the test bench.
> Failure to follow this direction will result in immediate fail of the lab.

Each task develops over the previous one, therefore try to do the tasks in this order:

1. Set up the test bench connections shown in **Figure 3.4**,
2. Using the test bench, measure the no load speed (n_0),
3. Measure the speed-torque behaviour during normal operation using the computer,
4. Measure the torque (T), the power factor ($\cos\phi$) and efficiency (η) with respect to rpm (n).
5. Calculate and apply the compensation network of the induction machine.
6. Redo step 4 with the compensation applied to the motor. Use the diagram in **Figure 3.5**.

3.5.2 Synchronous Generator

For the synchronous generator **only the star configuration** should be applied.

1. Remove the induction drive and its braking unit and replace it with the synchronous generator and its breaking unit,

2. Supply the excitation winding (**F1** and **F2**) with the variable DC source of the supply unit.

> Make sure, the voltage is zero before you start. Use **Figure 3.6** as the reference for your connections.

3. Run the generator via the brake with the nominal speed, and measure the induced voltage using a multimeter using the terminals (e.g., **U1** and **U2**).
4. Apply a 3 load to the generator windings and under a constant DC excitation measure the winding voltage. Use **Figure 3.7** as the reference for your connections.

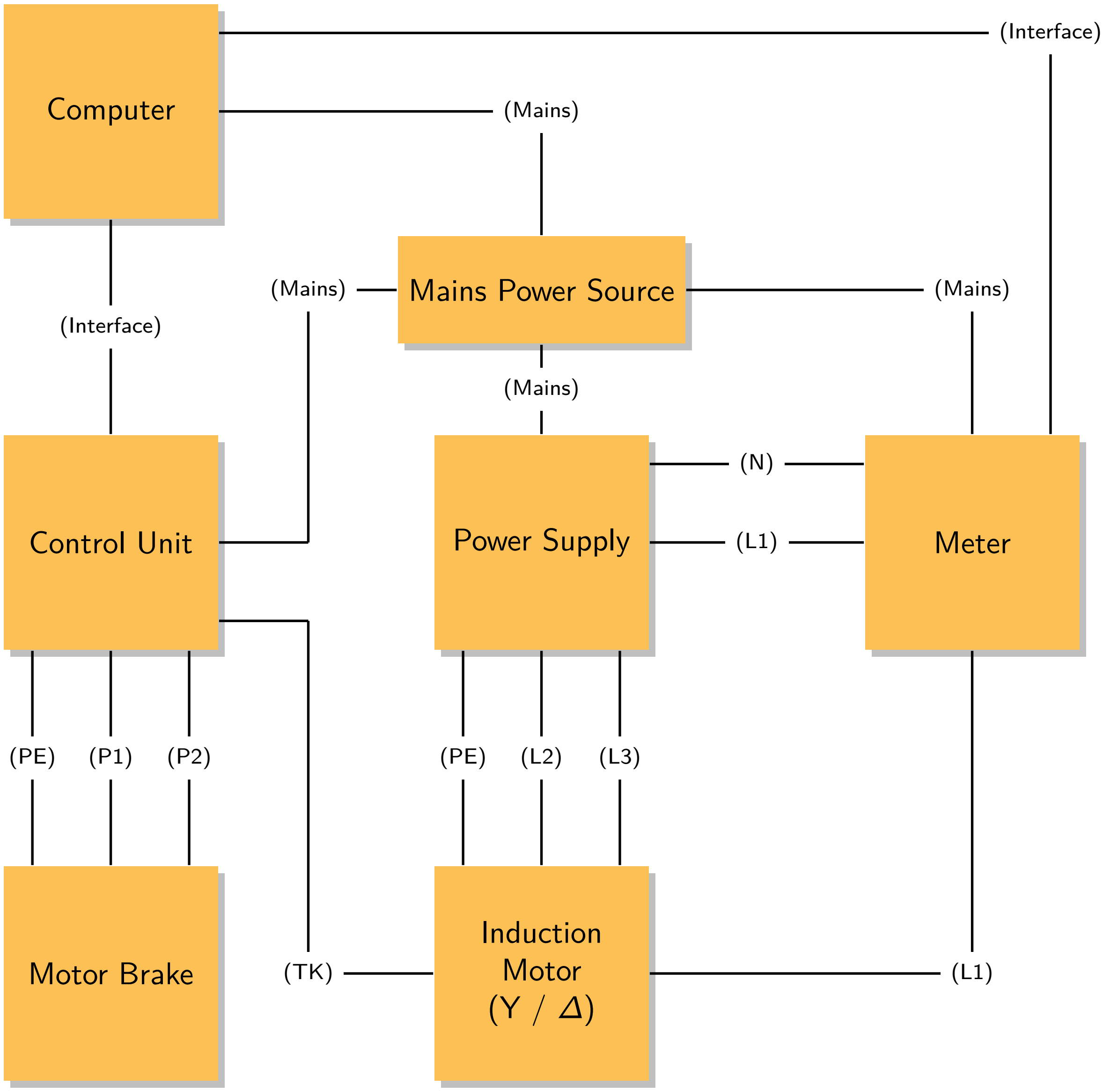


Figure 3.4: The connection Diagram for Induction drive exercise 1.

When you are plugging the control unit interface to the computer, make sure you plug it to the correct driver slot (i.e., from the backside view, it is the port on the right hand side) and make sure the dial is set to **INTERFACE**, int. /ext. switch on **int.** and int./INTERFACE on **INTERFACE**.

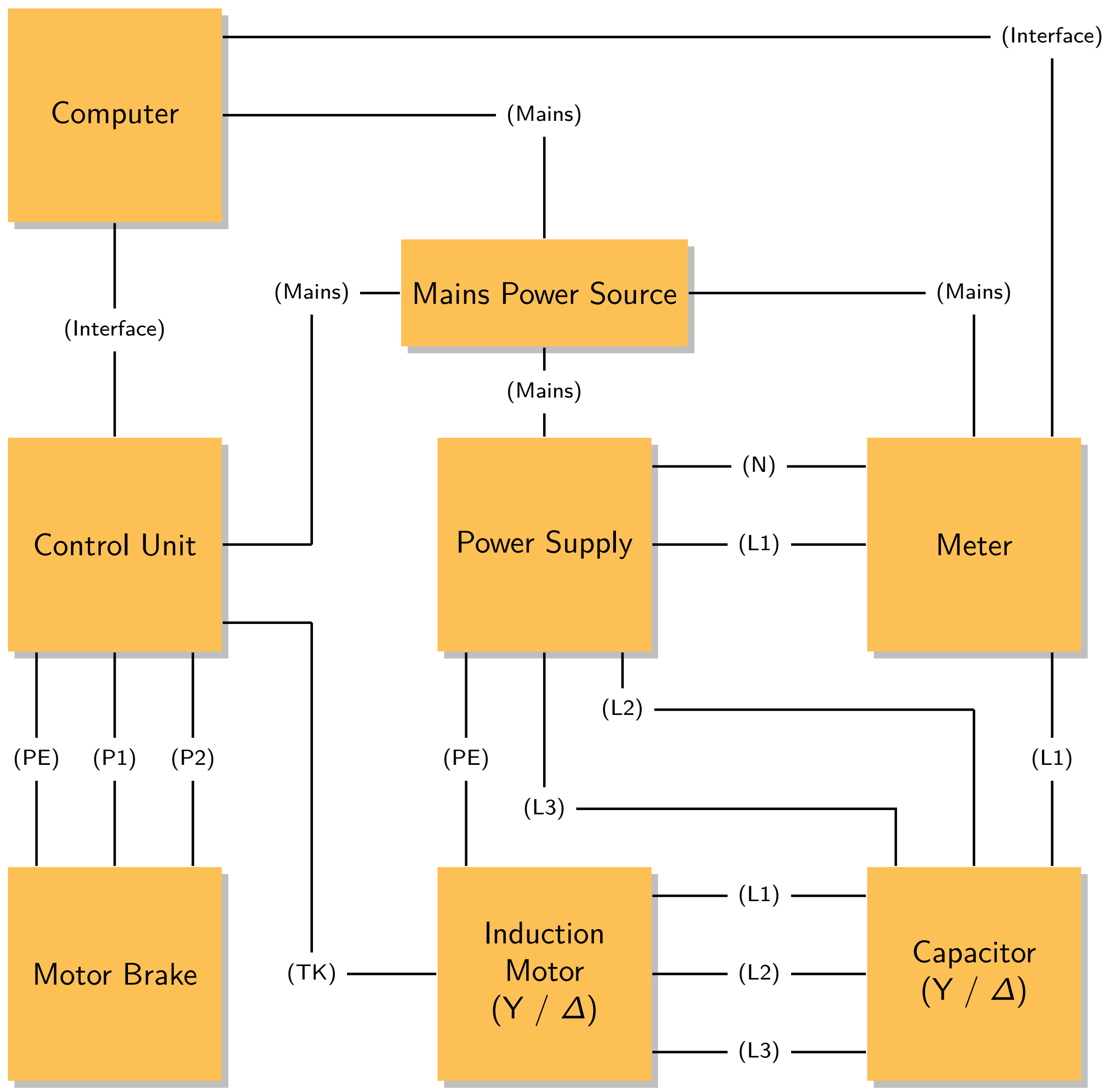


Figure 3.5: The connection Diagram for Induction drive exercise 2.

When you are plugging the control unit interface to the computer, make sure you plug it to the correct driver slot (i.e., from the backside view, it is the port on the right hand side) and make sure the dial is set to **INTERFACE**, int. /ext. switch on **int.** and int./INTERFACE on **INTERFACE**.

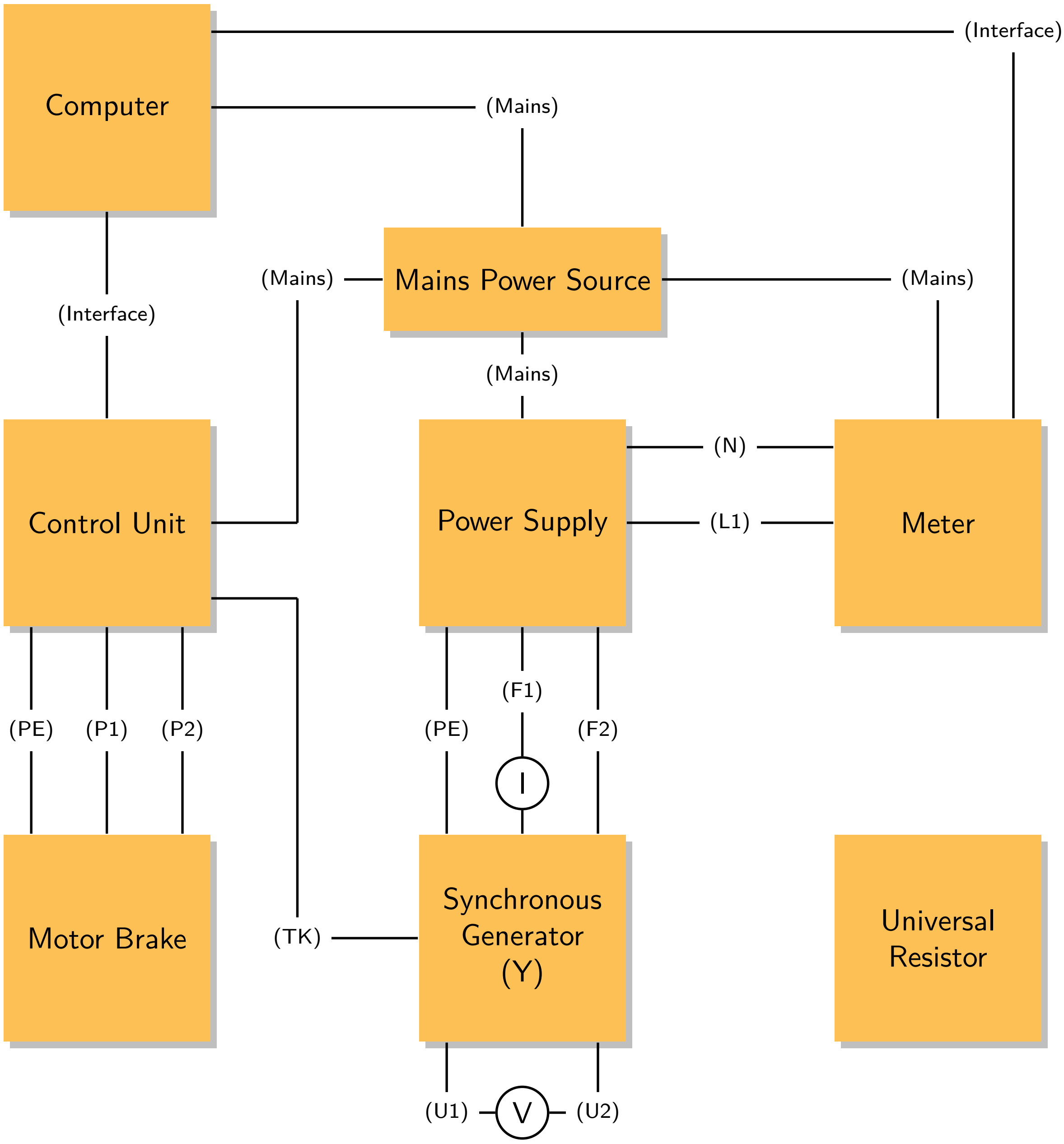


Figure 3.6: The connection Diagram for Synchronous drive exercise 1.

When you are plugging the control unit interface to the computer, make sure you plug it to the correct driver slot (i.e., from the backside view, it is the port on the right hand side), Make sure the dial is set to **MANUAL** To start/stop the motor press the START/STOP button.

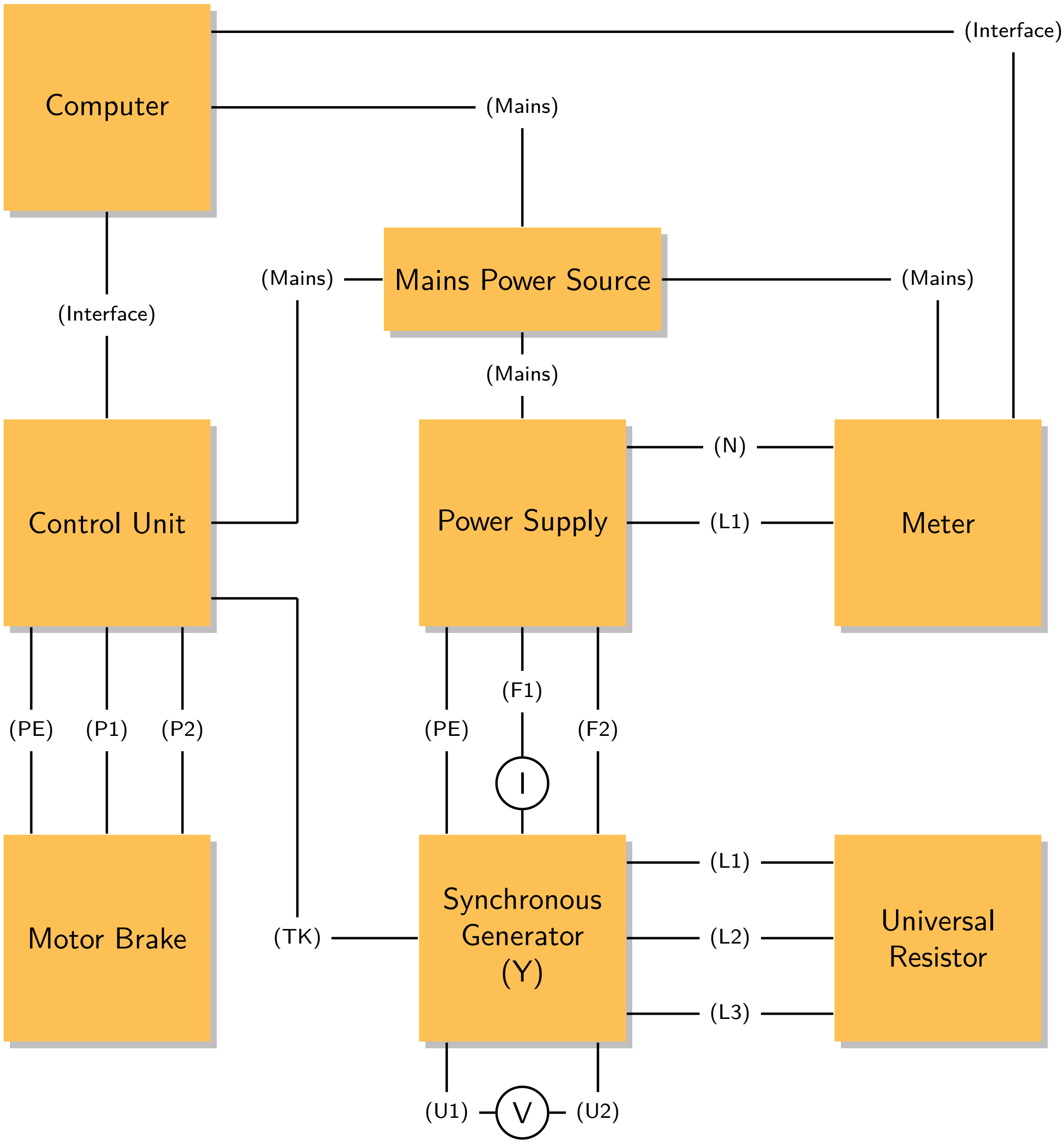


Figure 3.7: The connection Diagram for Synchronous drive exercise 2.

- When you are plugging the control unit interface to the computer, make sure you plug it to the correct driver slot (i.e., from the backside view, it is the port on the right hand side),
- Make sure the dial is set to **MANUAL**
- To start/stop the motor press the START/STOP button.

3.6 What to Hand in

Your lab report, with your findings **must** be submitted to SAKAI no later than **2 weeks** after the experiment is concluded. Your lab report should roughly include the following points:

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If you need a refresher of would like to learn more about scientific lab report writing, please look at Chapter 5.

Chapter 4

Photovoltaic Cells

4.1 Introduction

As the times are changing, so does the source of our energy. The industrial revolution has enabled the use of coal and other types of fossil fuels to power the machinery's which built the modern world. Currently we are in the midst of a transition of energy sources to something more renewable, and nothing is more renewable than the energy produced by the great fireball in the sky.

To harness this energy solar panels are being deployed which are used from charging a pocket calculator to feeding entire cities. This lab exercise will see you working with a small setup to show the working principle of photovoltaics in an island configuration and in connection with the grid [1].

4.2 Learning Objectives

This lab focuses on the use of solar cells in island and grid configuration together with a buffer (i.e., battery), network activators, inverters, chargers and transformers. After the successful completion of the exercise, you will be familiar with:

(LO1) Power and efficiency of the solar cell modules,

(LO2) Supplying loads in an island configuration,

(LO3) Supplying loads and feeding back energy to the grid.

4.3 Lab Preparation

As the topic of Solar cells are not covered in the B.Sc Drive System Fundamentals course, as its focus is on the aspect of machine design, some research will be required by the students to get the most out of the lab. The major topic suggest to students are:

- Understanding mono-, polycrystalline and thin-film panels,

- A brief literature survey on how to measure the maximum power,
- Have a read on what an island and grid configuration is.

4.4 Literature Review

4.4.1 The Electrical Grid

An electrical grid is an interconnected network for delivering electricity from producers (i.e., coal power-plants, hydro-dams) to consumers (i.e., manufacturers, residential households) [11]. In general, electrical grids consist of numerous power stations, electrical substations to

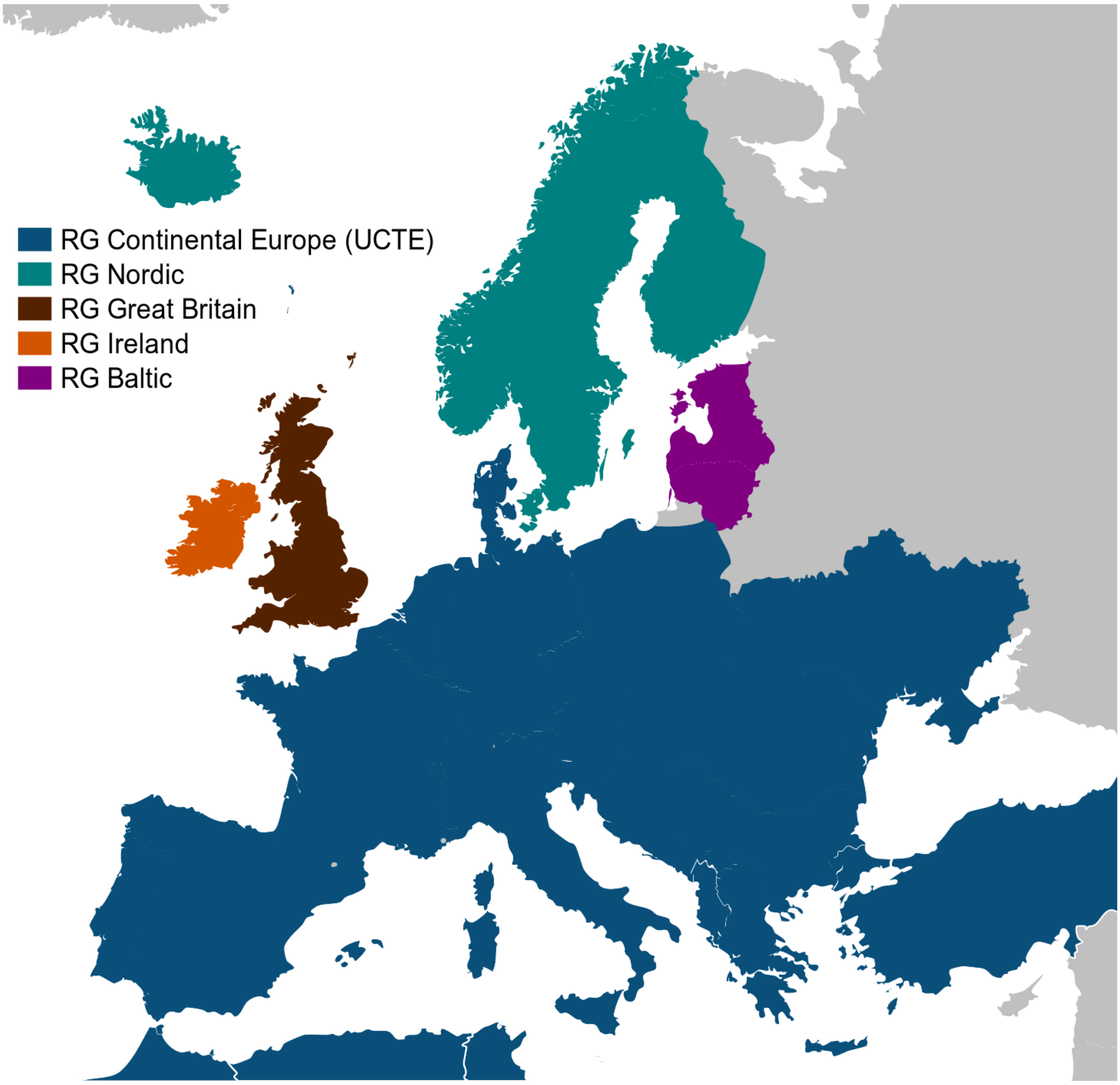

Figure 4.1: Map of European Transmission System Operators Organisations (Regional Groups) Continental Europe, Nordic, Baltic, Great Britain and Ireland/Northern Ireland (former UCTE, UKTSOA, NORDEL, ATSOI, IPS/APS) [7].

step voltage up or down, electric power transmission to carry power over long distances, and finally electric power distribution to customers [5].

In its last step of distribution, voltage is stepped down one last time to the required service voltage. Power stations are typically built close to energy sources and far from densely populated areas. This is generally done to mitigate environmental hazard affecting residential areas and faster energy generation from source to generator.
Electrical grids vary in size and can cover whole countries or continents (i.e., the European grid). From small to large there are micro-grids, wide area synchronous grids, and super grids. The combined transmission and distribution network is part of electricity delivery, known as the power grid.
Grids are almost nearly always synchronous. This means all distribution areas operate with three phase alternating current (AC) frequencies synchronised (so that voltage swings occur at almost the same time). This allows transmission of AC power throughout the area, connecting the electricity generators with consumers.
With a brief introduction of the electrical grid, it would be interesting to have a look at a continental grid known as the **European Grid**.

4.4.2 The European Grid

The synchronous grid of Continental Europe (formerly known as the UCTE grid) is the largest synchronous electrical grid (by connected power) in the world. It is interconnected as a single phase-locked 50 Hz mains frequency electricity grid that supplies over 400 million customers in 24 countries, including most of the European Union. In 2009, 667 GW of production capacity was connected to the grid, providing approximately 80 GW of operating reserve margin.

4.4.2.1 The Super Grid

There are current proposal by the EU Commission to create a super-grid which would ultimately interconnect the various European countries and the regions around Europe's borders – including North Africa, Kazakhstan, and Turkey – with a high-voltage direct current (HVDC) power grid.

4.4.3 Feeding to the Grid

The grid itself provides the frequency and voltage reference as discussed previous with the EU grid shown as example with its set Voltage level and 50 Hz frequency. The inverter is programmed to feed current into its connection with the grid, in a direction that feeds power in, and a magnitude that looks like a negative resistance.

Imagine a resistor connected to the grid, i.e., a 3kW kettle of roughly 20 Ω. When the instantaneous grid voltage is 100v, it draws 5A, when it's 300v, it draws 15A. Using electronic control system, a load that *sensed* the instantaneous voltage can be created, and drew that amount of current. This would look like a resistor at its terminals, and they're called power factor corrected power supplies.

This can be done in inverse, sense the grid voltage, and feed current into the grid. That's how a grid-tie inverter sends power into the grid in a controlled fashion. To inject efficiently and safely into the grid, grid-tie inverters must accurately match the voltage, frequency and phase of the grid sine wave AC waveform.

4.4.4 Island Grid

A micro-grid is a local grid that is usually part of the regional wide-area synchronous grid but which can disconnect and operate autonomously [10]. It might do this in times when the main grid is affected by outages. This is known as islanding, and it might run indefinitely on its own resources. Island grids are an electrical power supply task with a small number of

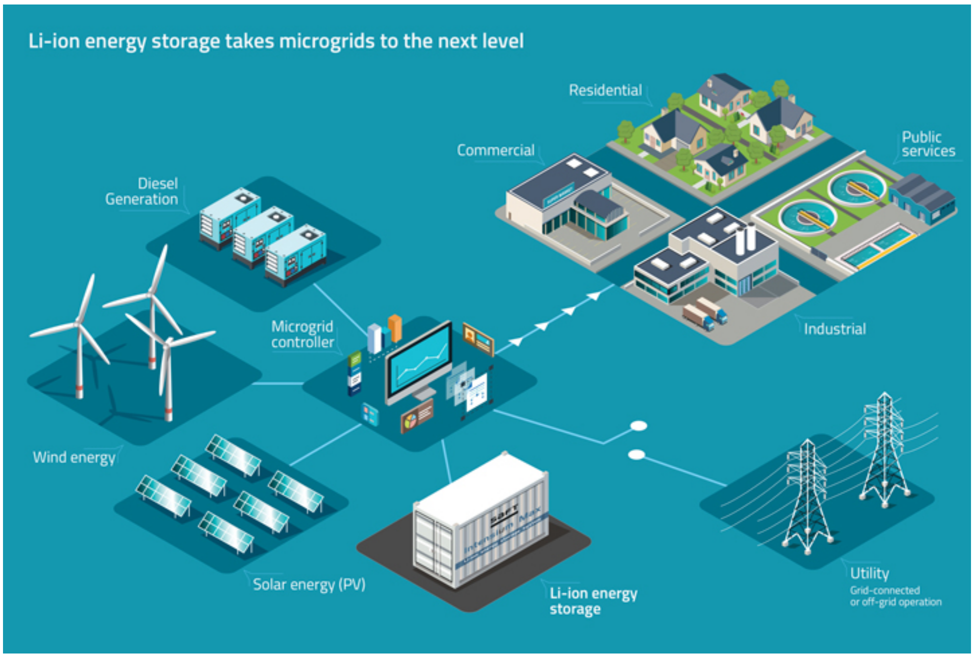

Figure 4.2: One of the fundamentals of Microgrids is that they can become a localised source of energy for a commercial, industrial, or residential application, and they can disconnect from the main grid to provide a renewable source of energy.

power generating plants and consumers. Island grids do not have a synchronous connection to a large network and therefore have to be able to provide all tasks necessary for long-lasting and safe operation on their own. Micro-grids are similar, but also have the capability to connect synchronously to a large network. Island grids are typically the result of geographical circumstances that render the connection to a large network costly or even impossible. Micro-grids, in contrast, are designed to increase the security of supply in case the large network breaks down.

4.4.5 Solar Panel Types

Solar panels are a popular choice for renewable energy generation. It is important to understand the different types of solar panels in order to make an informed decision for your energy needs. Here we will have a look at the key differences between monocrystalline, polycrystalline, and thin-film solar panels, highlighting their potential benefits and drawbacks.

- **Monocrystalline:** known for their high efficiency rates due to their single-crystal structure. The uniformity of the crystal structure allows for greater electron flow, resulting in higher power output. However, monocrystalline panels are also the most expensive option and can be less efficient in extreme temperatures. They typically have a lifespan of 25 to 30 years and provide a reliable source of clean energy.

- **Polycrystalline:** made from multiple silicon crystals, resulting in a lower efficiency compared to monocrystalline panels. However, they are more cost-effective to produce and perform better in high-temperature conditions. Polycrystalline panels have a slightly shorter lifespan of 20 to 25 years but still offer a reliable source of renewable energy.
- **Thin-film:** most lightweight and flexible option. They are made by depositing a thin layer of photovoltaic material onto a substrate, such as glass or metal. While thin-film panels have lower efficiency rates compared to monocrystalline and polycrystalline panels, they excel in low-light conditions and can be used in various applications. However, they have a shorter lifespan of around 10 to 20 years and may require more frequent replacement.

4.4.6 Lab Safety Rules

Before you begin, we have to come some lab safety rules.

> Experiment lights can become very hot, **do not touch it**, except the switches at the back.

> During grid testing, if something is not right, **press the emergency stop switch**.

4.5 Tasks

The 1st task is about the photovoltaic cells (consisting of two (2) panels in series) and their performance in parallel and serial configuration:

- Look and understand the components you'll be working with and set up the experiment.

> If you need help with the setup, ask your lab supervisor (Manuel Berger) for help.

- Switch on the lighting equipment(s) and measure the radiant power on all the panels.

> The dimension of a **single panel** is 1.125 m by 0.5 m.

- Measure the no-load voltage and current of all panels.
  1. You need to use multimeters for this part of the experiment.
- Put a variable power resistor(s) as load (ranging from 0 Ω to 84 Ω) to a single module and measure the consumed power to get the modules power with respect to the load. The connection should look roughly like below.

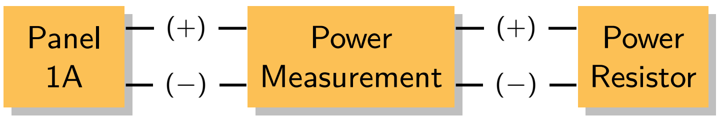

Figure 4.3: Connection diagram for the task 1.3 with a single power resistor.

- Redo the procedure for two modules in a parallel and four panels in serial configuration.

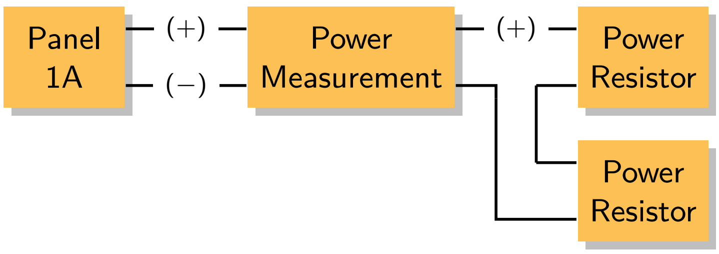

Figure 4.4: Connection diagram for the task 1.3 with two power resistors.

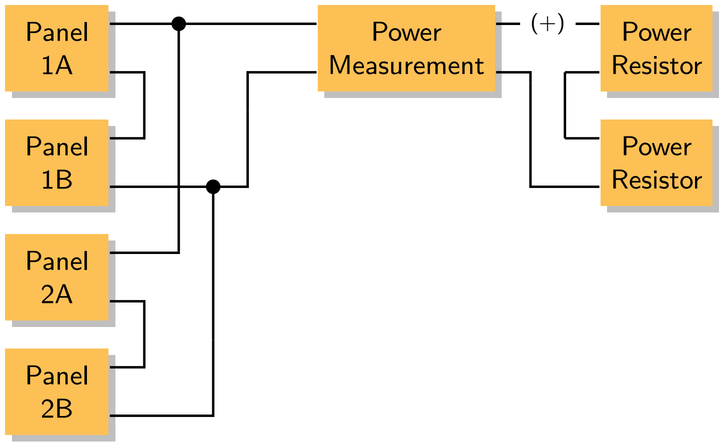

Figure 4.5: Connection diagram for the task 1.3 with a single power resistor.

The 2nd task is about **island grids (i.e., micro-grids)**:

1. Connect one module (i.e., two photovoltaic cells in series) to the grid-board for the island (i.e., micro-grid) configuration. Here the charger will have a load (R) ranging from 0 Ω to 42 Ω).
2. Once the connection has been set up, run the experiment and measure the efficiency (η) of the charger using the connected power measurement devices.
3. Redo the task with an additional second module in parallel.

The 3rd task is about **connecting the photovoltaic cells to the grid**.

1. Connect the modules to the board for the grid configuration (network activator, inverter, transformer).
2. **Plug the board to a power outlet**, run the experiment.
3. Estimate the efficiency (η) of the individual components and the whole setup.
   a) This means the energy from the photons is input, and the energy fed to the grid is output.
4. Observe the flow of the energy.

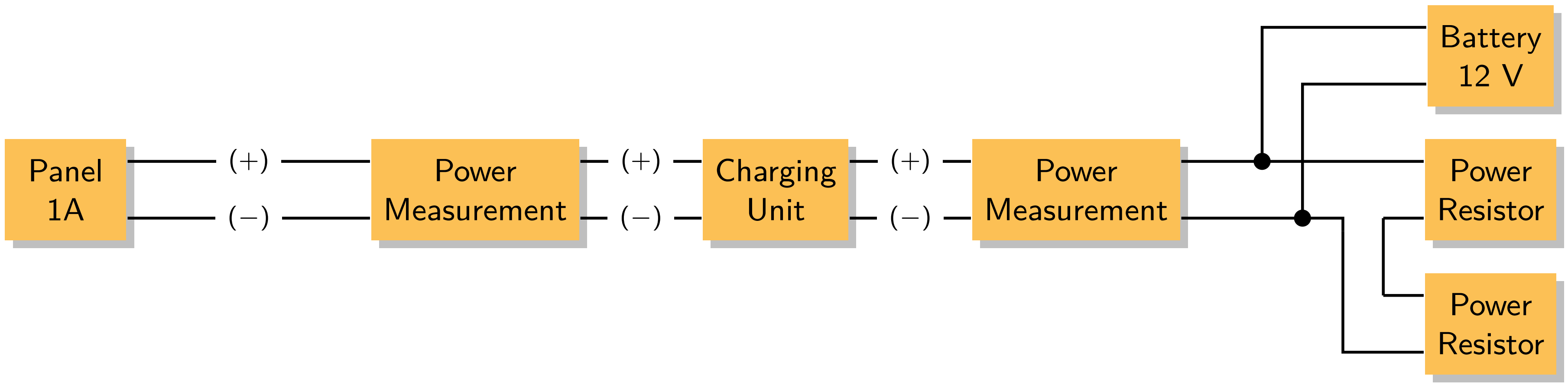

Figure 4.6: Connection diagram for the task 2.1, as a micro-grid setup.

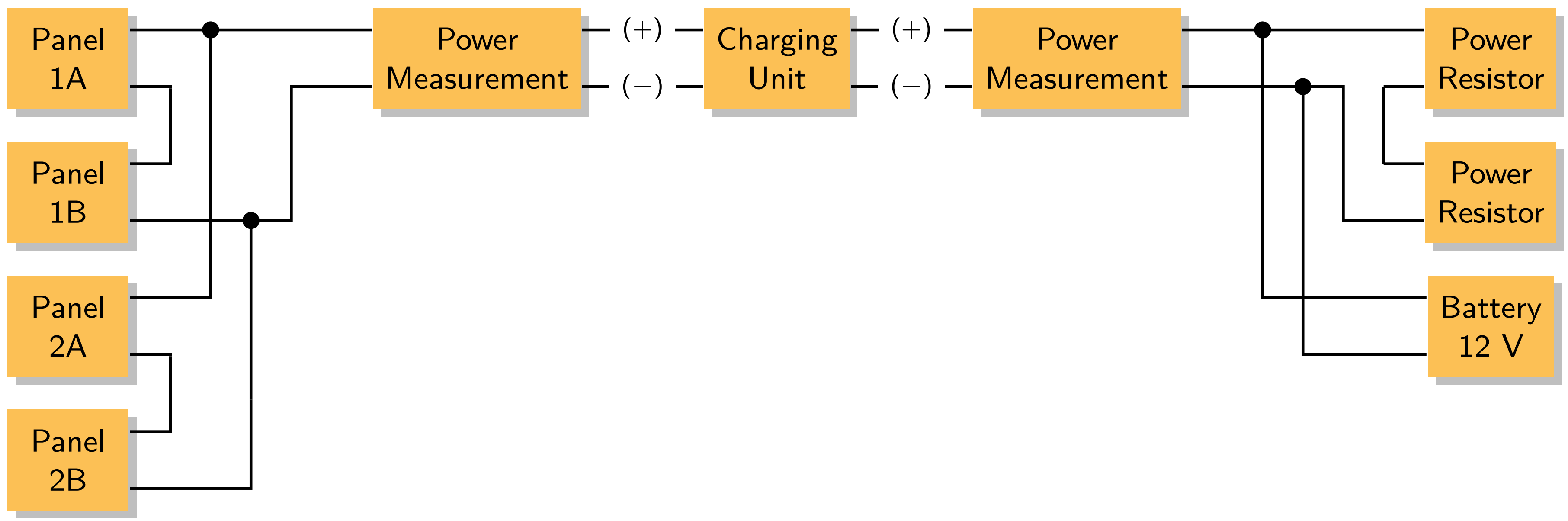

Figure 4.7: Connection diagram for the task 2.1, as a micro-grid setup.

4.6 What to Hand in

Your lab report, with your findings **must** be submitted to SAKAI no later than **2 weeks** after the experiment is concluded. Your lab report should roughly include the following points:

Topic	Description
Cover Page	The cover page needs to include: ■ Title of the Experiment ■ Student Name(s) ■ Student Number(s) ■ Module
Abstract	A short description of your work where you summarise your results in 100 - 200 words.
Introduction	The point in which you can hook the reader into reading your report. Start in with a broad picture and as you continue funnel the reader into what is relevant to your work. Here also include the literature research done for the lab preparation.
Materials and Methods	Explain to the reader what tools were used and give enough information for the work to be reproducible.
Results	Provide the reader with all the information gathered from the lab results and present them in a table of figure format.
Discussion and Conclusion	Considers whether the data you obtained support the hypothesis and discus the ramifications of your results.
References	Present all the relevant references for your work. As the work is carried out in the electrical engineering, it is recommended to use IEEE citation format.

Table 4.1: A brief look on the stages of writing a lab report.

If you need a refresher of would like to learn more about scientific lab report writing, please look at Chapter 5.

Chapter 5

OPTIONAL: Writing a Lab Report

5.1 A Brief Guideline

One really nice thing about writing lab reports is that they almost always follow a very specific format, so there's no question about what information goes first, second, third, etc. Lab reports generally have seven main parts [3]:

Section	Scientific Method Step
Title	Describe the main thesis of your work. This should contain the central idea of your work
Abstract	A reader should be able to gather all vital information of your work here without reading the rest of your report
Introduction	The point in which you can hook the reader into reading your report. Start in with a broad picture and as you continue funnel the reader into what is relevant to your work.
Materials and Methods	Explain to the reader what tools were used and give enough information for the work to be reproducible.
Results	Provide the reader with all the information gathered from the lab results and present them in a table of figure format.
Discussion and Conclusion	Considers whether the data you obtained support the hypothesis and discus the ramifications of your results.
References	Present all the relevant references for your work. As the work is carried out in the electrical engineering, it is recommended to use IEEE citation format.

Table 5.1: A brief look on the stages of writing a lab report.

5.1.1 Title

The title is a brief summary of the main ideas in the paper. It should be between 5 and 12 words long. If you studied a particular lab equipment in your experiment, make sure you include that in the title. The title should have enough details that any person could read it and know just what the study was about. But you don't need too many details, since you'll be talking about them in the lab report itself [6].

For example, a study on the numbers of bird species found in Phoenix parks might be called "**Species of birds in Phoenix city parks**" It's very simple and to the point.

5.1.2 Abstract

The abstract is a short summary of the main ideas found in the lab report. It should include:

- The purpose of the study or the question being addressed by the study,
- The procedures used in the study,
- The major results of the study,
- Any conclusions drawn by the author(s)

The abstract should generally be between 100 and 200 words in length.

5.1.3 Introduction

The introduction of your lab report is a chance for you to hook the reader and preview the important details you'll be talking about in the later sections of the paper. It's kind of like the first paragraph in a short story.
While the abstract was a very short summary of the entire paper, the introduction will be a longer section with more detail. It could be anywhere from three or four paragraphs to a few pages long, depending on the complexity of the topic and, of course, the requirements of your instructor. Some tips for organising your introduction:

- Start off with a very broad introduction to the topic. For instance, let's say you are writing a lab report about an experiment where you tested the effect of field current on the synchronous drives. You should start the introduction by talking about what synchronous drives are and how they work. Next, narrow down the introduction to talk more specifically about the topic you are investigating, and why the study you did was so important.
- The introduction should also include a literature review that discusses what is already known about the topic. This where you will summarise the research you have done about your topic. Make sure you properly cite all of the sources you used in your research.
- Finally, state the purpose of the study, the hypothesis you tested in your study, and/or the question(s) you were trying to answer.

> The introduction should not include details about the procedures you used in your study. Save these for the Materials and Methods section. You should also leave out the results, which will go in the Results section.

5.1.4 Materials and Methods

Once you've hooked your reader with a good introduction, start getting into the details about how you performed your study or experiment.

This section should be written with enough detail that anyone would be able to follow your procedures and repeat your experiment. But make sure you don't include so much detail that it becomes overwhelming!

> The Materials and Methods section is often the easiest part of a lab report to write because the procedure is either written in your lab manual, or you took notes on your procedure as you performed the study. Just make sure you write it in paragraph form with complete sentences, rather than just a list of your methods.

> As with the other parts of the paper, this section should usually be written in past tense with no personal pronouns (I or we).

It's very important that in the Materials and Methods section you write only what you did, not what results you got. Save those for the next section.

5.1.5 Results

You've given an introduction to the topic you studied and you've told the reader how you did your study, so you can finally start talking about the results of all your hard work!

Use the Results section to summarise the findings of your study. The text of this section should focus on the major trends in the data you collected. The details can be summarised in tables and/or graphs that will accompany the text.

In this section, just tell the reader the facts. Don't try to interpret the data or talk about why they are important. Save your interpretations for the Discussion/Conclusion section.

5.1.6 Discussion and Conclusion

Once you've discussed the most important findings of your study in the Results section, you will use the Discussion section to interpret those findings and talk about why they are important (some instructors call this the Conclusion section). You might want to talk about how your results agree, or disagree, with the results from similar studies.

Here you can also mention areas ways you could have improved your study or further research to be done on the topic. Do not just restate your results, talk about why they are significant and important.

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