Power measurement in three-phase electric circuits

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As preparation try to answer the following questions:

- What is the difference between active, reactive and apparent power?
- How does an electromechanical power meter work?
- How is three-phase electric power generated?
- What are the differences between wye (star) and delta connections and their respective use cases?

1 Tasks

1. Power measurement of an ohmic load in alternating current circuit

   - Measure the active power consumed by a light bulb as a function of the applied voltage. Vary the voltage from 0 V to 230 V in steps of about 20 V and plot the results $P = f(U)$. Fit your measurement data using an appropriate model.

For the following tasks you should wait until the heating resistor and light bulbs reach a stationary temperature (one or two minutes).

2. Measurement of active power in three-phase circuits for balanced loads in wye and delta connection using the Aron circuit.

   - First build a delta connection using a symmetric ohmic load – two light bulbs in series per line – as depicted in Fig. 1. Determine the apparent power for each line by measuring the currents and voltages and compare this to the total power as measured by the Aron circuit.
   - Build a wye connection using symmetric load as depicted in Fig. 2 and again measure the consumed power.
   - What difference can be observed between wye and delta connection?
   - Modify the wye connection circuit to achieve an unbalanced load in each line (e.g. Line 1: 1 x 60 W, Line 2: 2 x 75 W, Line 3: 2 x 60 W + 1 x 75 W). Again measure the total power by calculating the power from the currents and voltages of the individual lines and using the Aron circuit. Conduct two separate measurement series:
     - In 'normal operation' mode using an ampere meter in the neutral wire (I_0)
     - After simulated breaking of the neutral wire by using a voltmeter (instead of the ampere meter) in the neutral wire (U_0)
   - What difference in the measured total power can be observed between these two measurements and how can it be explained?

- Construct two vector diagrams: The first one containing all currents for the experiment with the ampere meter in the neutral wire. Construct the resulting neutral wire current I_0. The second one for the voltages of the experiment with the voltmeter in the neutral wire. Construct the resulting voltage between the neutral node (star point) and the disconnected neutral wire (U_0).
- Compare the measured values for I_0 and U_0 to your results obtained from the graphical method.

3. Active and reactive power measurements for general loads in three-phase circuits

   - Build a circuit according to Fig. 3 and measure the active power consumed in each line.
   - Should there be multiple loads in series in a line, measure each voltage individually in order to determine the phase angle. For the same reason, measure the current through different loads in a parallel connection individually. Additionally measure the total current per line and through the neutral wire.
   - For each of the lines use the following loads (where '+' symbolizes serial connection and '||' symbolizes parallel connection):

Line	Load	Load bonus task
Z1	heating resistor	heating resistor
Z2	light bulb + capacitor	heating resistor + (capacitor || coil)
Z3	heating resistor + coil	heating resistor + capacitor

   - Switch the phases L2 and L3 and document changed values (What causes these changes?).
   - Modify your circuit according to Fig 4 in order to measure the reactive power. Keep in mind that inductive reactive powers have opposing sign to capacitive reactive powers. The voltage measurement might therefore have to flipped. **Warning: When measuring reactive power a larger voltage is applied to the power meters - the voltage range has to be adjusted accordingly.**
   - Construct a vector diagram containing all currents and voltages for both measurement series (normal + switch phases). You can either plot currents and voltages in separate diagrams or construct a combined diagram for each measurement series.
   - Calculate the total apparent, active, and reactive power from your measurements.

4. Simple asynchronous motor

   - Build a asynchronous motor using three coils in serial connection with a heating resistor in wye connection. The rotor is a simple metallic disc.
   - Discuss the principle of operation of an induction motor and the method of changing the direction of rotation.

5. Uncertainty analysis, Discussion of the results, Summary

2 Appendix: Circuit diagrams

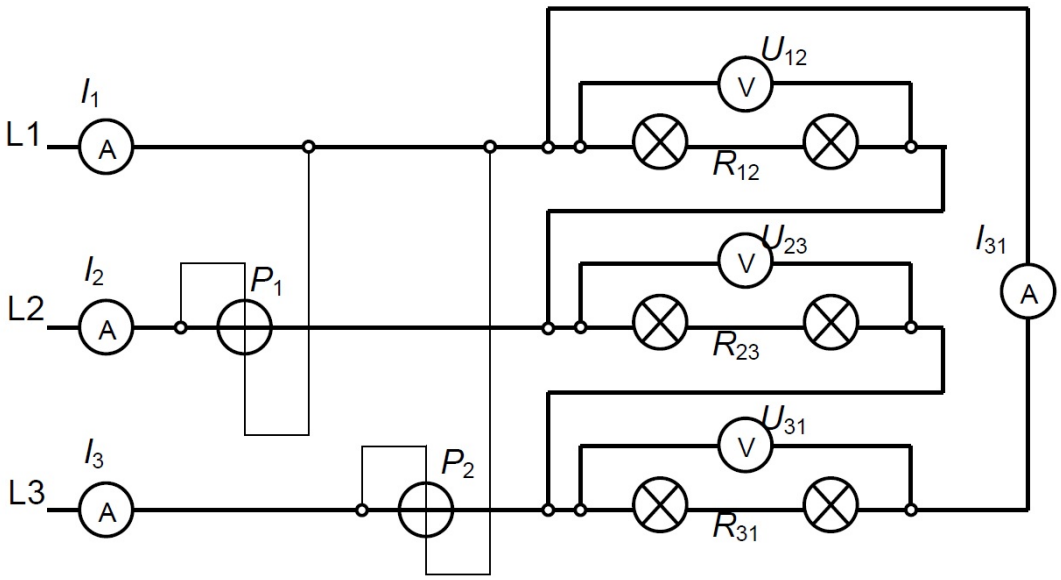

Figure 1: Measurement of the active power of a balanced delta configuration using the Aron circuit.

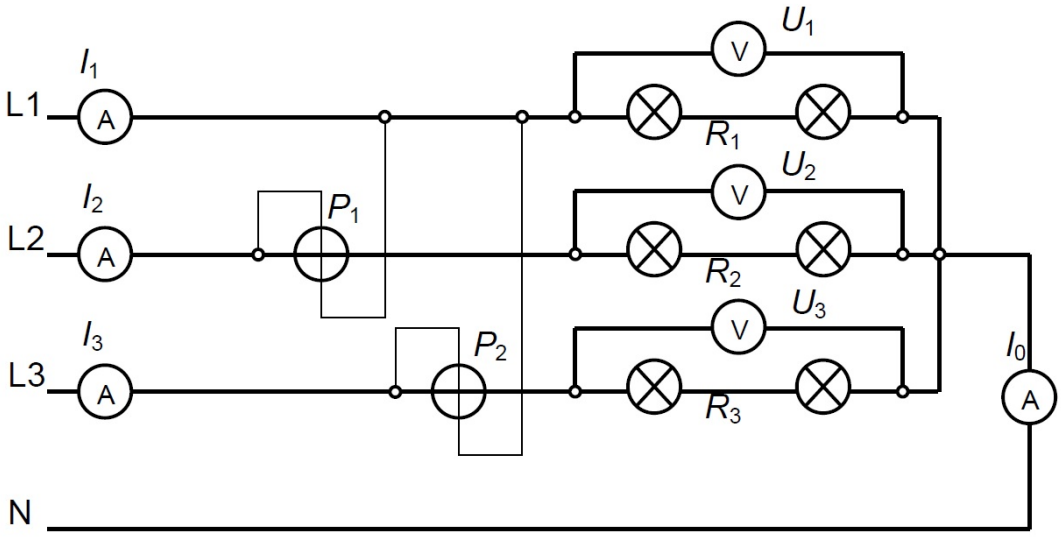

Figure 2: Measurement of the active power of a balanced wye (star) configuration using the Aron circuit.

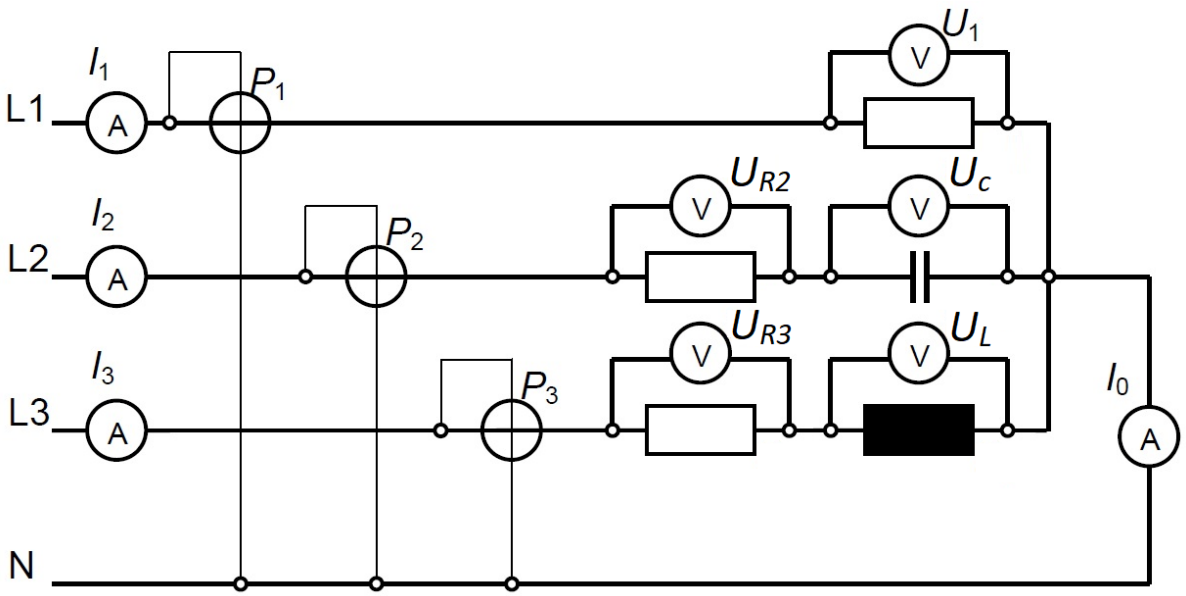

Figure 3: Measurement of the active power for general loads in wye configuration.

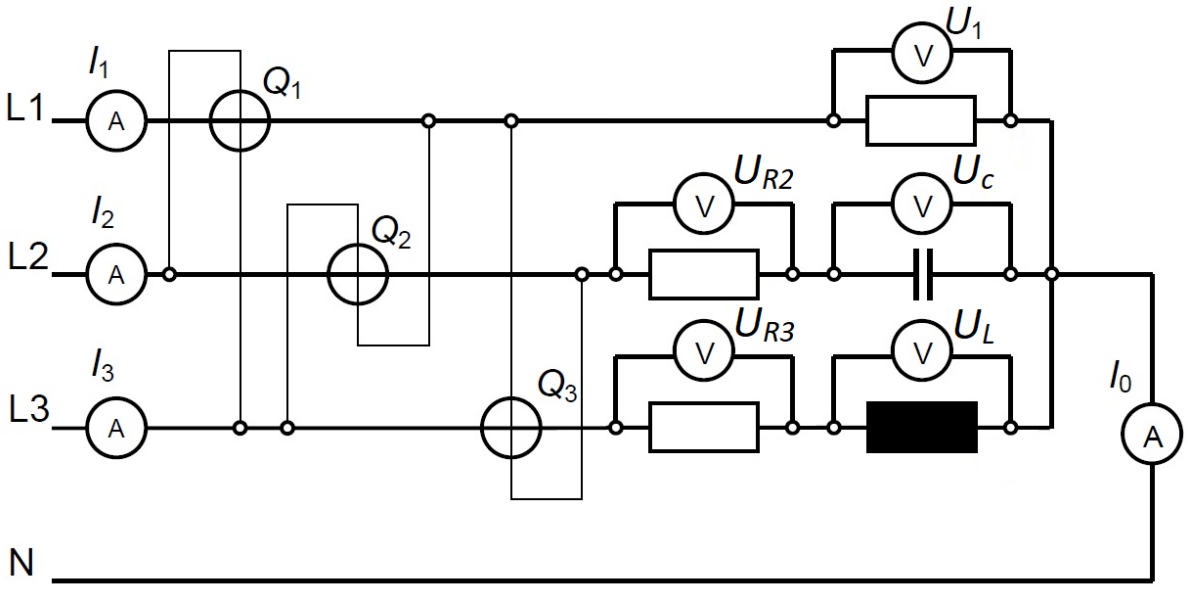

Figure 4: Measurement of the reactive power for general loads in wye configuration. The depicted configuration is designed for **inductive** loads. For capacitive loads the voltage measurement has to be reversed.