Power and Energy Measurements

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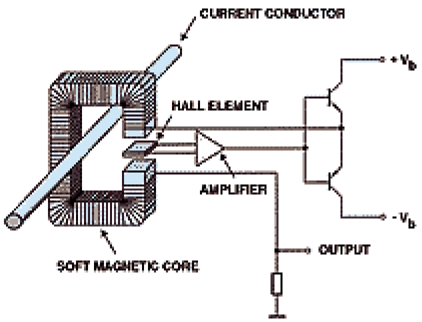
Contest

- Power measurements
  - DC circuits
  - AC circuits
    - Three-phase systems
    - High-frequency power measurements
- Energy measurements
  - DC circuits
  - AC circuits
- Example: Power and energy measurements in motor drives



Power in DC circuits

- Power

$$P = I_L V_L$$

- Can be carried out using a voltmeter and an ammeter (generally)
- Two measurement arrangements
- Wattmeter's:
  - Dynamometer
  - Digital wattmeter
  - Thermal wattmeter
  - Hall-power meter

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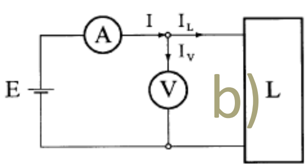
DC circuits

a) Ammeter measures current which flow into the voltmeter and load

b) Voltmeter measures voltage drop across the ammeter in addition to that dropping across the load



(a)

(b)

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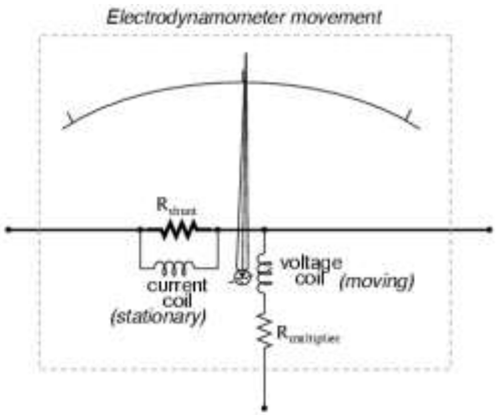
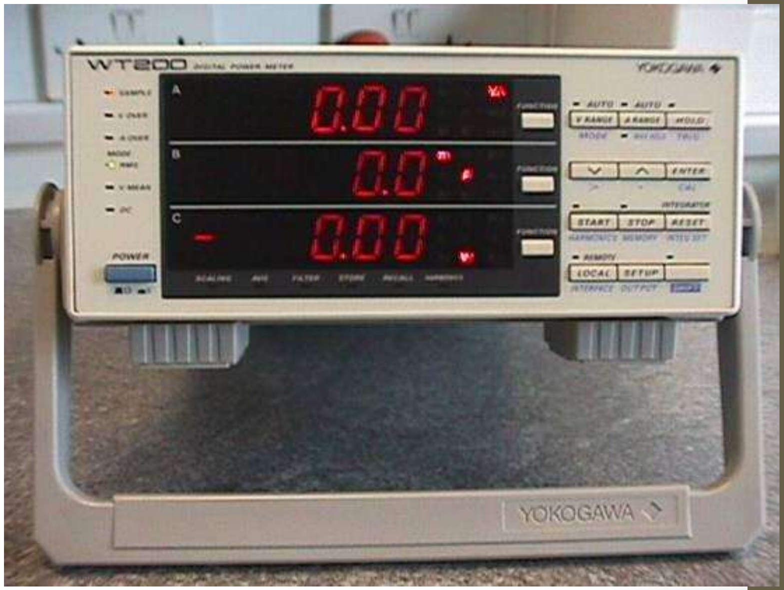
Dynamometer

- Power (direct) measurement device for DC and AC systems
- Accuracy better than 0,25 %
- Two coils: static and movable
- Torque is proportional product of current in current coil and current in voltage coil



Digital wattmeter (up to 100 kHz)

- Advantages:
  - High-resolution
  - Accuracy
- Several techniques (multiplication of signals)
- Electronic multiplier is an analog system which gives as its output a voltage proportional to the power indication required → A/D conversion



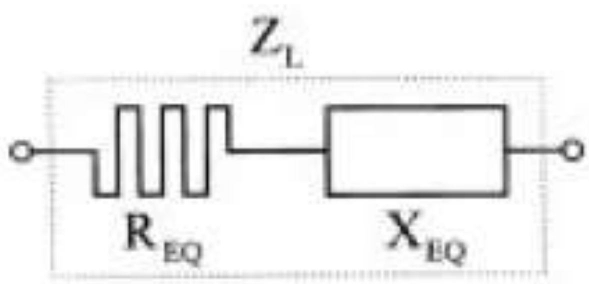
Power in AC circuits

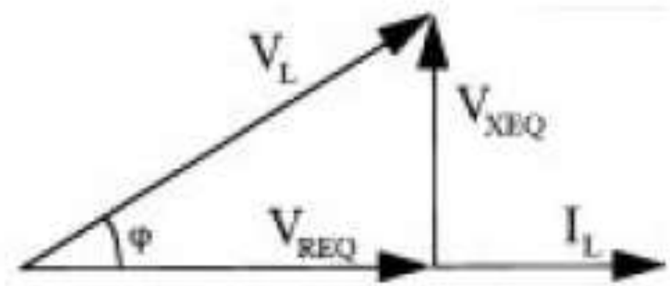
- Instantaneous power (time dependence)
- Mean power (usually the most interesting)
- Real power (active work), reactive power, apparent power
- Measures can be done same way as DC circuit (single-phase)

$$p(t) = v(t)i(t)$$

$$P = \frac{1}{T}\int_0^T p(t)dt$$

AC circuits



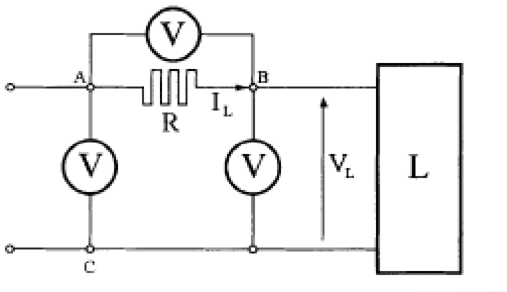


$$S = \sqrt{P^2 + Q^2}$$

Low- and Medium-Frequency Power Measurements

- Three-Voltmeter Method
  - Single-phase arrangements
  - Power in load can be measured using a non-inductive resistor and measuring the three voltage
  - Also in DC circuits

$$P_L = \frac{V_{AC}^2 - V_{AB}^2 - V_{BC}^2}{2R}$$



Line-Frequency Power Measurements

- Polyphase Power Measurements
  - Three-phase systems are most commonly used in industrial applications
  - Energy and power generation and distribution
  - “Real power for consumer”
  - Reactive power also important (loading)
  - Power can measured several ways
  - Power factor

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Line-Frequency Power Measurements (2)

- Four (main) different cases which affects to the measurement arrangements:
  1. Symmetrical load with neutral conductor
  2. Symmetrical load without neutral conductor
  3. Unsymmetrical load with neutral conductor
  4. Unsymmetrical load without neutral conductor

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Line-Frequency Power Measurements (3)

- Measurements can be done several ways (needed arrangements):
  - One-wattmeter arrangements
  - Two-wattmeter arrangements
  - Three-wattmeter arrangements

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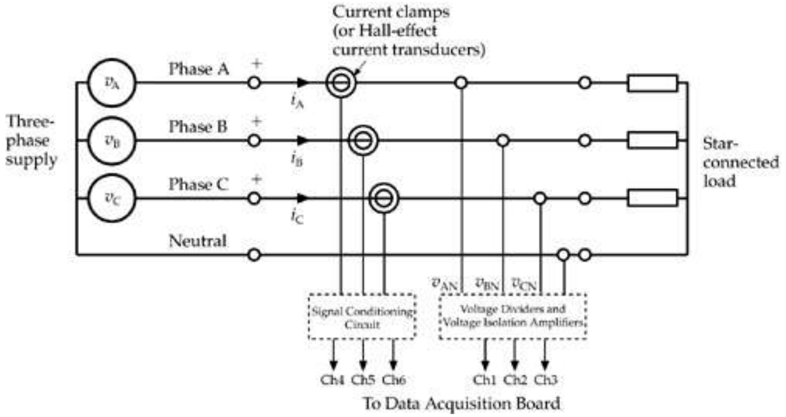
Symmetrical and Balanced systems

- The supply system is symmetrical and the three-phase load is balanced when phase currents and voltages are equal
- “Normal situation”

$$\begin{cases} V_1 = V_2 = V_3 \\ I_1 = I_2 = I_3 \end{cases}$$

Symmetrical load with neutral conductor



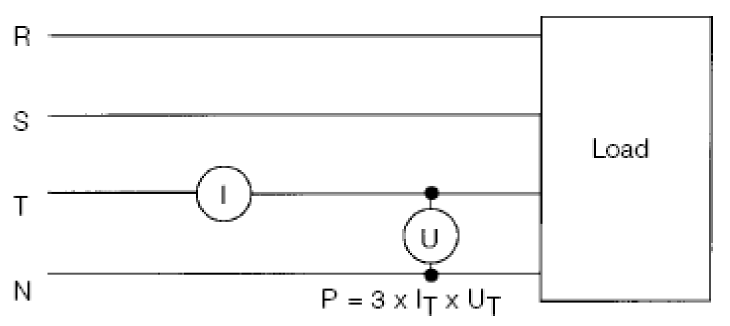
Symmetrical load with neutral conductor (2)

- Number of wattmeters (voltage/current meter) is (*n*-1) where *n* is number of conductors
- If *n=3,* only one wattmeter are needed
- Power factor can be measured for example with "power factor meter"
- Powers:

$$\begin{cases} S = V_1 I_1 + V_2 I_2 + V_3 I_3 \\ P = S\cos\delta \\ Q = S\sin\delta \end{cases}$$

Symmetrical load with neutral conductor (3)

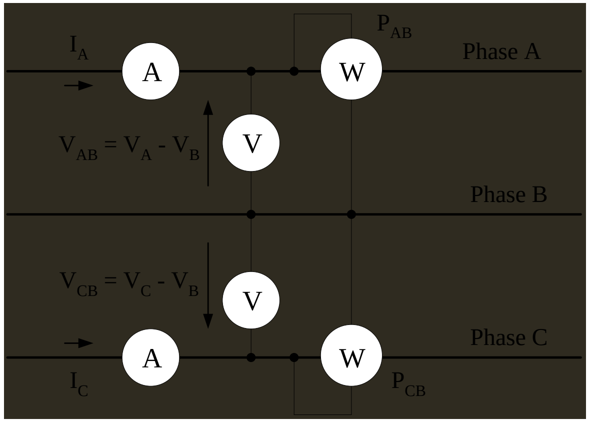
- One wattmeter arrangements for real and reactive power measurements



$$P = 3U_T I_T \cos\delta$$

Symmetrical load without neutral conductor

- Active and reactive power can be measured with two power meter (in three-wire system), case of symmetrical load and without neutral conductor (motors), Aron's theorem
- Possible to use also in case of unsymmetrical load
- If power factor is <0,5 then three wattmeter arrangement



$$P = P_{AB} + P_{CD}$$

$$Q = \sqrt{3} * \left(P_{AB} + P_{CD}\right)$$

Symmetrical Power Systems Supplying Unbalanced Loads

- Current amplitudes are different, and their relative phase is not equal 120°
- Usually it is caused by some fault (short circuit)
- Three- or two wattmeter arrangements (depends on neutral point)

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Symmetrical Power Systems Supplying Unbalanced Loads

- Four possible arrangements:
  - Three-wattmeter arrangement
  - Two-wattmeter arrangement
  - Barbagelata arrangement
  - Righi arrangement

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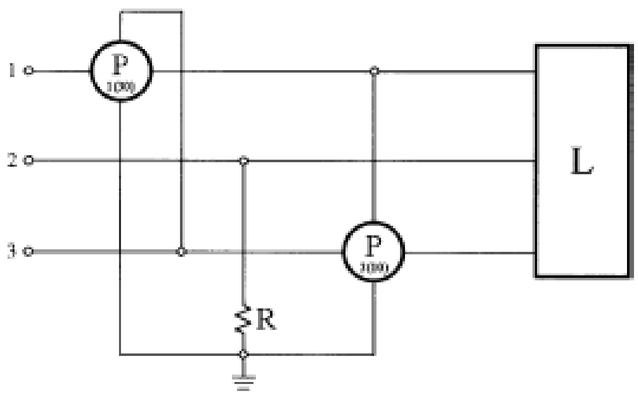
Two-wattmeter arrangements

- Measurements arrangements for reactive power measurements

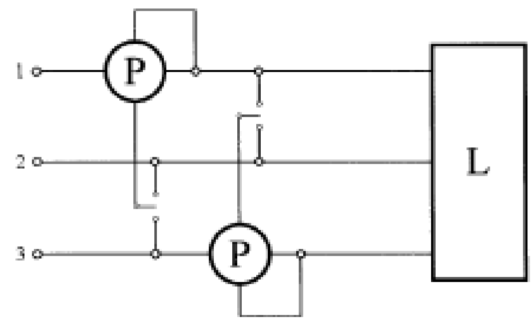


$$Q = \sqrt{3}\left[-P_{1(30)} + P_{3(10)}\right]$$

- where $P_{1(30)} = P_{10} - P_{13}$

Barbagelata arrangements

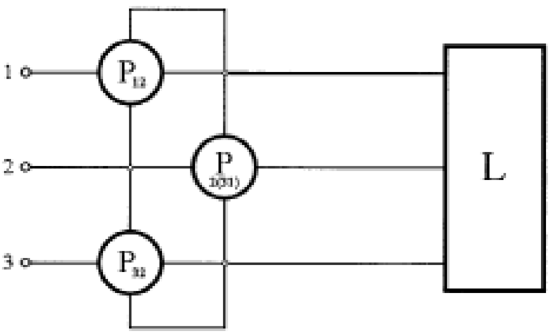
- Measurement arrangements for active and reactive power measurements
- “Two-wattmeter method”



$$\begin{cases} P = P_{12} + P_{32} \\ Q = \dfrac{1}{\sqrt{3}}\left[2\left(P_{13} - P_{31}\right) + P_{32} - P_{12}\right] \end{cases}$$

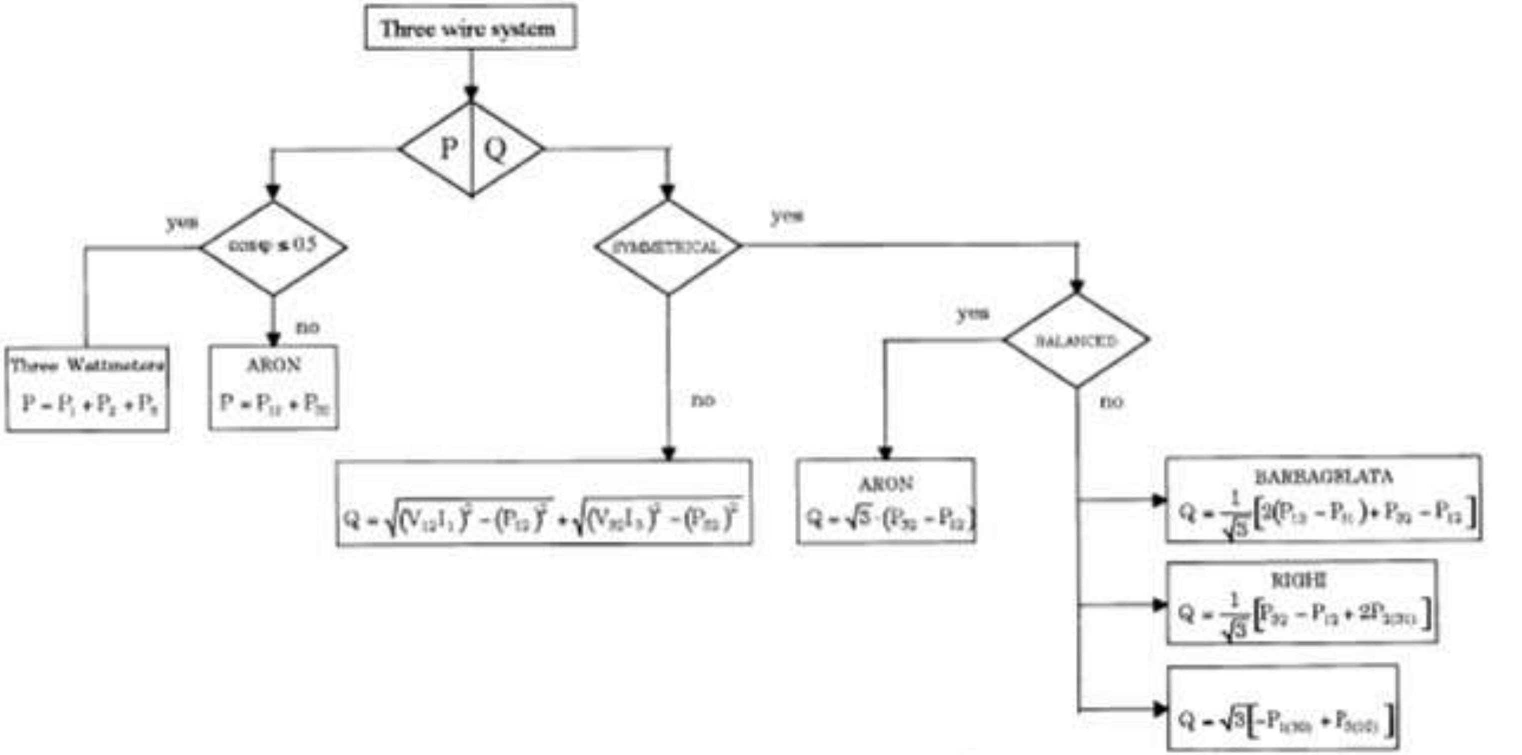
Righi arrangements

- Measurement arrangements for reactive power measurements



$$Q = \frac{1}{\sqrt{3}}\left[P_{32} - P_{12} + 2P_{2(31)}\right]$$

Conclusion about Three-Wire Systems



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High-frequency power measurements

- Radio (< 300 MHz) or microwave (> 1 GHz) frequencies
- Measurement devices are classified by absorption type and transmitted or throughline type
- Based on thermistors, thermocouples, diodes or radiation sensors
- Should be calibrated very carefully

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Energy measurements

- Simplest way is to measure current, voltage and observation interval and compute the product:

$$E = VI\Delta t = \int_{t_2}^{t_1} p(t)dt$$

- Observation interval measures by a chronometer or a time counter
- Electricity/energy meters:
  - Electrodynamic measurement device
  - Induction meter (AC)
  - Digital energy meter (AC/DC)
- Two main parts:
  - Transducer (Converts power to mechanical or electrical signal)
  - Counter (Integrates the "energy")

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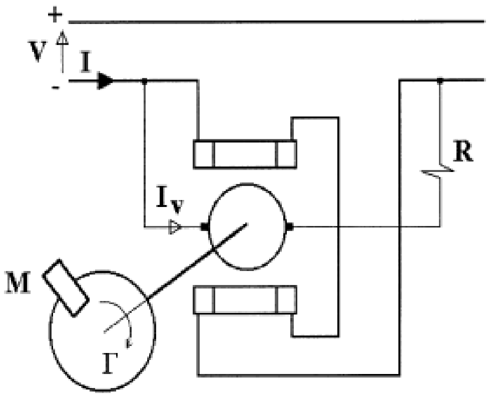
DC Energy Measurements

- Electrodynamic measurement device (integrating wattmeter)
- Based on DC motor (no iron)
- Magnetic field is generating by line current
- Torque

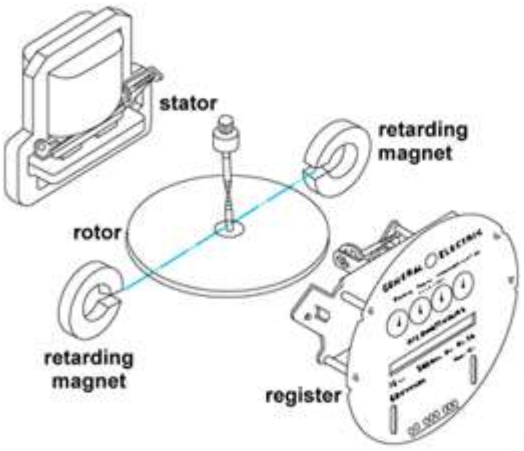
$$C_m = \frac{kIV}{R} = k_2 I_V \phi$$

- Aluminum disk and permanent magnet gives linear dependence of Γ and power
- Mechanical counter transfers the rotating motion into a digital or mechanical display



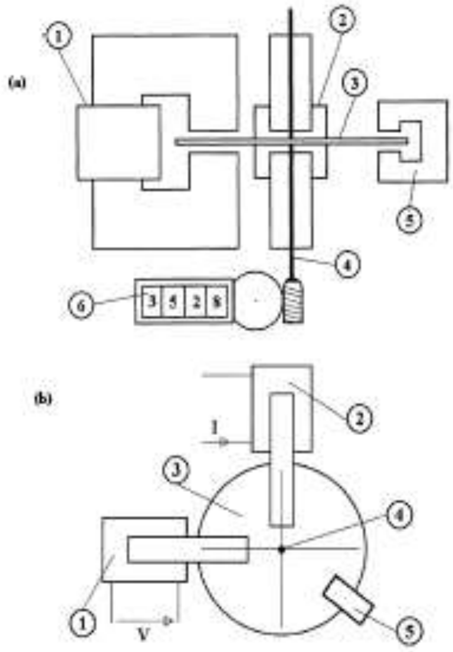
AC Energy Measurements

- Induction energy meter (every household)
- Accuracy about 2 %
- Current and voltage coil
- AC current (coil) → Eddy currents (disk) → Force to disk
- Variable powers cause variable rotating speed
- Day and night electricity



AC Energy measurements

1. Current coil and magnetic circuit
2. Voltage coil and magnetic circuit
3. Rotating disk
4. Disk axis
5. Permanent magnet
6. Display



Energy measurements

- Automatic remote reading in future
  - Pricing
  - Controlling generation/loads
- Several system under development (GSM, radio link, phone line…)
- Energy meters also in var (reactive power) hours and volt-ampere (apparent power) hours

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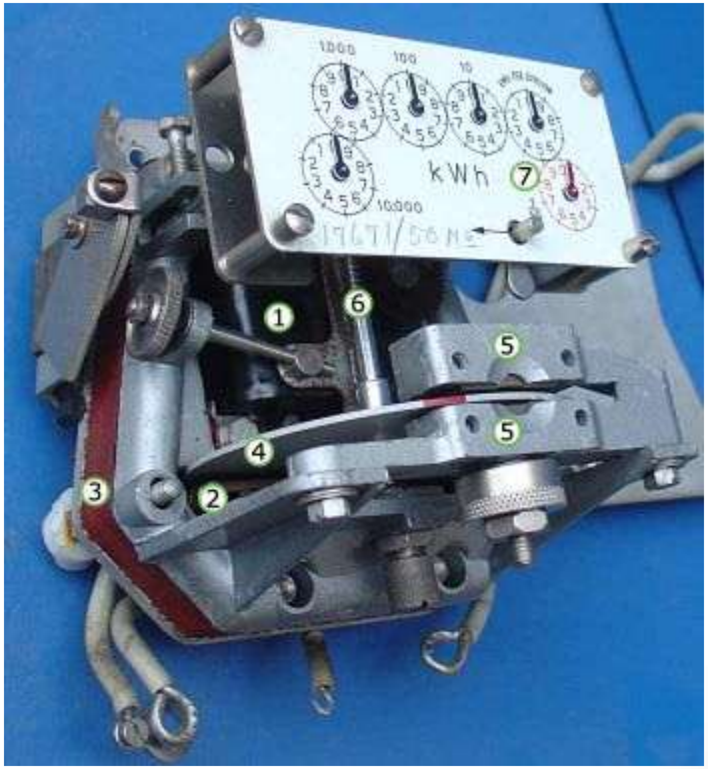
The End



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