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Basic properties of energy in power grid

- Voltage - AC/DC
- Typical household voltage
- Types of power in the electricity grid
- Electricity grid and power loss
- Measurements of power in modern meters
- Power quality

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AC or DC voltage?

- AC voltage is used in general
- Advantages over DC:
  - Cheaper generation
  - Simple AC machines, simple voltage change (using transformer)
  - More efficient transmission (smaller losses)
- Disadvantages
  - Safety (better insulation against peak values needed, attracts a person who touches it, unlike D.C. which gives a repelling shock)
  - Storage in batteries

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Typical household voltage

- In EU is the AC voltage for the households specified by EN 60038:2011 as 230/400V ±10%.
  - 230V = RMS voltage between a phase and the neutral connector
  - 400V = RMS voltage between two phases

- Note: RMS = root-mean-square (also called effective value) is the amount of AC power that produces the same heating effect as DC Power.

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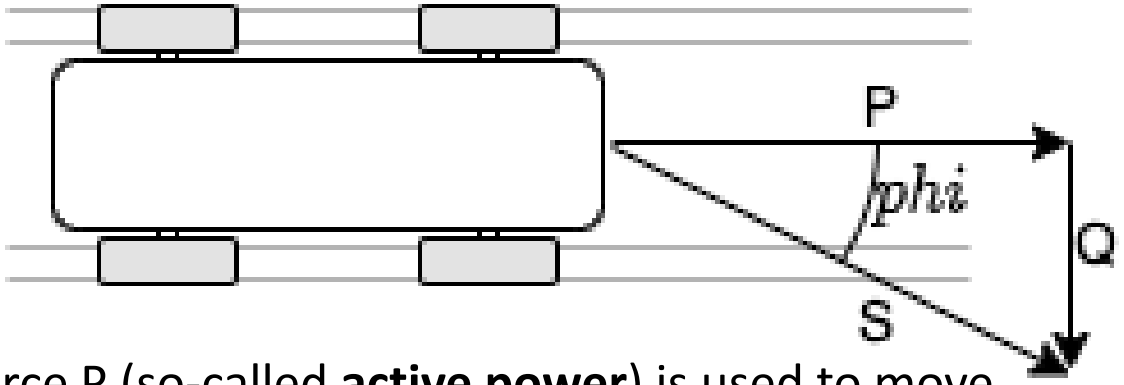
Types of power in the electricity grid

- Very simple example - based on horses and wagon



- The whole effort of the horse represented by the force P (so-called **active power**) is used to move the wagon.
- However, if the horse goes perpendicular to the rails, the car must overcome friction when moving (our **reactive power** Q) – this power cannot be used to move the wagon
- So the horse must use more force, the so-called **apparent power** S, that is present in this system
- The **cosine of the angle between the forces**, in our case the powers, **is the power factor**.
- In electricity power distribution, if the power factor is equal to 1, only the active component is transmitted, the apparent power is equal to the active and the operation of the device is the most economical (minimal voltage drops and power losses). However, this condition is ideal, in real life there is always at least minimal consumption of reactive energy.

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Electricity grid and power loss

- The major problem is the **reactive power flow**, which transmits no real power to the load.
- The corresponding reactive currents, are real and cause extra **heating losses** in the transmission circuit.
- The reactive power can be viewed as it flows **“back”to grid**, it is not consumed, but needs to be transported
- Households are charged based on their active power consumption, they are not charger for their reactive energy flows.
- Charges for corresponding losses are distributed among all households.
- Situation is different for small companies, where precise metering including power factor is performed. Here the bad power factor is usually already financially penalized.

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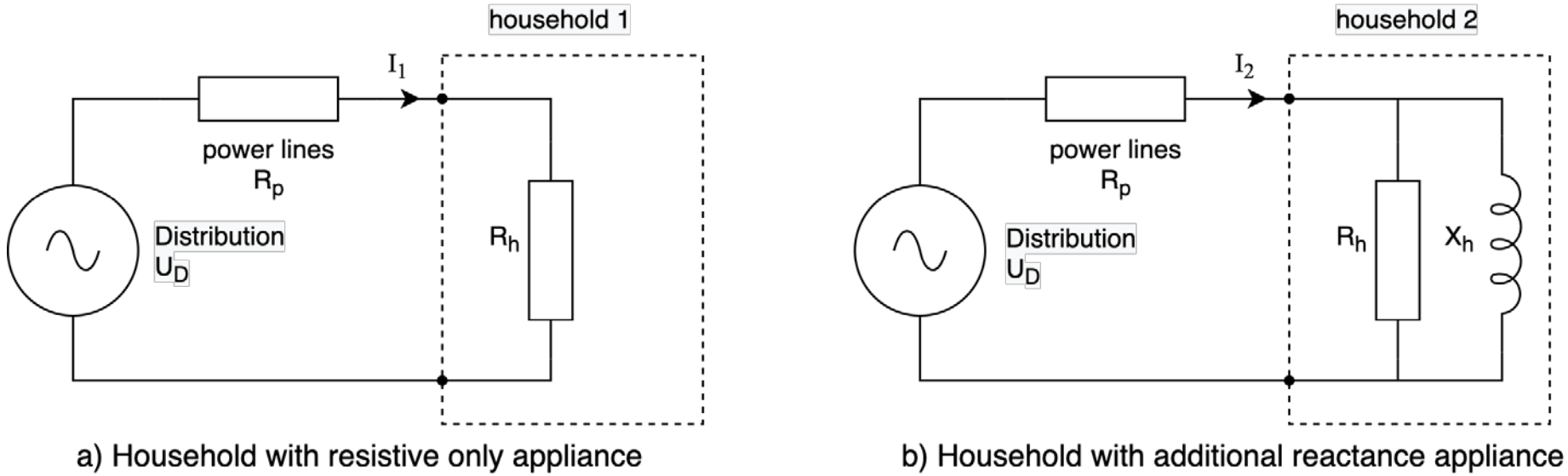
Electricity grid and power loss – schematic example

- Simple schematic example using resistances and added reactance



a) Household with resistive only appliance

b) Household with additional reactance appliance

- For alternating electric current, the RMS (Root Mean Square) values are equal to the value of the constant direct current that would produce the same power dissipation in a resistive load.
- Lets denote as the RMS values as U, I, the Impedance as Z, reactance as X, resistance as R. Then:
  - $I_1 = \frac{U_d}{Z_1} \quad ; Z_1 = R_p + R_h$
  - $I_2 = \frac{U_d}{Z_2} \quad ; Z_2 = R_p + \frac{R_h X_h}{\sqrt{R_h^2 + X_h^2}}$
  - as $\frac{X_h}{\sqrt{R_h^2 + X_h^2}} \leq 1$ then $Z_2 \leq Z_1$ and $I_2 \geq I_1$
  - **Bigger power loss in case b, because** $I_2^2 R_p \geq I_1^2 R_p$

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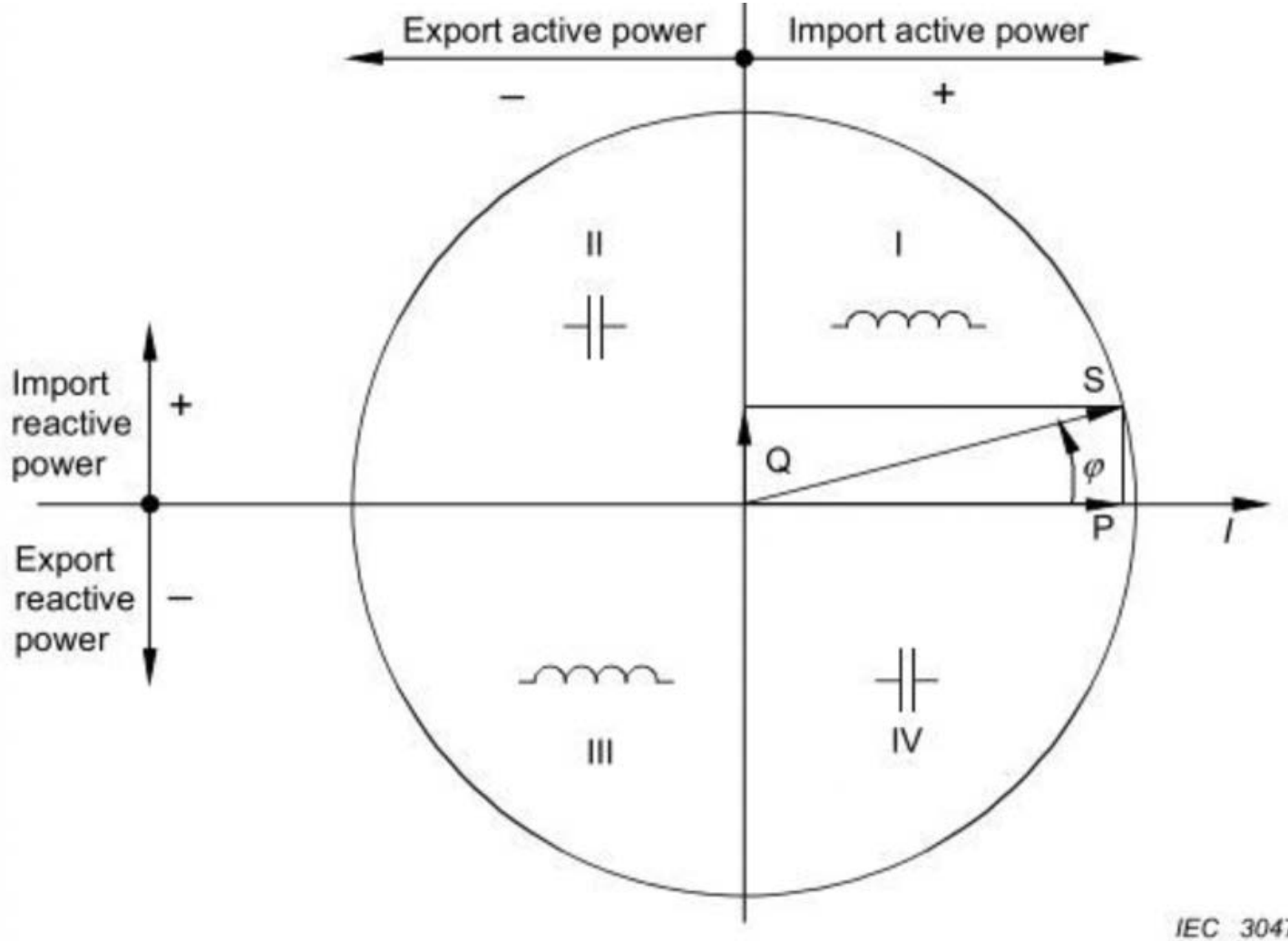
Measurements of power in modern meters

- Common split up among 4 quadrants, based on P and Q measurements
- Based on precise U and I waveform measurements on load



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Power quality

- **As the load varies in time**, environment changes, there is lot of transient effect, properties of the attached electrical equipment are not optimal, there can be **impact to other devices and customers** attached to the grid.
- The term power quality is the degree to which properties of the voltage, as frequency, waveform, harmonics, instability, imbalance in the power grid **conforms to prescribed parameters.**
- Operation of devices under bad power quality condition could cause e.g. **malfunction, prematurely failure, limited or even no operation**.
- Sometimes is power quality described from the **viewpoint of the electrical equipment** as its ability to consume the energy being supplied to it. Here comes explicitly the power factor as important parameter.
- The European standard for power quality, setting the acceptable limits of distortion for the different parameters defining voltage in AC power is EN50160.