Smart Energy and Smart Grids

Radoslav Vargic, Juraj Londák

1 Explanation of active, reactive, apparent power, principle of power loss, power quality

In the following text we would like to explain in more detail which kind of power are present in the electric power grid and how it relates to energy loss in power grid.

Let's use a simple example on Fig. 1 to show what is **reactive power**. If the horse pulls the wagon in the direction of the rails, the wagon will go easily and with minimal friction. 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 pulls perpendicular to the rails, the wagon must overcome friction when moving (our **reactive power Q**) and the horse must use more force, the so-called **apparent power S**, to get the wagon to the same place as in the first case. The cosine of the angle between the forces, in our case the powers, is the **power factor of the phi**.

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).

In real life, there is always at least minimal consumption of reactive energy (ideal power factor 1 is never reached).

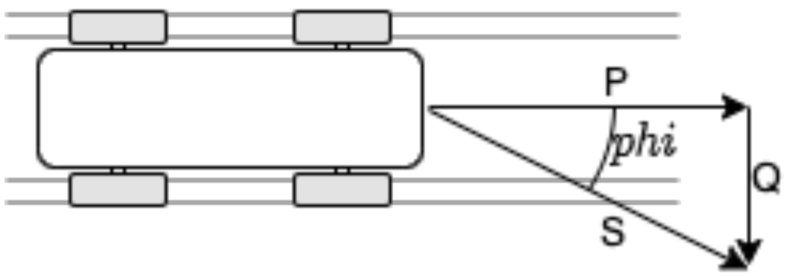

Fig. 1 Schematic explanation of active and reactive energy

The major problem is the reactive power flow, which transmits no real power to the load. But the corresponding reactive currents are real and cause extra **heating losses** in the transmission circuit.

Let's take a simple example Fig.2. Here, the extra reactance causes additional, phase shifted current, which is not consumed by the household, but when traversing the power lines (for the sake of simplicity depicted as real resistor) it causes the additional power loss. Since both households consume the same active power, they pay the same price per kWh.

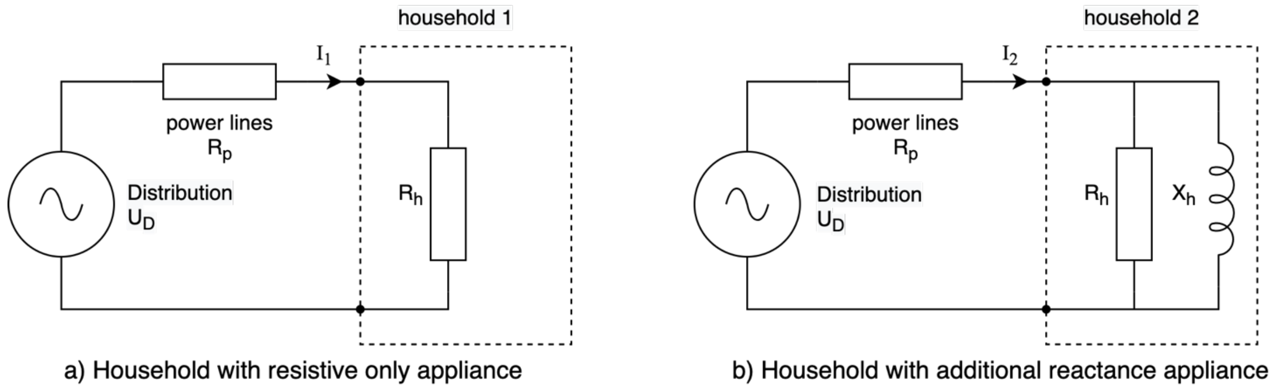

Fig. 2 Schematic comparison of power flows for households without and with additional reactance, it holds $I_2 > I_1$

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.

When:

$$I_1 = \frac{U_d}{Z_1}; Z_1 = R_p + R_h$$

$$I_2 = \frac{U_d}{Z_2}; Z_2 = R_p + \frac{R_h X_h}{\sqrt{R_h^2 + X_h^2}}$$

Than we can say, as $\frac{X_h}{\sqrt{R_h^2+X_h^2}} \leq 1$ then $Z_2 \leq Z_1$ and $I_2 \geq I_1$

It leads to **Bigger power loss in case b, because** $I_2^2 R_p \geq I_1^2 R_p$

The distribution company usually adjusts his prices (tariffs) also to cover electricity losses in its network. So payments for losses are distributed among all households, not just those who primarily cause them. But the situation is different for small companies, where precise metering including power factor is performed. Here the bad power factor is usually already financially penalized.

Note, in EU is the AC voltage for the households specified by **EN 60038:2011** as **230/400V ±10%**.

First is the root-mean-square (*RMS*) voltage between a phase and the neutral connector, the second is the RMS voltage between two phases (the household connection to the power grid has typically 3 phases). The phases are denoted L1, L2, L3 and are mutually phase shifted by 120°. For alternating electric current, RMS value is equal to the value of the constant direct current that would produce the same power dissipation in a resistive load.

When the measurements are done by modern meters, there is common split up among four quadrants (I, II, III, IV) as it is illustrated at Fig. 3. That classifies which type of reactance (capacitive, inductive) is prevailing and which direction the power is flowing (import = consumption = positive active power = A+, export = production = negative active power = A-).

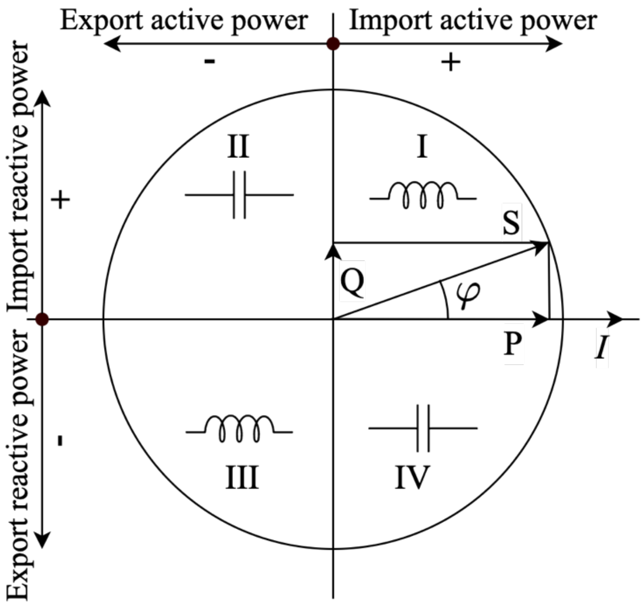

Fig. 3 The quadrant definition for active and reactive power according to IEC 62053-23

2 Power quality

Power quality can be described from multiple views. One of the basic description goes asAs 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.

Based on this description theThe 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.