# The Power Grid in a Nutshell

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## 1 Real, Reactive, and Apparent Power

Power generation mostly relies on electromagnetic induction; the constant changing of a magnetic field creates a current in a conductor. Large-scale power generation utilizes mechanical motion in order to provide a magnetic field changing in a constant and reliable manner. The rotating magnetic core, called rotor, induces current in the stator, a fixed wire. The stator ultimately interfaces with the power transmission system and the lines that lead from the power plant. Since it is the rotation of the magnetic core that induces the current in the field poles, the current alternates with the rotation. The frequency for the grid is fixed—e.g., 50 Hz in continental Europe—, and deviating from it causes damage to the grid and connected components.

In alternating current, there are actually three types of power. **Real Power** is the "visible force" that makes a motor run.

$$P = U \cdot I \cdot \cos\phi \tag{1}$$

Every conductor that carries power maintains an electric field. With alternating currents, these fields are created and inverted 50 times a second, which requires its own power. This power does not do actual, visible work, such as driving a motor; it "works" only to maintain the EM field.

$$Q = U \cdot I \cdot \sin\phi \tag{2}$$

Real and reactive power are shifted by the phase angle, denoted by $\phi$. Coils and conductors change this angle. Real and reactive power combined give the **apparent power**:

$$S = U \cdot I = \sqrt{P^2 + Q^2} \ . \tag{3}$$


## 2 Power Flow

A power flow study calculates how real and reactive power flow. For this grid, we consider each node—or, better, bus—as being one of three types:

- Generators supply real power and voltage; they are called **PV buses**.
- Load buses consume real and reactive power; they are called a **PQ buses**.
- At a special bus, called the *slack bus*, the voltage and phase angle are known; it is therefore the **VD bus**.

Power flow study is based on *Kirchhoff's Law*, stating that the sum of all currents at a node must be 0. The flow of current is defined by the voltage difference between $i$ and its $k$-th neighbor as well as the admittance of the grid elements between the two nodes.

$$\underline{I}_i = \sum_{k=1}^{n} \underline{I}_{ik} = \sum_{k=1}^{n} (\underline{V}_i - \underline{V}_k)\underline{Y}_{ik} \ . \tag{4}$$

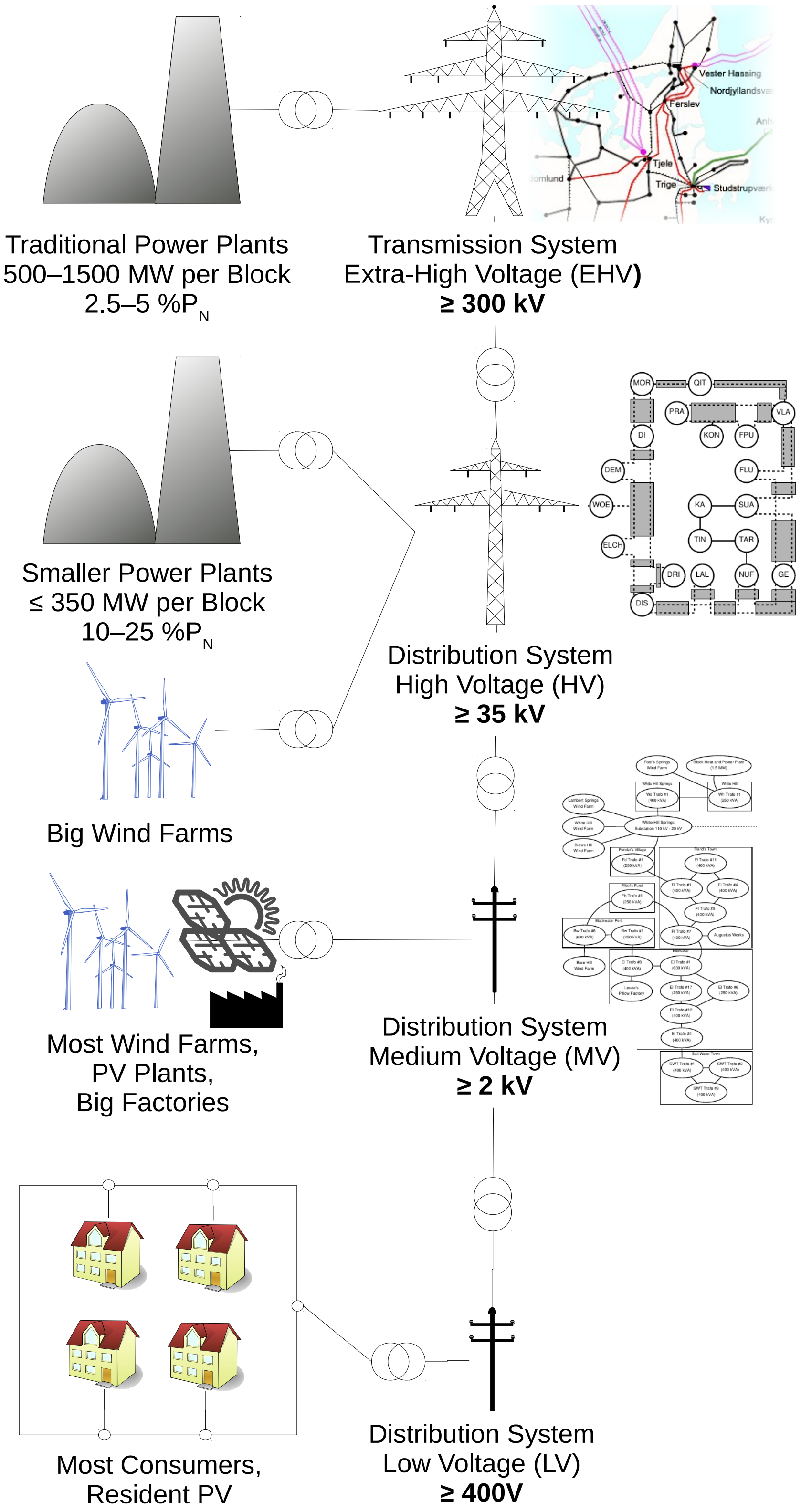
By reformulating the equations we can write them in matrix form,

$$\mathbf{I} = \mathbf{Y} \cdot \mathbf{V} \ . \tag{5}$$

This constitutes a system of non-linear functions. For solving this, especially in the case of power flow study, the Newton-Raphson method is often used. It works by stepwise refining of an approximation, expressed by:

$$\mathbf{x}_{t+1} = \mathbf{x}_t \mathbf{J}_t^{-1}[\mathbf{y} - f(\mathbf{x}_i)] \ . \tag{6}$$

## 3 Power Grid




## References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