Transmission from North Africa to Europe of Solar

Context

Summary

The present energy supply is mainly based of fossil energy sources. Because of decreasing resources, a worldwide increasing energy demand and the resulting growth of the environmental pollution, it’s necessary to tap other sources in the long term. In this context it is pointed to the large potential of solar energy in North Africa, which theoretically meets the world’s energy demand many times. On-site solar electricity can be produced by solar thermal power plants and then be transmitted via high voltage direct current transmission (HVDC) over long distances to Europe.

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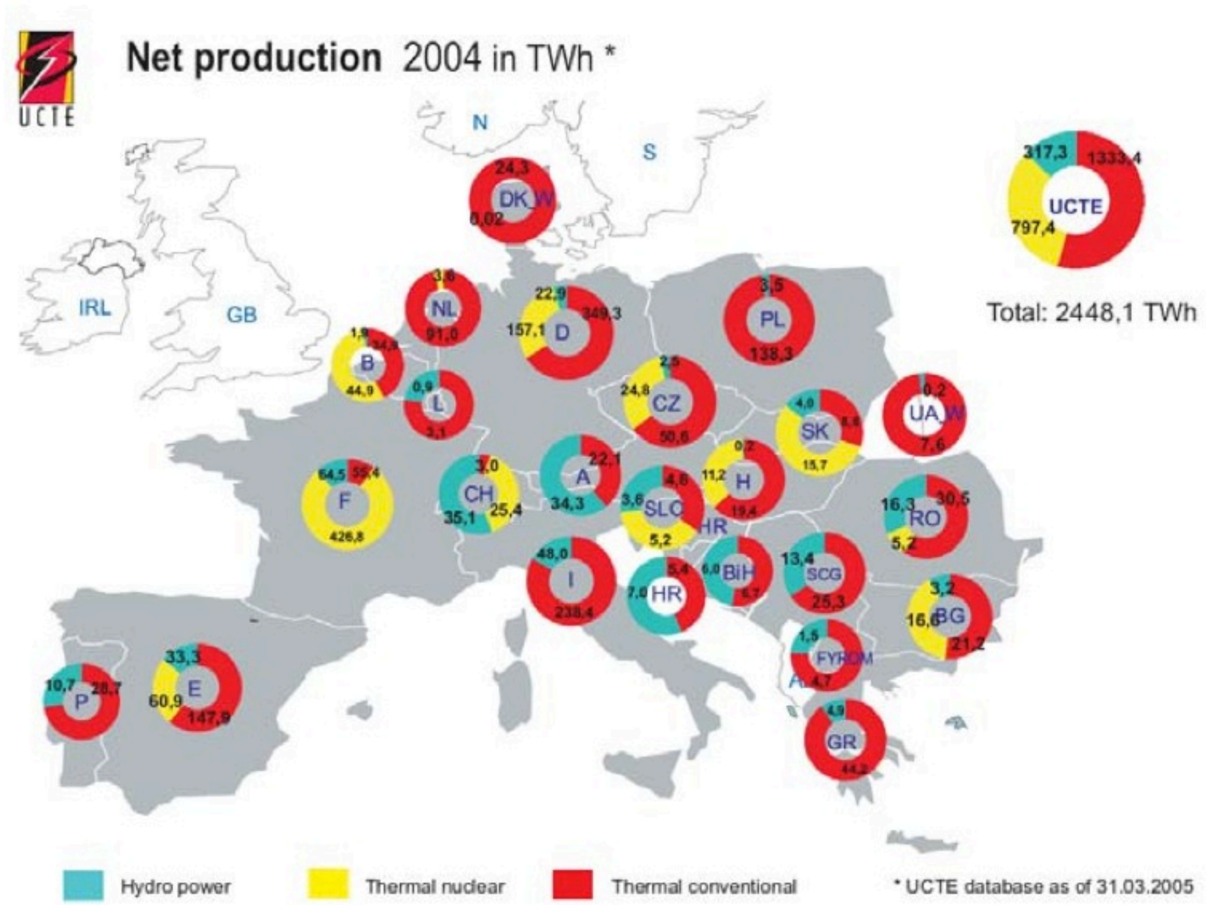
Present electricity supply

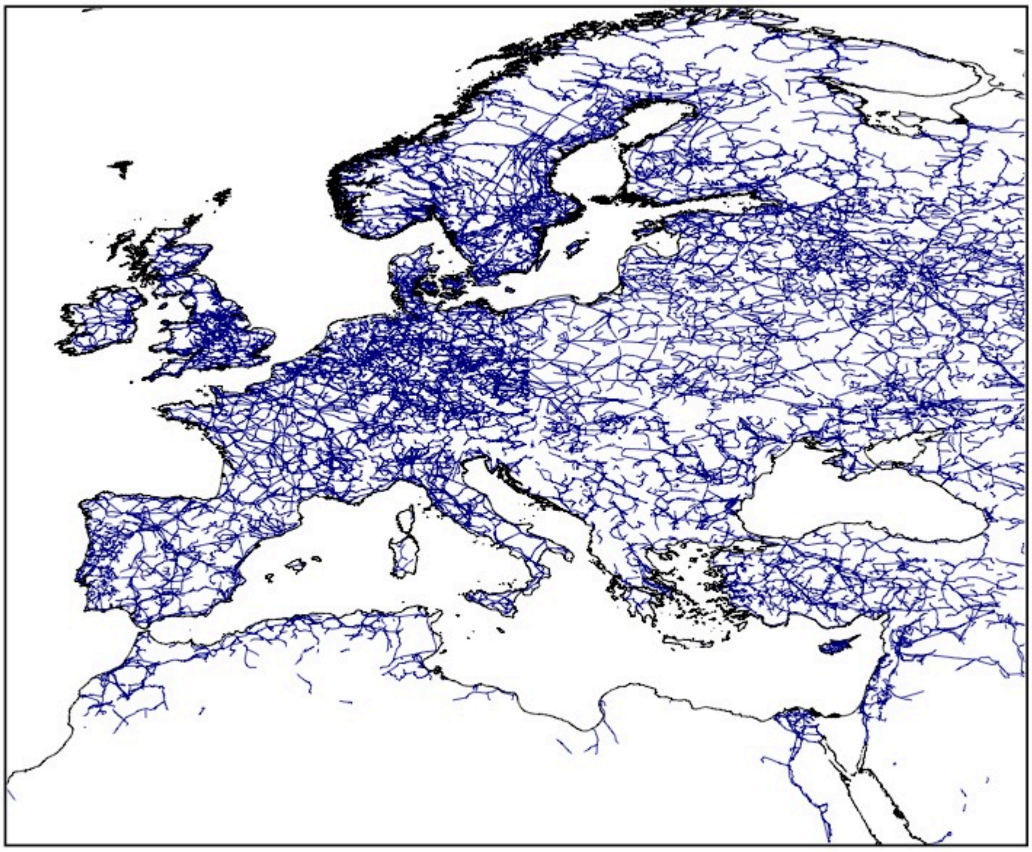
In the long term the present energy system is not able to guarantee a reliable energy supply for all nations of the world. The constant growth of population and the technological development cause a worldwide increase in the energy demand, until 2050 about 33 % compared to 2000.



Electricity mix 2004 within the UCTE (Source: UCTE, 2005b)

Alternatives must be found which guarantee a sure energy supply and preserve the climate and the environment. Besides, this energy must be provided free of risks and with low costs in order to avoid military conflicts on energy resources and an additional, environmental pollution. Renewable energies meet all these requirements of a sustainable energy supply today and in the future.

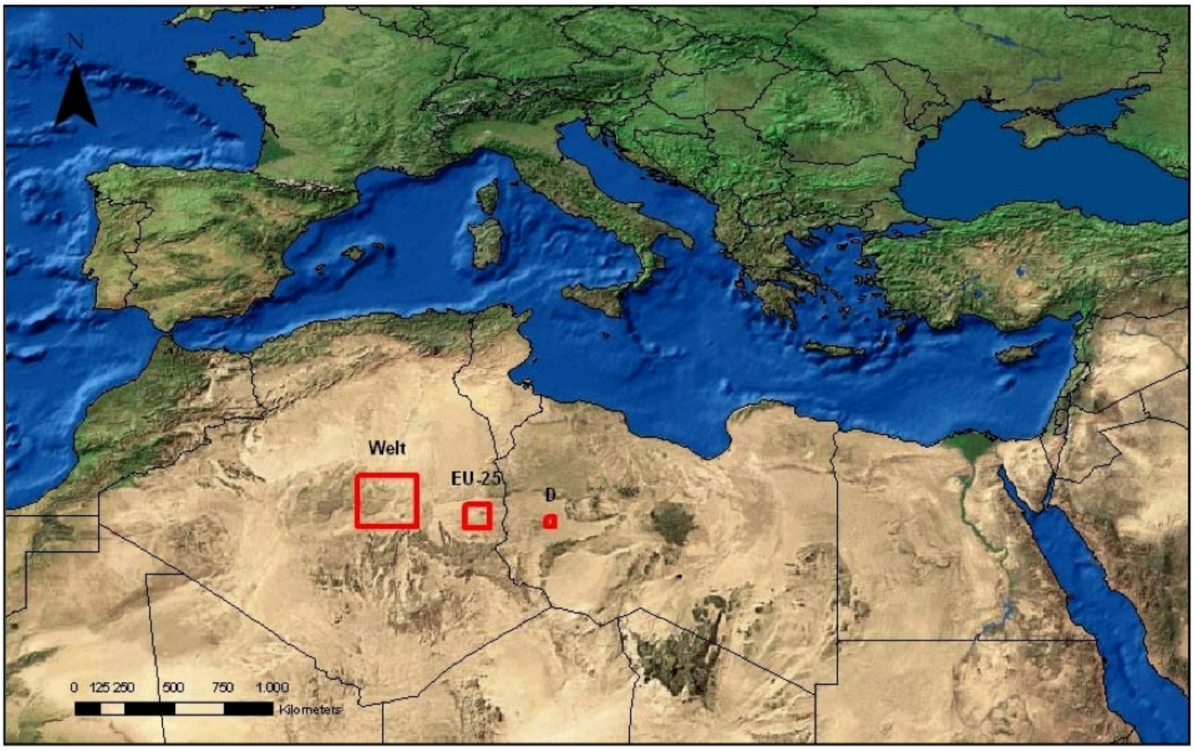
The European electricity supply network is very complex and operates on different voltage levels;



European and North African energy supply system

Utilization of renewable energy sources

The potential of renewable energy resources is unlimited, but there can be differences in spatial distribution and temporal deviations. The area around the tropic in North Africa belongs to the regions with the highest solar radiation intensity of the world and is therefore populated sparsely. A fast expansion of renewable energies should take account of foreign resources as well as state- owned resources. Especially the North African potential of solar radiation is far beyond the on-site demand so that a transcontinental export of solar electricity could be a source of revenue in the long term for these regions. On the other hand the import of solar electricity could benefit the European countries to fulfill their commitment for the reduction of carbon emissions.



Theoretical space requirement to meet the electricity demand of the world, Europe (EU-25) and Germany (Data from DLR, 2005)

Energy supply networks:

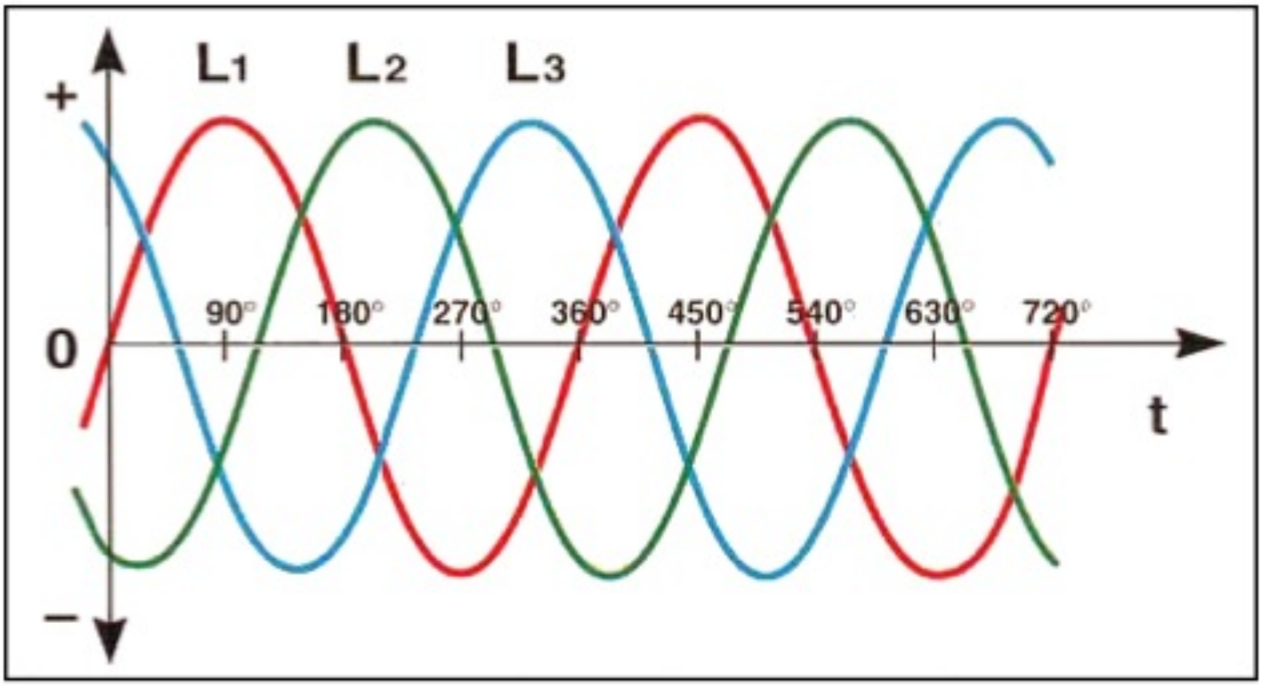
An energy supply network consists of different elements. At the beginning a turbine in a power plant is driven by exploiting a certain energy source. This turbine drives a generator. There, the mechanical energy is transformed into electric energy by the process of electro-magnetic induction. The alternating current produced this way is also called inductive current. Voltages up to 30 kV can usually be produced by the plant itself.

After that the voltage of alternating current can be increased by transformers for the purpose of transmitting electric energy over long distances. The voltage level is fixed in dependence on the power and the transport distance in order to transmit the current efficiently and with the lowest losses.

Basics of the transmission of electricity

Alternating Current:

In the European high voltage area electric energy is mainly transmitted in the form of three-phase alternating current, whose direction and amount changes with a sinusoidal periodicity. The frequency of the European electricity supply



Three-phase alternating current

Alternating current is produced in a power plant by a generator, whose electrical magnet is driven mechanically and passes three 120°-shifted coils during one rotation. Accordingly, the induced alternating currents are also 120°-phase-shifted. Each current is forwarded by the respective conductor. Because with symmetrical load the sum of the three currents amounts to zero at every moment, there is no need to have a return wire like single-phase alternating current.

The decisive advantage of three-phase alternating current is the simple regulation of voltage and frequency. The voltage can be stepped up and stepped down with few losses by a transformer and everywhere it is possible to branch off electrical power with the same. In addition, engines driven by alternating current can be produced small, compact and cheap. One disadvantage is that the synchronicity of producer and consumer voltage is absolutely necessary. Otherwise, unwanted swings could lead to serious problems with the network stability. The failure of one conductor means the total failure of the circuit.

Losses of alternating current

The current-carrying conductor produces a magnetic field around itself. If it concerns alternating current, this magnetic field changes periodically and induces a voltage again. Thus the power line behaves like a coil and puts up resistance to the alternating current through self-induction, what in turn causes a decrease in current. In this connection it is spoken of the inductive reactance *L* when the voltage runs in front of the current at a maximum phase angle of 90°.

In the opposite case alternating current is intensified let through because of the capacitive reactance *C* so that the voltage runs after the current. The problem of charge storage especially occurs with cables, which behave like a condenser due to their multi-layered structure.

These resistances cause no heat losses in contrast to the ohmic resistance *R,* but there is a not utilizable reactive power which swings permanently between generator and power source and reduces this way the effective power. The equation represents the correlation between the several resistances once more.

$$z = \sqrt{R^2 + (L \cdot \omega - \frac{1}{\omega \cdot C})^2} \quad \textit{(Equation 1)}$$

Z : impedance (Ohm)
R: effective resistance (Ohm)
L: coefficient of self inductance (Henry)
C: capacity (Faraday)
ω: angular frequency of alternating current (= 2 π f)

f : frequency (Hertz)

The maximum transferable load and transmission length are more limited by the fall of voltage along the line than by the thermal power rating of the conductor. That is why installations for the compensation are used every 600 kilometers in practice.

Losses of an overhead line

In addition to current-dependent losses there are also voltage-dependent losses in the form of gas discharges in areas of heavy curved surface and high field strength. These requirements are fulfilled by the conductors. If then the electric field strength at the conductor surface also called fringe field strength exceeds the disruptive strength of air, the ionization of air molecules is possible. Electron- impact ionization can happen if previously released electrons hit neutral molecules again. The energy needed for that is taken from the electric field.

Such corona discharges can be perceived as a luminous appearance and crackling sounds.

In the annual mean the corona losses amount to approximately 2-3 kW/km for a 400 kV-system, 1-10 kW/km for a 380 kV system and 2-60 kW/km for a 750 kV system that strongly depends on the respective atmospheric conditions and can be neglected in this order of magnitude.

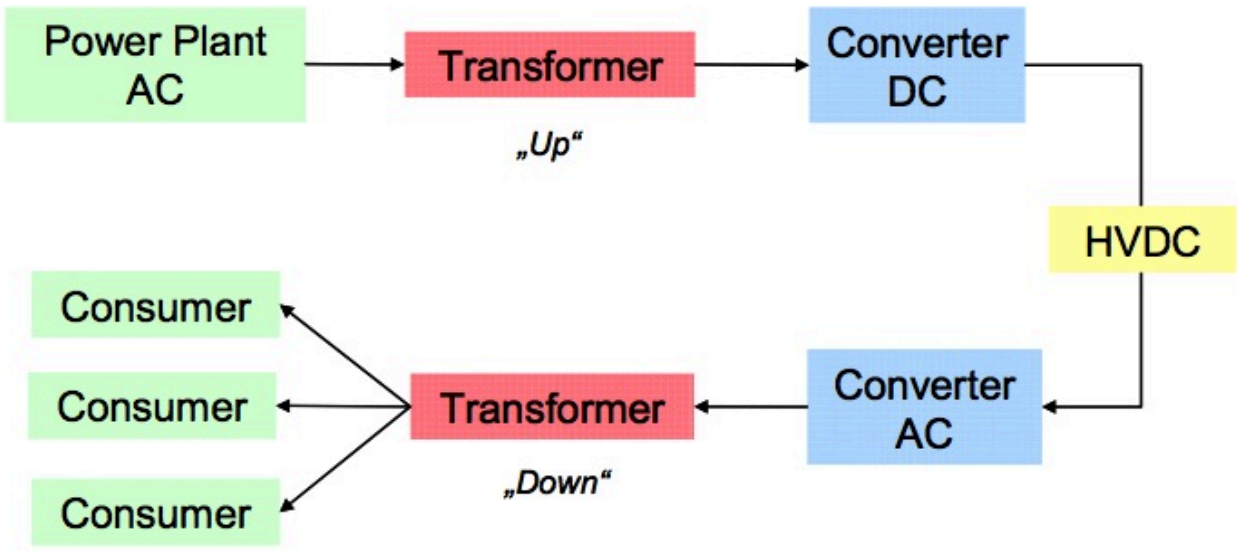
Altogether losses in high voltage AC-systems come to 15 %/1000 km (380 kV) and 8 %/1000 km (750 kV) respectively. In addition to this, each transformer station can loose 0.25 % of the energy .

Direct current

Technology

Electric direct current flows continuously in one direction with a constant amperage and can be generated by electrochemical processes or by rectification of alternating current.

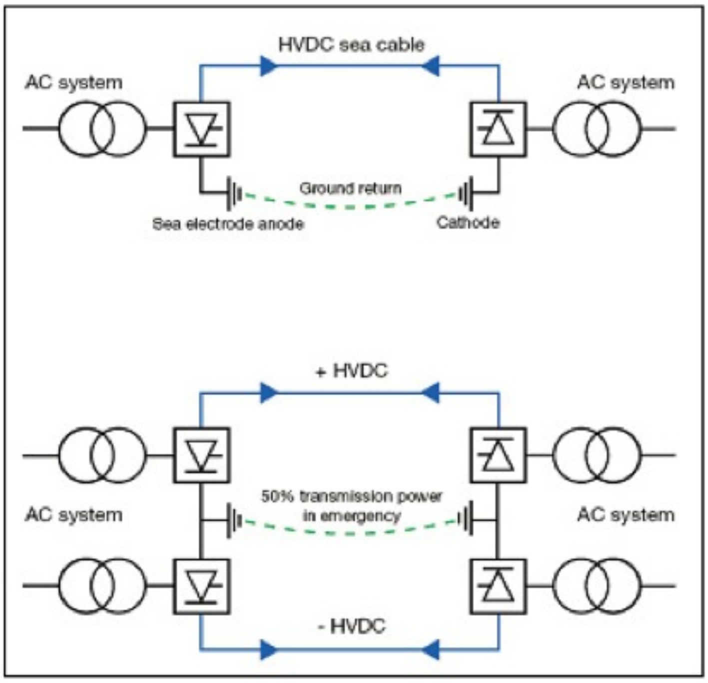
The principle of the transmission of electric energy as HVDC transmission is shown in figure.



First, alternating current, which is produced by the power plant, is stepped-up on transmission voltage by a transformer. Afterwards alternating current is transformed into direct current by a connected rectifier. The high voltage direct current is then transmitted to demand centers via overhead line or cable. Finally, the direct current must be retransformed into alternating current so that it can be stepped-down on consumer voltage by a transformer.

Capacity and losses

The utilization of direct current has got diverse advantages compared with alternating current. First of all the transmission length is only limited by an ohmic resistance. The cheaper the power input is, the less important the heat losses are. Besides, there are no capacitive, inductive or dielectric losses which would be shown as a fall of voltage along the line.



In comparison with a three-phase AC-system of three conductors a high voltage direct current transmission requires two conductors (bipolar case) or just one conductor (mono polar case) while the current flows back via earth .

This leads to lower costs for the lines, especially at long distances. The requirements on the line also turn out lower regarding pylon height and width.

Stability

HVDC can contribute to security of the network stability, for instance by connecting power plants with a high energy rating.
A direct current system has no problems with stability in principle and is quickly adjustable via rectifiers.

Disadvantages

Direct current has the disadvantage of not being directly transformable to another voltage, by which the erection of networks with different voltage levels becomes difficult as it corresponds to the recent situation of the energy economy.

Overhead line transmission losses

There is only an ohmic resistance *R* [Ω] in DC circuits, which results from the

relation of the voltage U [V] and the amperage I [A] according to the Ohmic Law:

$$R = \frac{U}{I} \quad \textit{(Equation 2)}$$

R is also called effective resistance and appears in the form of heat losses. (Joule Effect)

This resistance increases proportional with the length (L) of the conductor and, moreover, depends on the cross-section area (S). The lower the area is, the closer the passage for the electrons. The specific electric resistance ϱ represents the material-dependent value of *R* at a temperature of 20 °C for a conductor cross-section area of 1 m^2 and a conductor length of 1 m.

$$R = \rho \cdot \frac{L}{S}$$ *(Equation 3)*

The specific electric resistance ρ depend of the temperature θ is calculated with the following equation:

$$\rho = \rho_{20} \cdot \left[1 + \alpha_{20}\left(\theta - 20\right)\right]$$ *(Equation 4)*

ρ: specific electric resistance

ρ_{20}: specific electric resistance at 20°C

α_{20} :temperature coefficient (K^{-1})
θ : operating temperature (°C)

The Power *P* (W) transmitted in a certain moment results from the multiplication of the voltage and the amperage:

$P = I * U$ *(Equation 5)*

The energy losses P_l appearing during the transmission of electricity because of the ohmic resistance can be determined by the combination of equation 3 , 4 and 6. Basically it is valid that the higher the voltage and the lower the amperage is, the lower the energy losses, which are proportional to the square of the amperage:

Problems:

For all the exercises you need to choose the right formula in the context

1) Give the unit of ϱ: the specific electric resistance

2) Calculate the power lost to a 1000 km cable aluminum with direct current, knowing that ϱ_{20}: specific electric resistance at 20 ° C is $2.8\ 10^{-9}$, the cross-section area (S) is 321 mm², α_{20}: temperature coefficient is 0.004, the current was 5000 (A) for a U = 500 kV, and the operating temperature of 40 °C

3) Calculate the relative power lost (the%)

4) Why take aluminum that is less conductive than copper?