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SEC2T (Renewable Energy and Energy Harvesting)

Topic - Solar Energy

Introduction:

Part of the energy incident on the earth from the sun can be directly received as radiation on the surface on the earth and be converted into different utilizable forms of energy. Therefore, the main principles of solar radiation and its main characteristics are very crucial. The term “Utilization of Passive Solar Energy” was first introduced in the seventies of the last century. At that time, the criterion of “adding auxiliary energy” was used to clearly distinguish between active solar energy applications. When auxiliary units (such as fans) were used, the systems were referred to as hybrid systems. However, the delimitation between passive and active systems remained fluid: for a window equipped with automatic shading devices is both passive and hybrid. Only recently, the term “Passive Solar Energy Utilization” has been defined in a more realistic and precise manner. According to the new definitions passive solar systems convert solar radiation into heat by means of the building structure itself, i.e. by the transparent building envelope and solid storage elements. Utilization of passive solar energy (often also referred to as passive solar architecture) is thus characterized by the use of the building envelope as absorber and the building structure as heat store. In most cases, solar energy is transferred without any intermediate heat transfer devices. However, also this definition does not always allow for a clear differentiation of active and passive solar utilization.

Solar Pond Power Plants:

Solar ponds are power plants that utilize the effect of water stratification as a basis for the collector. A basin filled with brine (i.e. a water/salt mixture) functions as collector and heat storage. The water at the bottom of the solar pond serves as primary heat storage from which heat is withdrawn. The deeper water layers and the bottom of the solar pond itself serve as absorber for the impinging direct and diffuse solar radiation. Due to the distribution of the salt concentration within the basin, which increases towards the bottom of the basin, natural convection and the ensuing heat loss at the surface due to evaporation, convection and radiation is minimized. This is why heat of an approximate temperature between 80^0 and 90^0 C (approximate stagnation temperature 100^0 C) can be extracted from the bottom. By virtue of suitable thermodynamic cycles (e.g. ORC process) heat can be used for power generation.

Pond Collector. Pond collectors are either natural or artificial lakes, ponds or basins that act as a flat-plate collector because of the different salt contents of water layers due to stratification. The upper water layers of relatively low salt content are often provided with plastic covers to inhibit waves. This upper mixing zone of such pond collectors usually is approximately 0.5 m thick. The adjacent transition zone has a thickness of 1 to 2 m, and the lower storage zone is of 1.5 to 5 m thickness.

If deeper layers of a common pond or lake are heated by the sun, the heated water rises up to the surface since warm water has a lower density than cold water. The heat supplied by the sun is returned to the atmosphere at the water surface. This is why, in most cases, the mean water temperature approximately equals ambient temperature. In a solar pond heat transmission to the atmosphere is prevented by the salt dissolved in deeper layers, since, due to the salt, water density at the bottom of the pond is that high, that the water cannot rise to the surface, even if the sun heats up the water to temperatures that are close to the boiling point (Fig. 1).

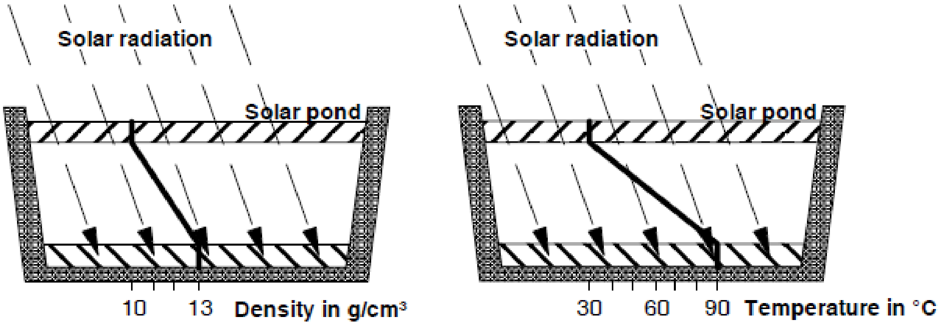

Fig. 1

To ensure stable stratification of a solar pond, with increasing depth the temperature increase must not exceed density increase (i.e. salt content). This is why all relevant parameters must be continuously monitored in order to take appropriate measures (e.g. heat withdrawal, salt supply) in due time. To achieve the utmost collector efficiency, a high portion of the solar radiation must reach the absorption zone. Yet, this can only be achieved, if the top layers are of sufficient transmission capability. During the operation of a solar pond, the transmissivity, the salt content and the temperature must be regularly monitored. The timely course of these parameters must be measured from the water surface to the ground in order to determine the heat quantity that can be withdrawn from the pond or to determine the measures to maintain the respective required salt concentration and the water quality (prevention of turbidity due to particulate matter, algae or bacteria).

Diffusion ensures permanent equalization of the salt concentration in a solar pond which is even intensified by wave motion due to wind near the surface. This is why salt needs to be withdrawn from the surface water and added to deeper layers. For this purpose surface water is evaporated in separate flat basins (salines). Subsequently, the extracted salt is added to deeper zones.

Solar Heating. One of the best ways of using solar thermal energy is heating open-air swimming pools; where the timing of demand for heat and the available solar radiation more or less correlate. Additionally, an external heat store is not required as the open-air swimming pool filled with water can function as the storage. As the water in the pool only has to be heated up to comparatively low temperatures (a maximum of approximately 28^0 C), the use of simple and inexpensive non-covered absorber mats, either installed on the roof of the open-air swimming pool or an adjacent free space, generates high energy output.

Absorber and Heat Storage:

While absorber and heat storage are individual components in active solar systems, they are integrated into the building structure of passive systems. Within direct gain systems, the room envelopes with solar radiation exposure, serve as absorber surfaces. Passive solar systems should thus offer well-absorbing outer surfaces and a heat-storing building structure which is well-adapted to the solar system.

The “classic” passive energy system is not equipped with any control. The thermal mass of a house, which is heated up by solar radiation, releases the heat back into the internal space with a certain time lag and reduced temperature without any user intervention. It is thus essential to prevent passive accumulators from overheating the rooms. For this purpose, the time lag and heat flow reduction by passive storage need to be known factors. Also, in most cases, additional (active) shading devices need to be provided to reduce energy absorption in summertime. Indirectly heated thermal mass (e.g. unheated internal walls) can only be used sensibly if the corresponding room temperature variations are permitted. In case of high room temperatures, heat is slowly absorbed by thermal mass which is gradually heated up by the space. If, by contrast, the room temperature falls below the thermal mass surface temperature, the stored heat is released back into the space.

Flat Plate Collector:

For higher temperature levels requirement glazed flat-plate collectors are used in many cases (Fig. 2). They can be built with one or more transparent cover sheets. In order to further reduce the convective thermal losses from the absorber to the cover, the space between the two can be evacuated, which turns the collector into a vacuum flat-plate collector. Due to the pressure difference, the cover sheet has to be supported from the inside in that case. Heat losses to the back of the collector are avoided by insulation material. Absorber, cover and insulation are fixed by a collector case. The piping in the collector can either be designed with many parallel tubes that are connected by a distributor and a collector in the absorber or by a single bent tube covering the whole collector area. In the former case there is a high total mass flow in the absorber (parallel tubes) but the temperature lift during irradiation is small (high flow principle), in the latter case the total mass flow is low (only one tube) but the temperature lift is high (low flow principle).

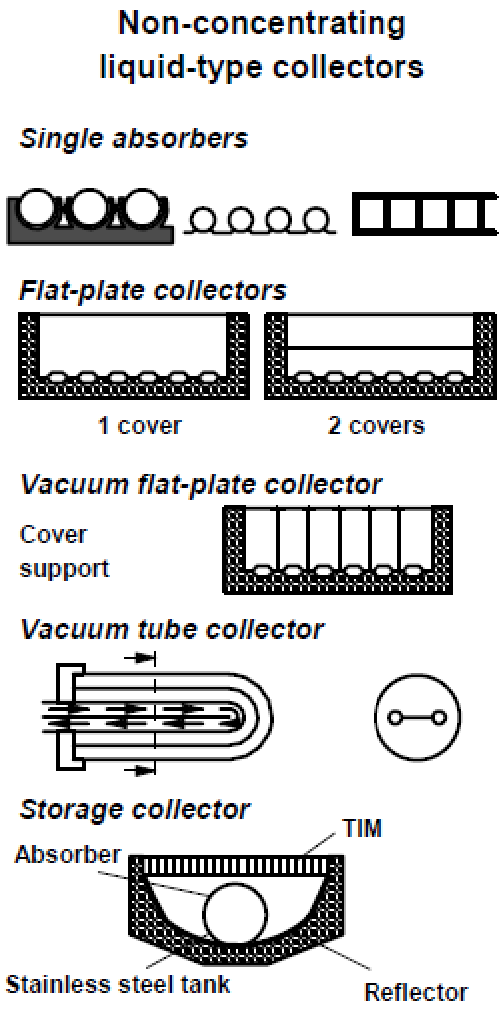

Fig. 2

Photo-Voltaic (PV) Power Generation:

Besides solar thermal heat and power generation photo-voltaic (PV) power generation is a further possibility to directly utilize solar radiation energy. However, in contrast to solar thermal electricity generation, solar energy is directly converted into electrical energy.

Energy Gap Model. Besides the positively charged protons and the uncharged neutrons inside the nucleus an atom is composed of the negatively charged electrons that assume discrete energy levels (such as “shells” or “orbitals”) around the nucleus. There is a limited number of electrons that can occupy a certain energy level; according to the so-called Pauli exclusion principle any possible energy level may only be occupied by a maximum of two electrons. These two electrons are only allowed if they again differ from each other by their “spin” (i.e. self angular momentum). If several atoms form a crystal, the different energy levels of the individual atoms overlap each other and stretch to form energy bands. Between these “allowed” energy bands there are energy gaps. There are narrow permitted bands for the inner electrons, closely bound to the nucleus, and wide permitted bands for the outer electrons. The width of the forbidden bands varies in the opposite way; forbidden bands are wide close to the nucleus and decrease with increasing energy level, so that outer bands overlap. The energetic distances of permitted bands and the width of energy gaps, respectively, and the distribution of electrons to the permitted bands determine the electric and optic properties of a crystal.

Also within these bands the number of energy levels to be occupied by electrons is limited (i.e. the number of spaces is restricted). There is thus a “finite energy state density”. The inner shells of atoms and the energy bands of solids with low energy levels, respectively, are almost entirely covered with electrons. The electrons are unable to move freely here; they are only able to change places. These electrons do not produce any conductivity. The most energy-rich energy band, fully occupied with electrons, is referred to as valence band; the electrons it contains determine the chemical bond type of the material.

A solid with electrical conductivity requires freely moving electrons. However, electrons are only able to move freely if they are located in an energy band that is not fully occupied. For energy reasons, this is only true for the energy band located above the valence band. This energy band is thus referred as the conduction band. The energy gap E_g between the valence band and conduction band is termed as “band gap”. This energy gap exactly equals the minimum amount of energy required to transfer one electron from the valence band into the conduction band.

Photo-Voltaic Effect. If photons, the quantum of light energy, hit and penetrate into a semiconductor, they can transfer their energy to an electron from the valance band (Fig. 3). If such a photon is absorbed within the depletion layer, the region's electrical field directly separates the created charge carrier pair. The electron moves towards the $n-$region, whereas the hole moves to the $p-$region. If, during such light absorption, electron-hole pairs are created outside of the depletion region within the $p-$ or $n-$region (i.e. outside of the electrical field), they may also reach the space-charge region by diffusion due to thermal movements (i.e. without the direction being predetermined by an electrical field). At this point the respective minority carriers (i.e. the electrons within the $p-$region and the holes in the $n-$region) are collected by the electrical field of the space-charge region and are transferred to the opposite side. The potential barrier of the depletion layer, in contrast, reflects the respective majority carriers.

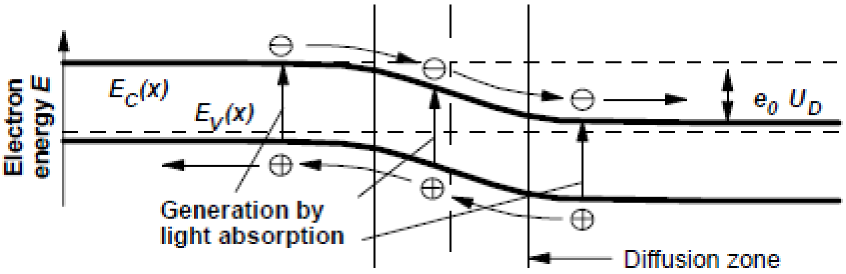

Fig. 3

Finally, the $p-$side becomes charged positively while the $n-$side is charged negatively. Both, photons absorbed within, and outside, of the depletion layer contribute to this charging. This process of light-induced charge separation is referred as photo-voltaic effect.

Thus, the photo-voltaic effect only occurs if one of the two charge carriers created during light absorption passes the $p-n$ junction. This is only likely to occur when the electron-hole pairs are generated within the depletion layer. Outside of this electrical field there is an increasing likelihood that charge carrier pairs created by light get lost by recombination. This is more likely the greater the distance is between the location of the generation of the electron-hole pair and the depletion layer. This is quantified by the "diffusion length" of the charge carriers inside the semiconductor material. The term "diffusion length" refers to the average path lengths to be overcome by electrons or holes within the area without an electrical field before recombination takes place. This diffusion length is determined by the semiconductor material and, in case of the identical material, highly depends on the impurity content – and thus also on doping (the more doping the lower the diffusion length) – and on crystal perfection. For silicon the diffusion length varies from approximately 10 up to several 100 μm. If the diffusion length is less than the charge carriers distance to the $p-n$ junction most electrons or holes recombine. To achieve an effective charge carrier separation the diffusion length should be a multiple of the absorption length of the solar radiation incident on a Photo-Voltaic cell (or popularly called a solar cell).

Sun Tracking System:

Heliostats are reflecting surfaces provided with a two-axis tracking system which ensures that the incident sunlight is reflected towards a certain target point throughout the day. In addition, heliostats commonly concentrate sunlight by means of a curved surface or an appropriate orientation of partial areas, so that radiation flux density is increased.

Heliostats consist of the reflector surface (e.g. mirrors, mirror facets, other sunlight-reflecting surfaces), a sun-tracking system provided with drive motors, foundations and control electronics. The individual heliostat's orientation is commonly calculated on the basis of the current position of the sun, the spatial position of the heliostats and the target point. The target value is communicated electronically to the respective drive motors via a communication line. This information is updated every few seconds. The concentrator surface size of currently available heliostats varies between 20 and 150 m^2; to date, the largest heliostat surface amounts to 200 m^2 (shown in Fig. 4).

The heliostat field accounts for about half the cost of the solar components of such a power plant. This is why tremendous efforts have been made to develop heliostats of good optical quality, high reliability, long technical life and low specific costs. Due to economic considerations there is a tendency to manufacture heliostats with surfaces ranging between 100 and 200 m^2 and possibly beyond. However, there are also approaches to manufacture smaller heliostats to reduce costs by efficient mass-production.

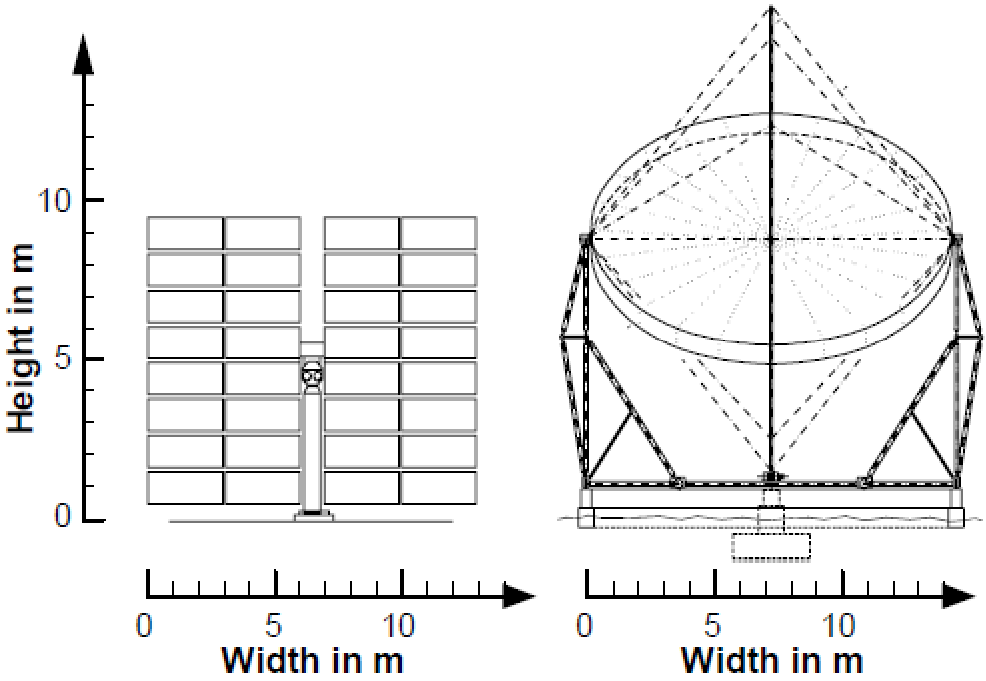

Fig. 4

Heliostats are usually centrally controlled and centrally supplied with electrical energy. As an alternative, autonomous heliostats have been developed which are controlled locally. There, the energy required for the control processor and the drives is provided by photo-voltaic cells mounted parallel to the reflector surface.

Topic - Wind Energy

Introduction:

In addition to the global water cycle, solar radiation also maintains the movement of the air masses within the atmosphere of the earth. Of the total solar radiation incident on the outer layer of the atmosphere, approximately 2.5% are utilized for the atmospheric movement. This leads to a theoretical overall wind power of approximately 4.3×10^{15} W. The energy contained in the moving air masses, which for example can be converted into mechanical and electrical energy by wind mills, is a secondary form of solar energy.

Wind energy converters (WEC) harness the kinetic energy contained in flowing air masses. Energy extraction from wind, by wind energy converters, is always related to a certain time difference as wind and operational conditions are usually subject to constant changes. This is why in most cases the instantaneous energy value (power) is determined in order to calculate its useful energy contribution (work) by summation over time (i.e. integration).

Wind Turbine Design:

On the basis of the physical principles outlined for wind energy exploitation, in the following the technical fundamentals of wind power generation are explained. Explanations consider state-of-the-art technology. There is a wide range of different types of wind turbines. The most important features of various concepts include

(i) Rotor axis position (horizontal, vertical),

(ii) Number of rotor blades (one, two, three or multiple blade rotors),

(iii) Speed (high and low speed energy converters),

(iv) Number of rotor revolutions (constant or variable),

(v) Upwind or downwind rotors,

(vi) Power control (stall or pitch control),

(vii) Wind resisting strength (wind shielding or blade adjustment),

(viii) Gearbox (converters equipped with gearbox or gearless converters),

(ix) Generator type (synchronous, asynchronous or direct current generator) and

(x) Grid connection for power generation plants (direct connection or connection via an intermediate direct current circuit).

Rotor. The system component of a modern wind energy converter that transforms the energy contained in the wind into mechanical rotations is referred to as rotor. It consists of one or several rotor blades and the rotor hub (see Fig. 5). The rotor blades extract part of the kinetic energy from the moving air masses according to the lift principle. The current maximum efficiency of the kinetic energy of the free flow in relation to the rotor surface amounts to 50 %; usually, the so-called aerodynamic efficiency of state-of-the-art rotors amounts to between 42 and 48 % at the turbine design point.

Rotor blades. Rotor blades (Fig. 5) are usually made of plastic, in individual cases also steel or wood are applied. As plastics in general fibre reinforced material containing glass, coal or aramide fibres is used. Up to now, usually glass fibre reinforced plastics (FRP) have been applied. Yet, with increasing plant size, there is a tendency to use coal fibre reinforced plastics. The predominant criterion for material selection is fatigue strength, but also the specific weight, admissible stress, modulus of elasticity and breaking strength. Deciding factors are also the development, material and manufacturing costs resulting from these technical key factors.

Depending on the installed plant capacity rotor blades of common wind energy converters used for power generation usually have lengths of about 5 m, in case of very small wind energy converters, and of about 60 m and above for multi-megawatt wind power stations, for instance required for potential offshore installations. The respective rotors thus cover surfaces ranging from 80 to above

10000 m^2. In exceptional cases, the surface size may fall below or exceed the above range.

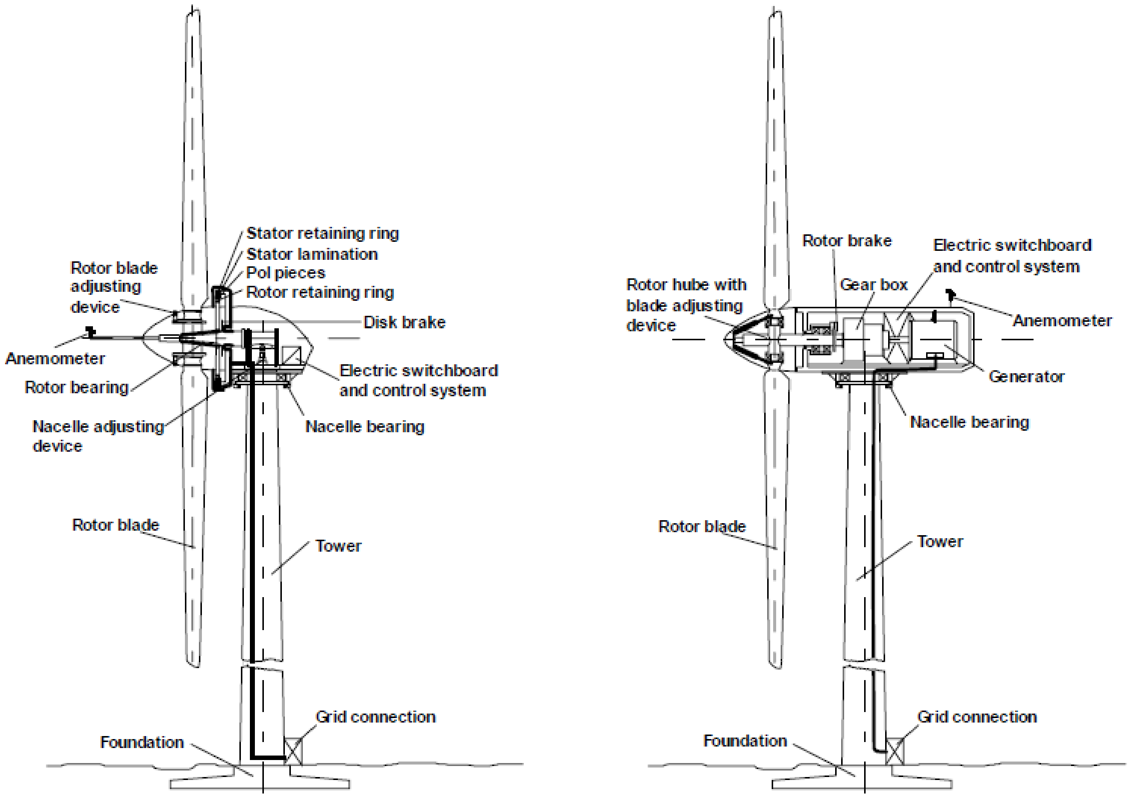

Fig. 5

Rotor hub. The rotor hub connects the rotor blades to the rotor shaft (Fig. 5). For wind energy converters provided with a blade adjustment mechanism the hub also contains the corresponding mechanics and the blade bearing. For the hub and the pertaining construction besides welded steel sheet constructions primarily cast-steel bodies and forged pieces are applied.

Gearbox. To convert the kinetic energy of the rotor into electrical energy, for conventional converters equipped with common four or six-pole synchronous or asynchronous generators, generally revolutions of 1000 or 1500 rpm are required when adhering as much as possible to grid specifications (50 Hz). Current rotor revolutions of 10 to 50 rpm with wind energy converters of installed capacities ranging from several 100 kW up to the multi-megawatt range thus require a transmission gear if no specific generators are applied.

Generator. The generator converts the mechanical rotation energy of the power train into electrical energy. For this purpose slightly adapted commercially available generators are used for conventional converters while especially designed three-phase alternators are applied for gearless converters. The main commonly applied generator types are synchronous and asynchronous generators.

Synchronous generators are equipped with a fixed stator at the outside and a rotor at the inside located on top of a pivoting shaft. In most cases direct current is transmitted to the rotor by slip rings. Direct current creates a magnetic field inside the rotor winding (excitation). When driving the shaft, a certain voltage is created by the rotating magnetic field inside the stator whose frequency matches exactly the rotational speed of the rotating field of the rotor. To prevent expensive maintenance, slip rings are often avoided by the application of so-called brushless synchronous generators, whose pivoting shafts are provided with small rotating exciters.

Asynchronous generators are also provided with a fixed stator and a pivoting rotor. However, excitation (creation of a magnetic field) of the rotor is performed differently. Rotors of asynchronous generators are provided with windings that have direct or shunt short-circuits. When an idle asynchronous generator is connected to an alternating current grid, voltage is induced into the rotor winding, similar to a transformer. The applied frequency is equal to the frequency of the applied voltage. As this winding is short-circuited, there is heavy current flow, so that a magnetic field is created inside the rotor. Since the rotor magnetic field tends to follow the stator magnetic field the rotor is accelerated. The faster the rotor turns, the lower is the resulting relative speed of the rotor winding and the rotating field and thus the voltage induced into its winding. During motor operation, the synchronous number of revolutions will be approached until the weakening rotor magnetic field is still sufficient to compensate for the friction losses of the rotor in idle mode. However, the synchronous number of revolutions cannot be reached as there would be no current induced into the rotor windings, no magnetic field and thus no torque. The specific difference between both numbers of revolutions of the rotor and the rotating field in relation to the rotating field is referred to as slip. Machine operation is thus asynchronous. The more weight is put on an asynchronous generator, the higher is the resulting slip, as higher capacities require stronger magnetic fields. More slip is associated with more induced voltage, more current and a stronger magnetic field. During motor operation, the operating speed is always below, and during generator operation always above the synchronous number of revolutions. Due to these excitation conditions, voltage and current are not in phase, so that reactive power is required.

Depending on the respective power, appropriate condensers need to be connected or disconnected. This disadvantage is even more severe for isolated systems. In countries such as Germany or the Netherlands, the respective reactive power required for public grid operation may be supplied by the available power stations equipped with synchronous generators.

Grid Connection:

With regard to the connection of wind energy converters to the public power grid or any isolated power grid, direct and indirect grid connections are distinguished, for both types asynchronous and synchronous generators are suitable.

For direct connection to an invariable frequency power grid, as it is the case for public European supply, synchronous generators turn at a constant number of revolutions and asynchronous generators at an almost constant number of revolutions according to the grid frequency (Fig. 6). Due to the inevitable “hard” connection, particularly in case of synchronous generators, high dynamic stress may be exerted onto the power train (hub, shaft, gearbox and generator rotor). This is why in most cases asynchronous generators are applied for direct grid connection.

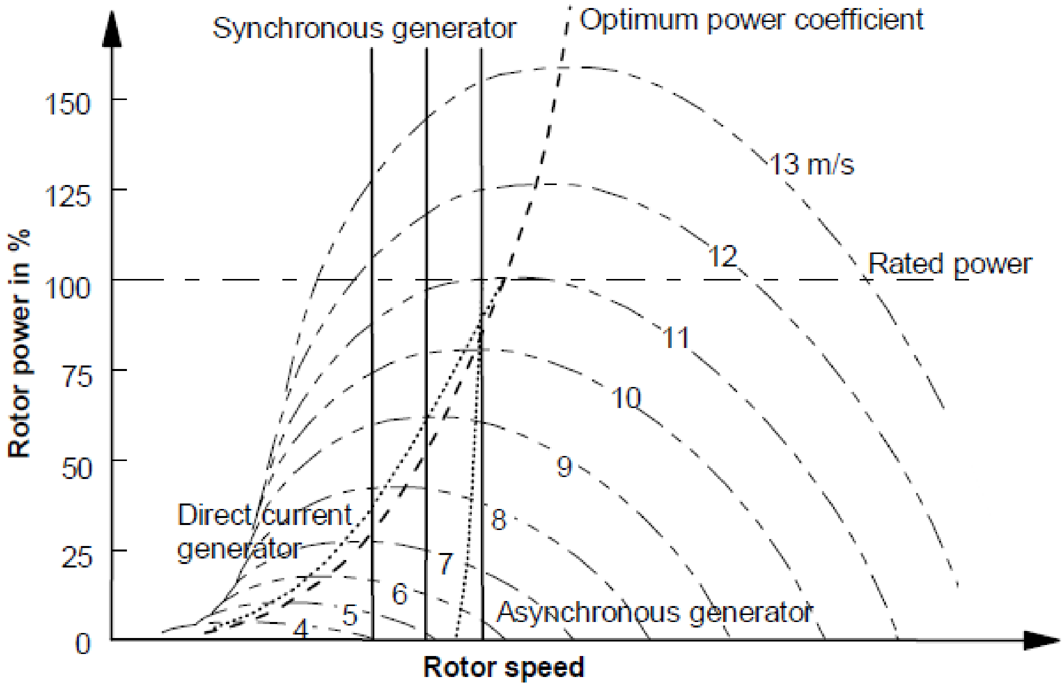

Fig. 6

Indirect grid connection converters may be connected via a direct current intermediate circuit, which allows for the operation of wind energy converters at a variable number of revolutions and generates alternate current at variable frequencies. Current is first converted to direct current by a rectifier and subsequently reconverted into alternate current by an inverted rectifier to match the voltage and frequency specifications of the power grid. This allows for optimum aerodynamic operation of the rotor within a revolution range from 50 to 120% of the nominal number of revolutions (Fig. 6). The variable number of revolutions reduces the dynamic stress exerted on the converter. However, the direct current intermediate circuit incurs in additional costs and increases electrical losses. Grid connection via direct current intermediate circuits is common practice for medium to large converters, preferably in conjunction with synchronous generators.

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Reference:

Renewable Energy: Technology, Economics and Environment, Martin Kaltschmitt, Wolfgang Streicher and Andreas Wiese, Springer

(All the figures have been collected from the above mentioned reference)

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