CAI335 SOLAR AND WIND ENERGY SYSTEM

UNIT II NOTES

2.5 Photovoltatics

The word „photovoltaic“ consists of two words: photo, a greek word for light, and voltaic, which defines the measurement value by which the activity of the electric field is expressed, i.e. the difference of potentials. Photovoltaic systems use cells to convert sunlight into electricity. Converting solar energy into electricity in a photovoltaic installation is the most known way of using solar energy.

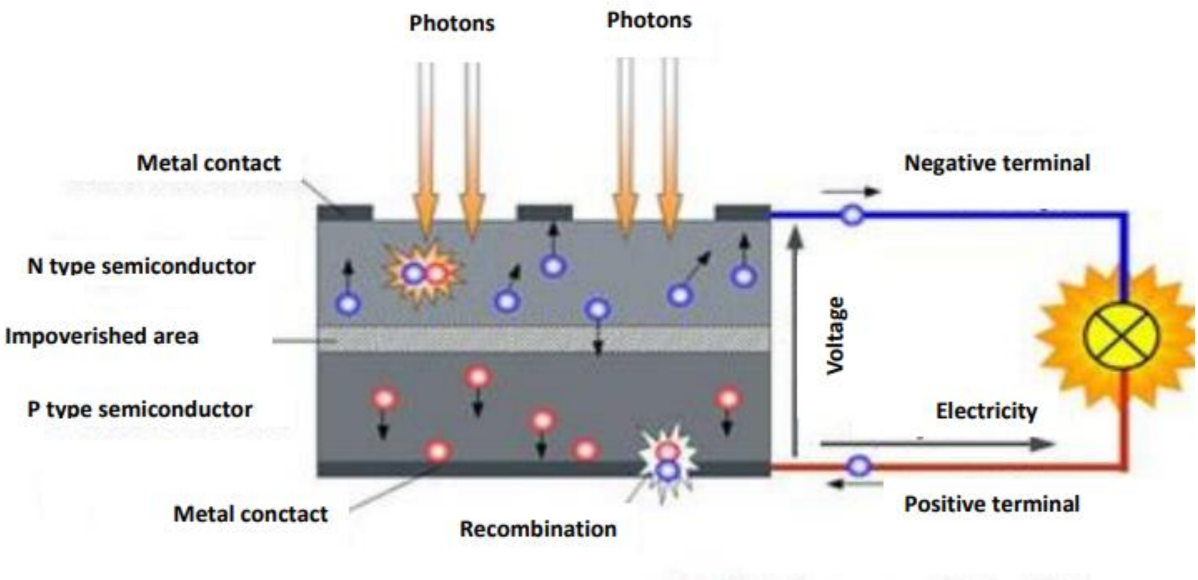
The light has a dual character according to quantum physics. Light is a particle and it is a wave. The particles of light are called photons. Photons are massless particles, moving at light speed. The energy of the photon depends on its wavelength and the frequency, and we can calculate it by the Einstein's law, which is:

$$E = h\nu$$

where: E - photon energy h - Planck's constanth = 6.626×10 − 34Js - photon frequency In metals and in the matter generally, electrons can exist as valence or as free. Valence electrons are associated with the atom, while the free electrons can move freely. In order for the valence electron to become free, he must get the energy that is greater than or equal to the energy of binding. Binding energy is the energy by which an electron is bound to an atom in one of the atomic bonds. In the case of photoelectric effect, the electron acquires the required energy by the collision with a photon.

Part of the photon energy is consumed for the electron getting free from the influence of the atom which it is attached to, and the remaining energy is converted into kinetic energy of a now free electron. Free electrons obtained by the photoelectric effect are also called photoelectrons. The energy required to release a valence electron from the impact of an atom is called a „work out“ Wi, and it depends on the type of material in which the photoelectric effect has occurred.

The photoelectric conversion in the PV junction. PV junction (diode) is a boundary between two differently doped semiconductor layers; one is a P-type layer (excess holes), and the second one is an N-type (excess electrons). At the boundary between the P and the N area, there is a spontaneous electric field, which affects the generated electrons and holes and determines the direction of the current.



To obtain the energy by the photoelectric effect, there shall be a directed motion of photoelectrons, i.e. electricity. All charged particles, photoelectrons also, move in a directed motion under the influence of electric field. The electric field in the material itself is located in semiconductors, precisely in the impoverished area of PV junction (diode). It was pointed out for the semiconductors that, along with the free electrons in them, there are cavities as charge carriers, which are a sort of a byproduct in the emergence of free electrons. Cavities occurs whenever the valence electron turns into a free electron, and this process is called the generation, while the reverse process, when the free electron fills the empty spaces - a cavity, is called recombination. If the electron-cavity pairs occur away from the impoverished areas it is possible to recombine before they are separated by the electric field. Photoelectrons and cavities in semiconductors are accumulated at opposite ends, thereby creating an electromotive force. If a consuming device is connected to such a system, the current will flow and we will get electricity.

$$\eta = \frac{P_{el}}{P_{sol}} = \frac{U \cdot I}{E \cdot A}$$

Pel - Electrical output power Psol - Radiation power (sun) U - Efective value of output voltage I - Effective value of the electricity output E - Specific radiation power (for example W/m2) A - Area .

The usefulness of PV solar cells ranges from a few percent to forty percent. The remaining energy that is not converted into electrical energy is mainly converted into heat energy and thus warms the cell. Generally, the increase in solar cell temperature reduces the usefulness of PV cells.

2.5.2 Solar IV characteristics curves

The **Solar Cell I-V Characteristic Curves** shows the current and voltage (I-V) characteristics of a particular photovoltaic (PV) cell, module or array. It gives a detailed description of its solar energy conversion ability and efficiency. Knowing the electrical I-V characteristics (more importantly P_{max}) of a solar cell, or panel is critical in determining the device's output performance and solar efficiency.

Photovoltaic solar cells convert the suns radiant light directly into electricity. With increasing demand for a clean energy source and the sun's potential as a free energy source, has made solar energy conversion as part of a mixture of renewable energy sources increasingly important. As a result, the demand for efficient solar cells, which convert sunlight directly into electricity, is growing faster than ever before.

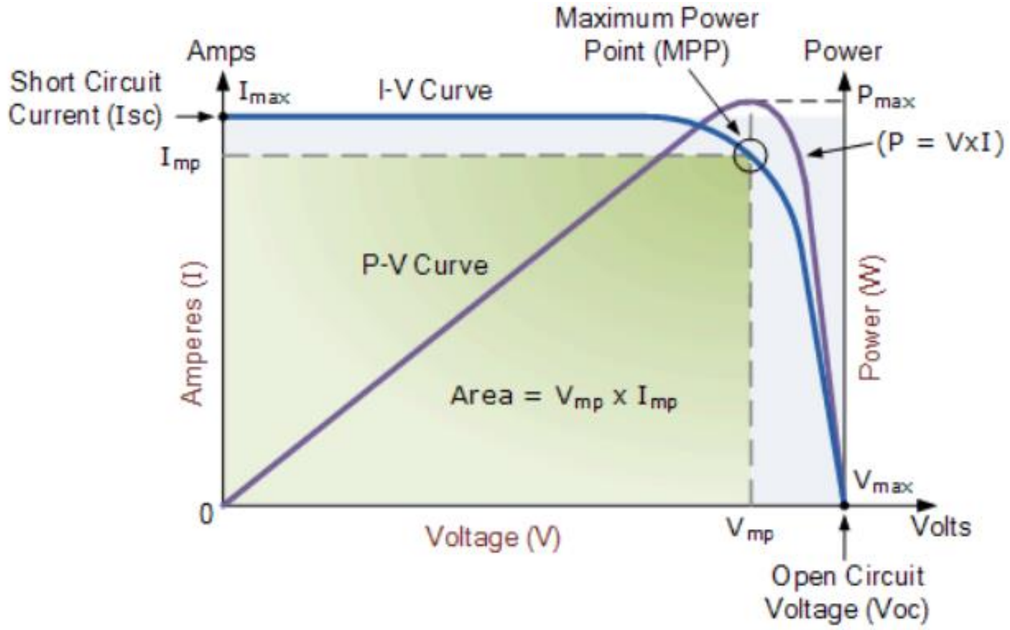
Photovoltaic (PV) cells are made made almost entirely from semiconductor silicon that has been processed into an extremely pure crystalline material which absorbs the photons from sunlight.

The photons hit the sillicon atoms releasing electrons causing an electric current to flow when the photoconductive cell is connected to an external load. For example, a battery. There are a variety of different measurements we can make to determine the solar cell's performance, such as its power output and its conversion efficiency.

The main electrical characteristics of a PV cell or module are summarized in the relationship between the current and voltage produced on a typical solar cell I-V characteristics curve. The intensity of the solar radiation (insolation) that hits the cell controls the current (I), while the increases in the temperature of the solar cell reduces its voltage (V).

Solar cells produce direct current (DC) electricity and current times voltage equals power, so we can create solar cell I-V curves representing the current versus the voltage for a photovoltaic device.

Solar Cell I-V Characteristics Curves are basically a graphical representation of the operation of a solar cell or module summarising the relationship between the current and voltage at the existing conditions of irradiance and temperature. I-V curves provide the information required to configure a solar system so that it can operate as close to its optimal peak power point (MPP) as possible.



2.5.3Types of solar photovoltaic cells

Electricity is produced in solar cells which, as noted, consist of more layers of semiconductive material. When the sun's rays shine down upon the solar cells, the electromotive force between these layers is being created, which causes the flow of electricity. The higher the solar radiation intensity, the greater the flow of electricity.

The most common material for the production of solar cells is silicon. Silicon is obtained from sand and is one of the most common elements in the earth's crust, so there is no limit to the availability of raw materials.

Monocrystalline Si cells: conversion efficiency for this type of cells ranges from 13% to 17%, and can generally be said to be in wide commercial use. In good light conditions it is the most efficient photovoltaic cell. This type of cell can convert solar radiation of 1.000 W/m2 to 140 W of electricity with the cell surface of 1m2 . The production of monocrystalline Si cells requires an absolutely pure semiconducting material. Monocrystalline rods are extracted from the molten silicon and sliced into thin chips (wafer). Such type of production enables a relatively high degree of usability. Expected lifespan of these cells is typically 25-30 years and, of course, as well as for all photovoltaic cells, the output degrades somewhat over the years.

- Multicrystalline Si cells: this type of cell can convert solar radiation of 1.000 W/m2 to 130 W of electricity with the cell surface of 1m2 . The production of these cells is economically more efficient compared to monocrystalline. Liquid silicon is poured into blocks, which are then cut into slabs. During the solidification of materials crystal structures of various sizes are being created, at whose borders some defects may emerge, making the solar cell to have a somewhat lower efficiency, which ranges from 10% zo 14%. The lifespan is expected to be between 20 and 25 years.

- Ribbon silicon has the advantage in its production process in not needing a wafer cutting (which results in loss of up to 50% of the material in the process of cutting). However, the quality and the possibility of production of this technology will not make it a leader in the near future. The efficiency of these cells is around 11%.

Photovoltaic system types

Photovoltaic systems can be generally divided into two basic groups: 1. Photovoltaic systems not connected to the network, stand-alone systems (off-grid) 2. Photovoltaic systems connected to public electricity network (on-grid) There are lots of different subtypes of photovoltaic systems according to type and method of connecting to the network, or a way of storing energy on independent systems.

Network-connected photovoltaic systems (on-grid)

The main components of PV systems are photovoltaic modules, photovoltaic inverter, mounting subframe and measuring cabinet with protective equipment and installation. Photovoltaic modules convert solar energy into DC current, while photovoltaic inverter adjusts the produced energy in a form which can be submitted to the public grid. The AC voltage is supplied to the electricity network through the protection and measuring equipment.

Photovoltaic inverter is usually located indoors, although there are inverters for outdoor installation, where it must not be directly exposed to sunlight. Inverters produce high-quality AC current of corresponding voltage and are suitable for a network-connected photovoltaic systems. Network inverters operate like any other inverter, with the difference that the network inverters must ensure that the voltage they supply is in phase with the network voltage. This allows the photovoltaic systems to deliver the electricity to the electrical network.

Electrical connection is usually located in the electrical control box, which is located in a separate room, but can also be placed in the measurement and terminal box, which then connects to the electrical control box. The meter is installed at the point of connection, a single phase, two-tariff, electronic system for single-phase, and a three phase, two-tariff, electronic system for two-phase and three phase systems. In such installations it is regularly proposed to setting up a fuse in front of and behind the counters in order to permit replacement of the meter at a no-load condition.

The exact conditions of connection are synchronized with the local distributor of electric energy - HEP ODS. Power OFF buttons must be provided both on the side of photovoltaic modules as well as on the side of network connection. The output voltage of the inverter must be in accordance with the Regulation on standardized voltages for low voltage electricity distribution network and electrical equipment. Standard sizes of the nominal voltage is 230V, up to 400V between phase and neutral conductor, between phase conductors, the quad-phase network nominal frequency of 50 Hz, and, under normal conditions, it should not differ from the nominal value by more than ± 10%.

Network-connected home systems (possibility for own consumption- Green houses

These are the most popular types of solar photovoltaic systems that are suitable for home and commercial installations in developed and urban areas. Connection to the local electricity network allows selling to the local distributor of electric energy any excess of electricity generated and not used in the household consumption, because the PV system is connected to the network via a home installation in parallel operation with the distribution system. Also, the home is supplied with electricity from the grid when there is no sunny weather.

The inverter, as already discussed, is used to convert direct current (DC) produced by the photovoltaic modules into alternating current (AC) located in the electrical grid and used to drive all the household appliances. This system gives two choices to the user: to sell the entire electricity produced to the local distributor, delivering all the electricity in the network (especially if there is a price incentive for electricity produced from renewable sources according to the status of eligible producer of electric energy - feed-in tariffs) or the electricity produced can be used to meet the current needs of households and sell any surplus in the electricity grid. It is necessary to mention that the local distributor in Croatia, ODS-HEP, is currently trying to avoid the second solution and prefers supplying of all the electricity produced into the network, without the possibility for the own consumption.

Standalone systems (off-grid) or isolated systems

These systems are used in rural areas where there is no electricity network and infrastructure. The systems are connected to a reservoir of energy (battery) by a control over the filling and emptying. The inverter can also be used to provide alternating current for standard electrical equipment and appliances. Typical stand-alone photovoltaic installations are used to ensure the availability of electricity in remote areas (mountain resorts, islands, rural areas in the developing areas). Rural electrification means either small home solar photovoltaic installations covering basic electricity needs of an individual household, or bigger solar photovoltaic network that provides enough electricity for several households

Hybrid systems A solar photovoltaic system can be combined with other energy sources, such as biomass generator, wind turbines, diesel generator, all to ensure a constant and sufficient supply of electricity, since it is known that all renewable energy sources, including photovoltaic systems, are not constant in energy production. It means that, when there is no sun, the system does not produce electricity, although the need for energy is constant, and therefore must be met from other sources. The hybrid system can be connected to a network, stand- alone or as a support network.

2.5.4. Photovolatic Inverter

A solar inverter or photovoltaic (PV) inverter is a type of power inverter which converts the variable direct current (DC) output of a photovoltaic solar panel into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network.

2.5.5.Inverters used in solar PV system

To recap, there are three kinds of inverters: string inverters, microinverters, and power optimizers. They all transform the power your solar panels generate from direct current (DC) to alternating current (AC).

2.6 . PHOTOVOLTAIC SOLAR PUMPING SYSTEM

Photovoltaic water pumping systems convert solar energy into electrical energy to power the water pump. Solar water pumping technology can be considered a **promising alternative** to electricity, diesel, or gasoline-based pumping systems as they are **cost-effective** and **environment friendly**.

Solar pumping systems make it possible to collect water from a source (river, basin, well,even if **no energy source is present on the site**. Often used to provide drinking water, irrigation or to fill reservoirs, these systems allow access to water **in the most remote areas**.

Working

Photovoltaic water pumping systems convert solar radiation into electricity via PV panels with the mission to **power the electric pumps**. The electrical energy produced by the PV modules is used **to supply DC motors** or to be converted into alternating current by the inverter. Depending on the installation, it is possible to **store energy in batteries**. However, it is not always necessary to store the energy produced because the **installation of a reservoir at the pump outlet makes it possible to store water** and thus obtain a usable reserve even without the sun. Another option is the **thermodynamic conversion** which converts solar energy into mechanical energy to **run the solar pump**.