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Introduction to PV Systems

17.1 Introduction

After discussing the fundamental scientific theories required for solar cells in Part II and taking a look at modern PV technology in Part III, we now will use the gained knowledge to discuss complete PV systems. Besides PV modules that already were covered in Chapter 15, a PV system contains many different components. For successfully planning a PV system it is crucial to understand the function of the different components and to know their major specifications. Further, it is important to know the effect of the location on the (expected) performance of a PV system.

17.2 Types of PV systems

PV systems can be small and very simple, consisting of just a PV module and load, as in the direct powering of a water pump motor, which only needs to operate when the sun shines. On the other hand, PV systems also can be built as large power plants with a peak power of several MW; they are connected to the electricity grid. Many systems are placed on residential homes. When a whole house should be powered and is not connected to the electricity grid, the PV system must be operational day and night. It also may have to feed both AC and DC loads, have reserve power and may even include a back-up generator. Depending on the system configuration, we can distinguish three main types of PV systems: stand-alone, grid-connected, and hybrid. The basic PV system principles and elements remain the same. Systems are adapted to meet particular requirements by varying the type and quantity of the basic elements. A modular system design allows easy expansion, when power demands change.

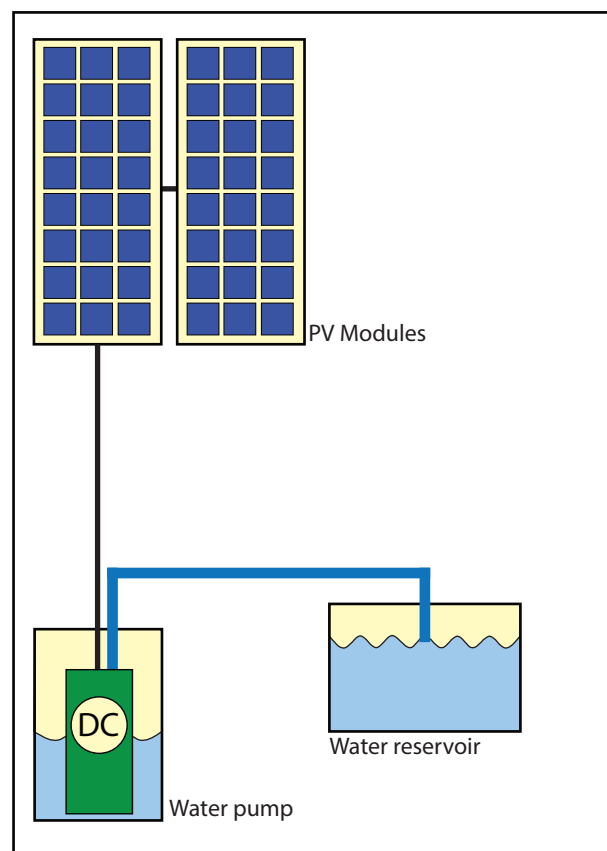


Figure 17.1: Schematic of a simple DC PV system to power a water pump.

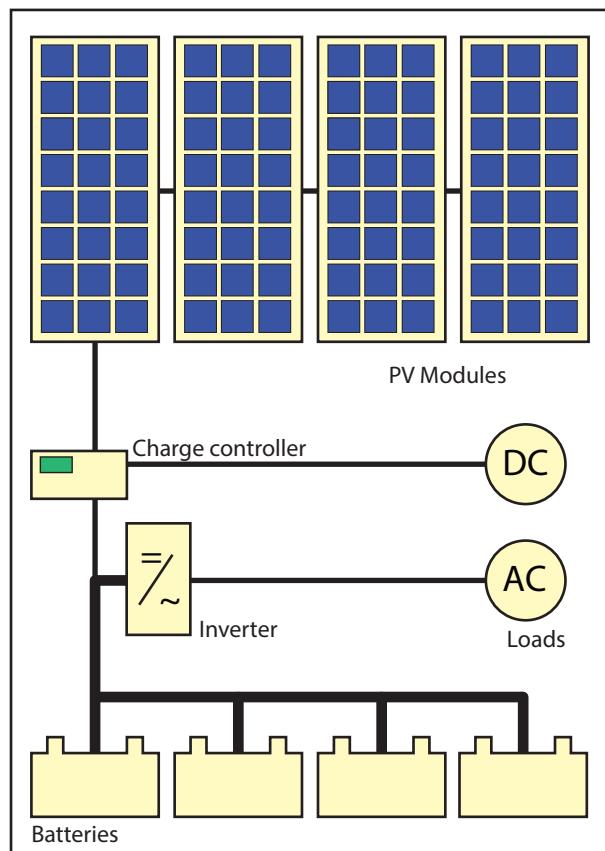


Figure 17.2: Schematic representation of a complex PV system including batteries, power conditioners, and both DC and AC loads.

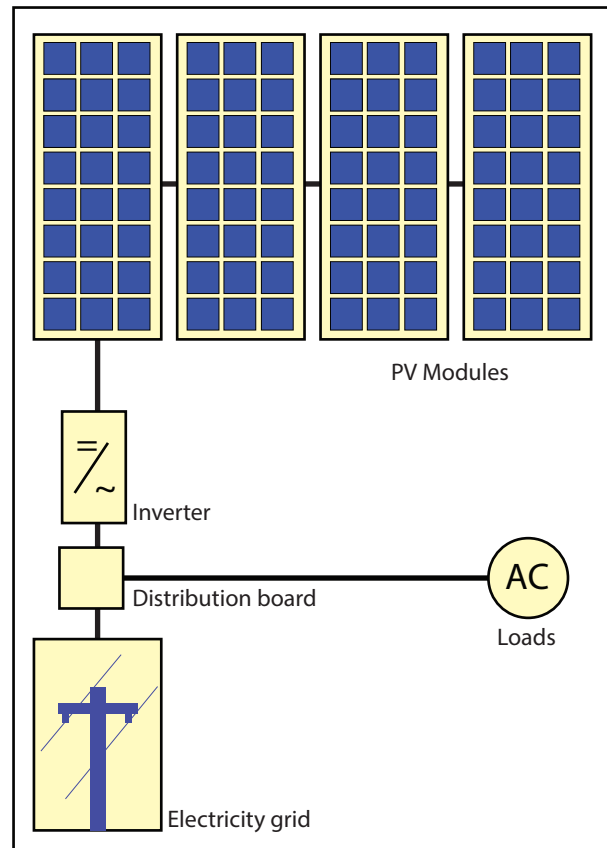


Figure 17.3: Schematic representation of a grid-connected PV system.

17.2.1 Stand-alone systems

Stand-alone systems, which are also called *off-grid* PV systems, rely on solar power only. These systems can consist of the PV modules and a load only or they can include batteries for energy storage. When using batteries charge controllers are included, which disconnect the batteries from the PV modules when they are fully charged, and may disconnect the load to prevent the batteries from being discharged below a certain limit. The batteries must have enough capacity to store the energy produced during the day to be used at night and during periods of poor weather. Figure 17.1 shows a schematic representation of a simple DC PV system without a battery. In Fig. 17.2 a complex PV system with both DC and AC loads is shown.

17.2.2 Grid-connected systems

Grid-connected PV systems have become increasingly popular for applications in the built environment. As illustrated in Fig. 17.3, they are connected to the grid via inverters, which



Figure 17.4: The 25.7 MW_p Lauingen Energy Park in Bavarian Swabia, Germany [136].

convert the DC power into AC electricity. In small systems as they are installed in residential homes, the inverter is connected to the distribution board, from where the PV-generated power is transferred into the electricity grid or to AC appliances in the house. In principle, these systems do not require batteries, since they are connected to the grid, which acts as a buffer into which an oversupply of PV electricity is transported while the grid also supplies the house with electricity in times of insufficient PV power generation. However, more and more grid-connected systems also contain batteries in order to increase *self consumption*, i.e. the amount of generated PV electricity that is consumed by the household [135].

Large PV fields act as power stations from that all the generated PV electricity is directly transported to the electricity grid. They can reach peak powers of up to several hundreds of MW_p. Figure 17.4 shows a 25.7 MW_p system installed in Germany.

17.2.3 Hybrid systems

Hybrid systems combine PV modules with a complementary method of electricity generation such as a diesel, gas or wind generator. A schematic representation of a hybrid system is shown in Fig. 17.5. In order to optimise the different methods of electricity generation, hybrid systems typically require more sophisticated controls than stand-alone or grid-connected PV systems. For example, in the case of a PV/diesel system, the diesel engine must be started when the battery reaches a given discharge level and stopped again when the battery reaches an adequate charging state. The back-up generator can be used to recharge batteries only or to supply the load as well.

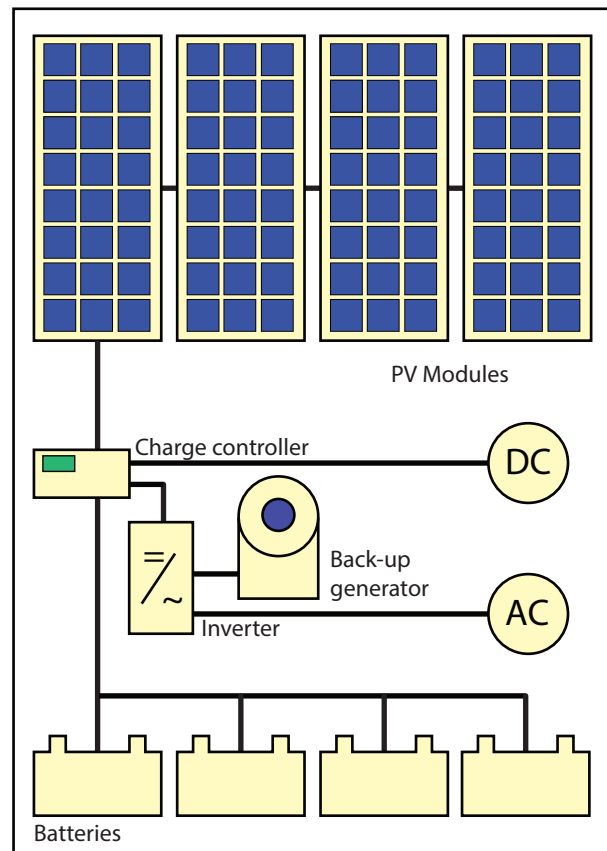


Figure 17.5: Schematic representation of a hybrid PV system that has a diesel generator as alternative electricity source.

17.3 Components of a PV system

Due to the limited size of the solar cell it only delivers a limited amount of power under fixed current-voltage conditions that are not practical for most applications. In order to use solar electricity for practical devices, which require a particular voltage and/or current for their operation, a number of solar cells have to be connected together to form a *solar module*, also called a *PV module*. For large-scale generation of solar electricity solar panels are connected together into a *PV array*.

Although, the solar panels are the heart of a *PV system*, many other components are required for a working system, as we already discussed very briefly above. Together, these components are called the *Balance of System* (BOS). Which components are required depends on whether the system is connected to the electricity grid or whether it is designed as a stand-alone system. The most important components belonging to the BOS are:

- *A mounting structure* in order to fix the modules and to direct them towards the sun.
- *Energy storage* as a vital part of stand-alone systems, because it assures that the system can deliver electricity during the night and in periods of bad weather. Usually, *batteries* are used as energy-storage units.
- *DC-DC converters* in order to convert the module output, which will have a variable voltage depending on the time of the day and weather conditions, to a compatible output voltage that can be used as input for an inverter in a grid-connected system.
- *Inverters* that are used in grid-connected systems to convert the DC electricity originating from the PV modules into AC electricity that can be fed into the electricity grid. Many inverters have a DC-DC converter included to convert the variable voltage of the PV array to a constant voltage that is the input for the actual DC-AC converter. Also stand-alone systems may have an inverter that is connected to the batteries. The design of such an inverter differs considerably from that for a grid-connected system.
- *Charge controllers* that are used in stand-alone systems to control charging and often also discharging of the battery. They prevent the batteries from being overcharged and also from being discharged via the PV array during night. High-end charge controllers also contain DC-DC converters together with a maximum power point tracker in order to make the PV voltage and current independent from the battery voltage and current.
- *Cables* that are used to connect the different components of the PV system with each other and to the electrical load. It is important to choose cables of sufficient thickness in order to minimise resistive losses.

Even though not a part of the PV system itself, the *electric load*, *i.e.* all the connected electric appliances has to be taken into account during the planning phase. Further, it has to be considered whether the loads are AC or DC loads.

The different components of a PV system are schematically presented in Fig. 17.6 and will be discussed in detail in Chapter 19.