overcharging or deep discharging. The appliances are supplied from the battery either directly or via a DC/AC converter. The typical representative of this first system group is the Solar Home System (SHS), which is operating in hundreds of thousands of rural households. It will supply lights and TV sets and delivers, in a standard version, approximately 0.25 kWh of electricity per day. Larger systems may deliver up to 5 kWh per day.

The second group of systems combine a photovoltaic generator with a diesel gen-set and possibly with additional wind turbines or hydroelectric generators. Including a diesel gen-set as a controllable generator gives an additional degree of freedom to the system sizing.[8] It allows reducing the battery capacity, especially if the solar radiation undergoes strong seasonal variations. These systems are called hybrid systems. They are designed to deliver from 1 kWh per day to typically between 10 and 100 kWh per day. They may be used to supply power to telecommunication equipment, mountain lodges, hospitals or hotels in non-electrified rural areas and small villages.

A typical hybrid system with a 4.5-kW_p PV generator, a diesel generator and 32 kWh of lead acid battery storage is in operation since 1992 in the Black Forest in Germany. It has to deliver 10 kWh per day to the hikers inn "Unterkrummenhof". An analysis done in model calculations based on measured data shows the flow of energy in the system and the effect of internal losses (Figure 18.4). Two-thirds of the power delivered (E_{consumer}) is drawn from the battery storage. The numbers given in the diagram are normalised to the nominal energy production of the PV generator under the radiation conditions at the site. A detailed discussion of the energy-flow diagram is given in [6].

Figure 18.4 underlines the key role that battery storage has to fulfil in hybrid systems. More than 80% of the energy used goes via the battery storage. This is a typical value for all hybrid systems and is even higher in many pure PV battery systems.

18.3.2 Classification of Battery-operating Conditions in PV Systems

An intensive study of the operational data of close to 30 batteries in stand-alone PV systems with and without a diesel generator was made. All systems were operated under European radiation conditions [7]. The study resulted in a classification of the battery-operating conditions into four classes. Figures 18.5 and 18.6 show measured data on the annual operating conditions of four systems selected to represent the four different classes. Figure 18.5 shows scatter graphs of the battery current versus battery voltage and Figure 18.6 shows the time series of the state of charge within a complete year.

The hybrid system "Unterkrummenhof", characterised in Figure 18.4 is a system from Class 2. Class 3 and Class 4 represent systems with an increasing role of the diesel gen-set and relatively smaller PV generators and batteries. The "Class 1" system is a system without a back-up generator, designed to operate with high reliability in Europe.

Solar home systems (SHSs), which were not included in the survey, operating under the favourable conditions of low latitudes would typically be equipped with a three- to five- "day" battery and would not show the pronounced long-lasting period of

[8] Diesel gen-sets are currently the most common solution for an additional controllable generator. Other solutions like thermoelectric, thermophotovoltaic or fuel cell generators have been developed in many places and might be alternatives in the near future.