# Energy Conservation using Photovoltaic Plants

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***ABSTRACT:*** *Energy conservation and development are critical activities across countries. Optimum energy use ensures and protects the environment. In this work, we designed a solar energy system using photovoltaic cells. The use of photovoltaic cells helps the conversion of energy into electricity.*

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## 1. Introduction

The Sun is the largest fully renewable source of electricity production. The technology for direct conversion of sunlight into electricity is called photovoltaic (PV). It has rapidly developed in recent years. Photovoltaic systems are more widely used in civilian areas since the beginning of the 21st century. They offer environmentally friendly electricity production and reduce environmental pollution with the use of traditional methods for energy production [1, 2, 3]. The Solar PV system is a very reliable and clean source of electricity that can suit a wide range of applications such as residence, industry, agriculture, livestock, etc.

The basic components of the photovoltaic system are the PV modules. They change the solar energy into DC power that can be converted into AC power by an inverter. Then the power can be connected to the grid or used for AC load (appliances). Therefore, the photovoltaic systems could be divided into grid-connected systems, off-grid systems and hybrid systems.

The Solar PV systems include also many other components that should be selected according to the type of system, site location and applications. Backup batteries store unused at the moment electricity in order to supply electrical appliances when there is a demand. The solar charge controller regulates the voltage and the current coming from the PV panels and going to the battery. It prevents from battery overcharging and prolongs the battery life.

The Balance of system equipment (BOS) includes mounting systems and wiring systems used to integrate the solar modules into the structural and electrical systems of the building. The wiring systems include disconnects for the DC and AC sides of the inverter, ground-fault protection, and overcurrent protection for the solar modules. Meters providing indication of system performance could be also included in the installation. Some meters can indicate energy usage.

The aim of this paper is to design a grid-connected PV system for converting solar energy into electricity using solar modules mounted on the roof of the building. Produced power will serve the domestic use of the laboratory "Renewable energy sources" in the "University of Transport"– Sofia. The design and construction of this PV installation will create possibilities of research and experiments by PhD students and teachers, as well as laboratory exercises with students in the programs of "Power Engineering and Electrical Equipment" and "Electric Vehicles".

## 2. Solar PV System Sizing

The designs of a PV system include the determination of the size and orient the PV array to provide the expected electrical power and energy as well as selection of the other components of the solar installation.

### 2.1. Determine Power Consumption Demands

This solar PV system will be mainly used for experimental research and training of students. The selected power is 3 kW, because such solar plants are widely used in residential PV power systems. Lighting of the laboratory and the corridors of the building as well as computers and other low-power consumers will be the load of the system.

### 2.2. Determine The Pv Modules Output Power

PV systems produce power in proportion to the intensity of sunlight striking the solar array surface. The intensity of light on a surface varies throughout a day, as well as day to day, so the actual output of a solar power system can vary substantially.

Most PV systems produce 55-to-110 Watts per square meter of array area. This is based on a variety of different technologies and the varying efficiency of different PV products. We dispose 32 solar modules Kaneka HB105, which will be installed on the roof.

| | |
|---|---|
| STC Power | *PSTC* (*Pmax*) 105 Wp |
| STC Nominal Voltage | *Umpp* 53,5 V |
| STC Nominal Current | 1,96 A |
| STC Open circuit voltage | *Uoc* 71,0 V |
| STC Short circuit current | *Isc* 2,40 A |
| Power tolerance | +10%...-5% |
| Nominal Operating Cell Temperature (NOCT) | 44oC |
| Ambient temperature (from … to) | -25...60 oC |
| Temperature coefficient of *Isc* | +0,1%/K |
| Temperature coefficient of *Isc* | -0,248V/K |
| Temperature coefficient of *Pmax* | -0,33%/K |
| Dimensions: 1210/1008/40 mm; Weight | 18,0 kg |

Table 1. Technical Data Of The Solar Modules Kaneka Hb105

They are ideal for large-scale PV plants and open-space installations. They offer a higher initial power and achieve excellent efficiency in diffuse light. These modules generate energy even in low irradiation and are suitable for grid-connected systems and for heavy snow loads up to 2,400 Pa (2.4 kN/m$^2$). Their technical data is given in Table 1 [6].

Solar modules produce DC electricity. The DC output of solar modules is rated by manufacturers under Standard Test Conditions (STC). These conditions are easily recreated in a factory, and allow for consistent comparisons of products, but need to be modified to estimate output under common outdoor operating conditions. STC conditions are: solar cell temperature = 25$^o$C; solar irradiance (intensity) = 1000 W/m$^2$ (often referred to as peak sunlight intensity, comparable to clear summer noon time intensity); and solar spectrum as filtered by passing through 1,5 thickness of atmosphere (Air mass $AM$ =1, 5). The modules Kaneka HB105 have a production tolerance of -5/+10% of the rating. It would be better to use the low end of the power output spectrum as a starting point (for example, 95 W for a "100-Watt module").

The module output power reduces as the module temperature increases [4]. When operating on a roof, a solar module will heat up substantially, reaching inner temperatures of 50-75$^o$C. For crystalline modules, a typical temperature reduction factor ($K_{tr}$) is 89% in the middle of a spring or fall day, under full sunlight conditions.

Dirt and dust can accumulate on the solar module surface, blocking some of the sunlight and reducing the output. If the solar panels are regularly cleaned, a typical annual dust reduction factor ($K_d$) to use is 90%.

The maximum power output of the total PV array is always less than the sum of the maximum output of the individual modules. This difference is a result of slight inconsistencies in performance from one module to the next and is called module mismatch and amounts to at least a 2% loss in system power. Power is also lost to resistance in the system wiring.

These losses should be kept to a minimum but it is difficult to keep these losses below 3% for the system. A reasonable reduction factor for these losses ($K_l$) is 95%.

The DC power generated by the solar module must be converted into AC power using an inverter, which could be connected to the electric power system. Some power is lost in the conversion process, and there are additional losses in the wires from the rooftop array down to the inverter. Modern inverters commonly used in residential PV power systems have peak efficiencies of 92-94% indicated by their manufacturers, but these again are measured under wellcontrolled factory conditions. Actual field conditions usually result in overall DC-to-AC conversion efficiencies $\eta_{inv}$ of about 88-92%, with 90% a reasonable compromise.

So the module output has to be reduced by production tolerance ($K_{pt}$), heat ($K_{tc}$), dust ($K_d$), AC conversion ($\eta_{inv}$), wiring and other losses ($K_l$). Therefore, the coefficient of the reduction $K_{red}$ may be calculated by Eq. 1:

$$K_{red} = K_{pt}.K_{tc}.K_d.\eta_{inv}.K_l \qquad (1)$$

After the calculation, the value of the $K_{red}$ is 0,65.

Figure 1. Roof mounted solar PV panels

So the rated power PSTC of one module $P_I$ should be reduced by $K_{red}$ and could be calculated by Eq. 2:

$$P^I = K_{red}.P_{STC} = 0{,}65.P_{STC} \quad (2)$$

Therefore, the solar plant output power could be determined by Eq. 3:

$$P = n.P^I = 32.0{,}65.105W = 2186W \approx 2{,}19kW \quad (3)$$

where $n$ = 32 is the number of the modules.

The PV array will be mounted above and parallel to the roof surface with a standoff of several centimeters for cooling purposes (Figure 1) [8]. During the course of a day, the angle of sunlight striking the solar module will change, which will affect the power output. The output from the modules will rise from zero gradually during dawn hours, and increase with the sun angle to its peak output at midday, and then gradually decrease into the afternoon and back down to zero at night. While this variation is due in part to the changing intensity of the sun, the changing sun angle (relative to the modules) also has an effect. The pitch of the roof will affect the sun angle on the module surface, as well as the orientation of the roof.

If the module surface on a 32°-pitch roof faces due South in Sofia, the array will give the greatest output (correction factor $K_o$ of 1.00). The South-West facing roof at a little bigger pitch would reduce the annual energy by 95% approximately (correction factor $K_o$ of 0.95).

Annual energy production depends of the duration of solar radiation during different months of the year. According to the weather station the maximum sunshine throughout the year in Sofia is $t_s$ = 1993 $h$ [9, 10]. Thus the energy produced by the solar plant for 1 year may be calculated by Eq. 4:

$$E_y = P.K_o.t_s = 2{,}19kW.0{,}95.1993 = 4146{,}5kWh \quad (4)$$

Dividing the total energy per year by 365 the average value of the produced solar energy for 1 day may be obtained:

$$E_d = 4146{,}5kWh / 365 \approx 11{,}4kWh \quad (5)$$

This energy will be sufficient to power the system load.

**2.3. Inverter**

The input rating of the inverter should never be lower than the total power of the load. The inverter must have the same nominal voltage as the battery. An IBC ServeMaster 3300MV inverter will be used in the solar installation. Its technical data is given in the Table 2 [7]. These inverters are innovative and ideal for small and medium photovoltaic systems. They are suitable for outdoor installation. Two individual DC inputs with separate MPP trackers are available. Maximum power point tracking (MPPT) is a technique that inverters use to get the maximum possible power from the solar PV panels. MPP trackers compensate for potential performance loss in partial shade or in the case of varying module alignments. The inverters are made by ride-through technology and tolerate voltage fluctuations that frequently occur in grids. They have very low standby and night consumption (8W and 0,2W respectively). A useful added benefit is the communications interface for system monitoring.

**2.4. Battery**

The battery type recommended for usage in the solar PV system is the deep cycle battery. The deep cycle battery is specifically designed in order to be discharged to low energy level and rapid recharged or cycle charged and discharged day after day for years. The battery should be large enough to store sufficient energy to power the load at nightfall and cloudy days.

The number of batteries depends on the inverter voltage.

8 pcs lead-acid 24-V batteries or 60 pcs lithium-ion cells will be used [5]. When they are fully charged, the voltage of the inverter input will be 202V approximately.

| | |
|---|---|
| Nominal DC power (*PDC*) | 3,6 kW |
| Nominal AC power (*PAC*) | 3,3 VA |
| Nominal input voltage (*UDC*) | 310 V |
| MPP-voltage | 180-350 V |
| Max DC voltage – individual/parallel | 450/410V |
| Output voltage range (*UAC*) | 230V+15% |
| AC frequency range (*f*) | (50+5)Hz |
| Nominal DC current | 5,8 A |
| Max DC current *IDC* (2 DC inputs) | 2x10 A |
| Nominal AC current | 14,5 A |
| Max. AC current | 15,5 A |
| Max. efficiency / Euro efficiency | 94,2/93,4% |
| Power factor at >20% load | 0,97 |
| Max THD (total harmonic distortion) | 5 |
| Max night consumption | 0,2 W |
| Dimensions: 618/434/182 mm; Weight | 20,0 kg |
| Interfaces | RS-485modem |

Table 2. Technical Data of the Inverter IBC Servemaster 3300mv

**2.5. Solar charge controller**

The charge controller limits the rate at which electric current is added to or drawn from electric batteries. It prevents from overcharging and may prevent against overvoltage, which can reduce battery performance or lifespan, and may pose a safety risk. It may also prevent completely draining ("deep discharging") a battery, or perform controlled discharges, depending on the battery technology, to protect battery life. Some controllers have a "PWM" mode. Pulse Width Modulation (PWM) is often used as one method of float charging. The controller constantly checks the state of the battery to determine the pulses frequency.

The selected solar charge controller has to match the voltage of PV array and batteries. The solar charge controller must also have enough capacity to handle the current from PV array. Thus, the selection of the charge controller depends on PV panel configuration. The PV modules will be connected in series 4 and 8 parallel (4x8 configuration). According to standard practice, the sizing of solar charge controller is to take the short circuit current (Isc) of the PV array multiplied by 1.3. So the solar charge controller should be rated 26A at 200V or greater.

The scheme of the designed solar PV system is shown in Figure 1. Measuring, safety and protective equipment are not represented, but they are also appropriately selected.

**3. Experimental Research**

The conduct of research and training of the students require appropriate measuring equipment. Many ammeters, voltmeters and

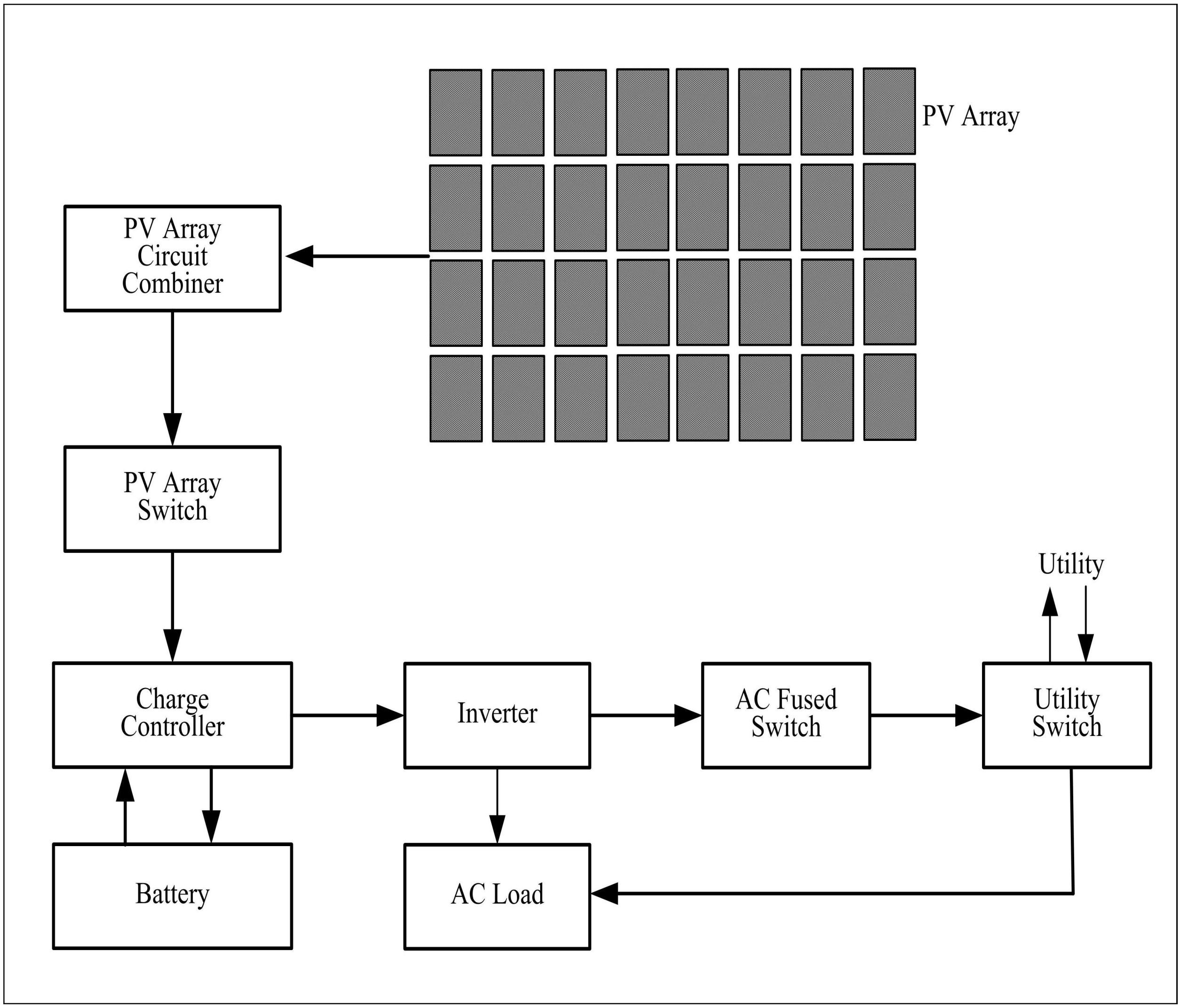


Figure 2. Principle of operation of the designed solar PV system

wattmeters are necessary. The efficiency of the solar PV system will be examined by them. The influence of the sun angle and radiation on the produced electricity, as well as the load changes on the AC voltage could be also studied. Energy consumption meter will be used to indicate recuperated energy.

Using communication interface of the inverter the values of the all-important parameters could be exported to a computer and traced in real time: $U_{DC}$, $I_{DC}$, $P_{DC}$, $U_{AC}$, $I_{AC}$, $P_{AC}$, $f$, $t\,^oC$, Electricity (day, week, month, and year, as well as total). The device status and faults could be displayed.

**4. Conclusion**

In this paper the design of a solar PV plant is made. This system will be used for research and training of the students. It will also reduce electricity costs. Produced energy will power the lighting and other low-voltage consumers.

The construction of the laboratory "Renewable energy sources" in the 'University of Transport' – Sofia will improve the quality of students education in this promising field. Possibilities of research will increase. The lecturers and PhD students will have the opportunity to set examinations on the solar PV system.

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