UNIT 3 SOLAR PHOTOVOLTAIC HYBRID POWER GENERATION

Structure

3.1 INTRODUCTION

There are many state nodal agencies which are installing solar PV systems for large scale applications in the country. Madhya Pradesh Urja Vikas Nigam (MPUVN) has been setting up decentralised solar photovoltaic applications in the rural areas of Madhya Pradesh for the last few years. A capacity of 66 KW has already been installed in the rural areas spread over 80 remote locations. In addition to this, the largest solar photovoltaic plant in India (capacity 239 KW) has been set up in the private sector at Steel Tubes of India, Dewas near Indore. MPUVN is now experimenting with grid connected photovoltaic systems. First such 100 KW grid connected system has already been installed by M/s Tata B.P. Solar, India at village Jaitpur Kalan of Rajgarh district in Madhya Pradesh. The Urja Bhawan at Bhopal is having a 10 KW SPV installation to meet emergency lighting needs which may be increased to 25 KW. You will learn the design features of such power generating systems.

Objectives

After studying this unit, you will be able to

- understand design features of solar PV systems,
- solar PV systems for irrigation purposes, and
- solar PV systems for power generation.

3.2 DESIGN OF SOLAR PV POWER SYSTEM

The photovoltaic power generation unit may be stand alone for supplying power to the scattered loads in the areas where it is difficult to take grid connected power. The output of a solar PV system is DC. For AC loads DC power may be converted to AC power by using inverters. A photovoltaic array consists of several solar cell interconnected in series or parallel combination. SPV systems need very little maintenance since only the cleaning of glass cover of PV module is required. Rain may do this job but these can also be washed. However, batteries may need proper care to perform at their maximum efficiency and to last longer.

A Photovoltaic power system for DC load is shown in Figure 3.1 and for AC load is shown in Figure 3.2.

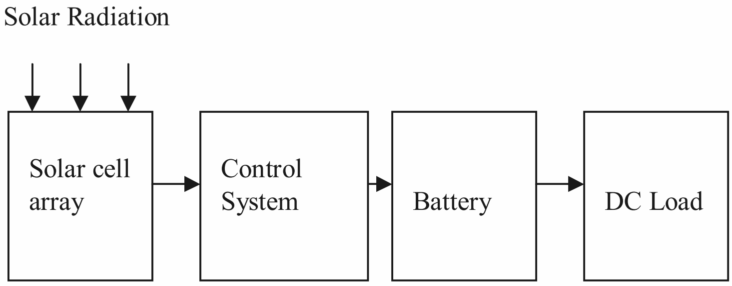

Figure 3.1 : Photovoltaic Power for DC Loads

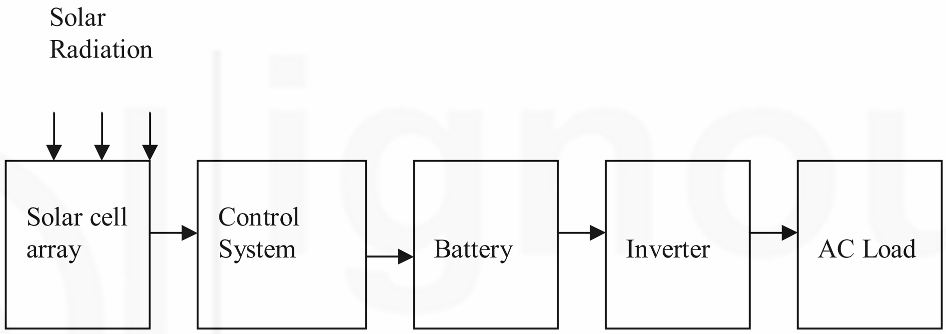

Figure 3.2 : Photovoltaic Power for AC Loads

A complete design process for SPV systems is beyond the scope of this course. However, we will give the salient features of the design process for you to understand the whole process.

Step 1 The first step is to know the conversion efficiency of a photovoltaic cell array. This may be defined as follows :

$$\eta = \frac{E}{A H \tau} \qquad \ldots (3.1)$$

where η = PV cell array efficiency,

E = Electrical energy produced by the PV cell array,

A = Area of PV cell array,

H = Solar irradiance per unit area on the PV cell array, and

τ = Transmissivity of the PV cell array cover.

Step 2 The second step is to calculate the electrical energy output of the PV cell array. The electrical energy output of the PV cell array is the difference between the absorbed solar radiation and the energy loss to the environment.

Thus, Electrical energy output of the PV cell array

= Absorbed solar radiation

– Energy loss to the environment

$$= A H \tau \alpha - A U (T_c - T_a) \qquad \ldots (3.2)$$

where α = Absorptivity of the cell,

U = Overall loss coefficient of the array, W/m^2-°C,

T_c = Temperature of the cell, °C,

T_a = Ambient air temperature, °C, and

$\tau\,\alpha$ = Tansmissivity-absorptivity product.

Step 3 The third step is to calculate the daily electrical energy produced, averaged over a month by the PV cell array. This average is given by

$$\overline{E} = A\,\overline{\tau}\,\overline{H}\,\overline{\eta} \qquad \ldots (3.3)$$

where $\overline{E}$ = Monthly average daily electrical energy produced by the PV cell array,

$\overline{H}$ = Monthly average daily irradiance per unit area on the cell surface, and

$\overline{\eta}$ = Monthly average array efficiency, defined as follows :

$$\overline{\eta} = \frac{\int \eta\, H\, dt}{\int H\, dt}$$

Step 4 Estimate the efficiency of the control system (battery, inverter etc). Let it be η_c. Then monthly average daily electrical energy available to the load, $\overline{E}_l$, is

$$\overline{E}_l = \eta_c\,\overline{E} \qquad \ldots (3.4)$$

Example 1

For a 1 m^2 solar cell array, the following data are given.

The array is used to supply a constant load of 20 W. The efficiency of power conditioning system is 95%. H = 15 MJ/m^{2}day. The average cell efficiency = 0.12. The transmissivity = 0.97. Determine the monthly average daily array output and monthly average daily electrical energy available.

Solution

Using Eq. (3.3), you can determine monthly average daily array output. This is given as follows :

$$\begin{aligned}\overline{E} = A\,\overline{\tau}\,\overline{H}\,\overline{\eta} &= (1\ \text{m}^2)\ (0.97)\ (15 \times 10^6\ \text{J/m}^2)\ (0.12)\\ &= 1.75 \times 10^6\ \text{J}\\ &= 1.75 \times 10^6\ \text{J/(3600 s/J)}\\ &= 485\ \text{Wh}\end{aligned}$$

The monthly average daily electrical energy available may be calculated by sing Eq. (3.4).

$$\overline{E}_l = \eta_c\,\overline{E} = 0.95 \times 485\ \text{Wh} = 460\ \text{Wh}$$

SAQ 1

What are the maintenance requirements of a solar photovoltaic system?

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3.3 SOLAR PV SYSTEM FOR LIFT IRRIGATION

The solar photovoltaic power generation system for lift irrigation depends upon the suction head and water requirements. You can see three options given in Table 3.1. The characteristics are for a clear sunny day and when solar panels are tilted towards south to get maximum solar radiation.

Table 3.1 : Solar PV Power Generation System for Lift Irrigation

Sl. No.	Water Requirement	Suction Head	PV Characteristics
1.	30000 to 40000 liters/day	5 meters	300 W panel
2.	50000 liters/day	7 meters	600 W panel
3.	(a) 75000 liters/day	10 meters	900 W panel
	(b) 110000 liters/day	6 meters	900 W panel

3.4 SOLAR PV POWER IN MW RANGE

At present, capital investment in a solar plant is Rs 15-18 crore/MW, four times that of thermal at Rs. 4-5 crore/MW. The cost is expected to reduce by half and efficiency double when nano technology is integrated in solar cells in about five years.

A solar project comprising 9,000 crystalline type solar modules of 230 W each has been commissioned in 2009 in West Bengal. The plant will generate three million units of electricity a year, enough to light 2,000 rural or 500 urban households.

The facility will save seven lakh tonnes of CO_2 emission a day. That's as much CO_2 as two MW thermal projects emit daily. The power that the solar plant will generate will be fed into the grid for distribution to customers in the Asansol-Raniganj belt.

As on June 2009, half the project has been completed with the 4,500 solar modules generating 1.25 MW electricity. The project is expected to play a crucial role in achieving the solar mission of 15,000 MW under the Prime Minister Climate Action Plan. That is imperative with the Planning Commission projecting a capacity addition of 6.5 lakh MW from thermal, nuclear, hydel and gas by 2030, leaving a deficit of 1.5 lakh MW that only solar energy can meet.

With current technology, solar energy can generate eight lakh MW by utilizing wastelands across the country (MNRE Annual Reports).

3.5 SOLAR PV POWER PLANTS

In SPV power plant, electricity is centrally generated. This electricity is either made available to users through a local grid in a 'stand-alone' mode, or connected to the conventional power grid in a 'grid interactive' mode. Stand-alone power plants provide grid-quality power locally to people to meet their requirements for lighting and other needs. Power plants are preferred over individual SPV systems if a number of users are in close proximity. The cost of power may be of the order of Rs. 15 per KWh for a grid interactive power plant and higher for stand-alone power plant.

3.5.1 Stand-alone Solar Power Plant

A stand-alone SPV power plant is typically designed for specific requirements. The capacity of a stand-alone power plant usually varies from 1 KWp to 25 KWp. These systems are used where conventional grid supply is not available, or is erratic or irregular. A stand-alone power plant functions like an uninterrupted power supply (UPS) and provides a constant, stable, and reliable supply to the loads. These power plants can also be used in areas where grid supply is available; in such places the power plants operate like a hybrid power plant, working with grid, as well as with SPV. The capacity of its battery bank depends on user requirements. The most common use for such plants is the electrification of remote villages. Other uses include power for hospitals, hotels, communications equipment, railway stations, border outposts, etc.

Stand-alone SPV power plants comprise PV array, battery bank, inverter, and charge controller. Depending on the system voltage, SPV modules are arranged in series and parallel combinations. The standard combinations are 2, 4, 6, 10, 20 or more modules. The corresponding system voltages are in the range of 24 to 240 V. The size of the battery bank is determined by the system voltage and ampere-hour requirements of the load. The inverter is selected based on the system voltage and peak-load capacities. Other components such as junction boxes, distribution boxes, and cables are selected according to the maximum amount of current to be handled by them.

The cost of a stand-alone power plant depends on the PV array size, battery bank capacity, inverter, etc. The approximate cost of a standalone power plant is between Rs. 3.00 lakhs and Rs. 3.50 lakhs per KW of PV capacity. Distribution costs (such as in a village) may be extra.

3.5.2 Solar Generators

A solar generator is a small capacity, stand-alone SPV power system based on a PV array, connected to a battery bank and an inverter of appropriate size. This system is designed to supply power to limited loads (such as lights and fans) for a period of two to three hours daily in situations such as conventional power failure or load-shedding. The MNRE, Govt. of India is promoting four models of solar generators, with capacities of 150, 350, 450, and 600 Wp. These solar generators are mainly meant to replace the conventional small-capacity petrol-based generators that are used during routine load-shedding periods in urban areas by shops, clinics, and other small establishments.

The components of a typical solar generator are a small SPV array connected to a battery bank of appropriate size and an inverter based on 12, 24, or 48 V. The system is designed to supply power to loads such as lights, fans, credit-card operating machines, and personal computers for a period of two to three hours.

The cost of such solar generator models promoted by the MNRE varies from Rs. 35 000 to Rs. 145 000.

3.5.3 Building-integrated PV Systems

In a building-integrated photovoltaic (BIPV) system, PV panels are integrated into the roof or façade of a building. BIPV systems are becoming common in Europe, USA, and Japan. The SPV panels generate electricity during the daytime, which is used to meet a part of

the electrical energy needs of the building. BIPV systems have significant potential in India, where a large number of buildings are constructed every year for different purposes, and where energy consumption in buildings is growing at a rapid rate. Although the initial costs of a BIPV system are high, long-term savings result from a reduction in electricity consumption.

India needs more experience in the field of BIPV technology. In order to encourage this application and to prepare manufacturers and users, the Ministry supports BIPV projects by meeting 80% of the cost of PV modules installed in the systems on government and semi-government buildings.

3.5.4 SPV Pumping System

Water pumping is one of the most important applications of PV in India. A SPV water pump is a DC or AC, surface-mounted or submersible or floating pump that runs on power from an SPV array. The array is mounted on a suitable structure and placed in a shadow free open space with its modules facing south and inclined at local latitude.

A typical SPV water-pumping system consists of an SPV array of 200-3000 Wp capacity, mounted on a tracking/non-tracking type of structure. The array is connected to a DC or AC pump of matching capacity that can be of surface mounted, submersible, or floating type. Interconnecting cables and electronics make up the rest of the system. SPV water pumps are used to draw water for irrigation as well as for drinking. The normal pumping heads are in the range of 10 meter for irrigation, and 30 meter for drinking water. It is possible to use pumps with even greater head, especially for drinking water supply.

The SPV array converts sunlight into electricity and delivers it to run the motor to pump up water. The water can be stored in tanks for use during non-sunny hours, if necessary. For maximum power output from the SPV array, the structure on which it is mounted should track the sun. Electronic devices are used to do this in some models, thereby enabling the systems to operate at maximum power output. The power from the SPV array is directly delivered to the pump in the case of DC pumps. In the case of AC pumps, however, an inverter is used to convert the DC output of the array into AC. No storage batteries are used in an SPV pump.

An SPV pump based on a one-horsepower motor can irrigate about 1-1.5 hectares of land under a variety of crops except paddy and sugar cane (assuming a 10 m water table). Using the same pump along with drip irrigation, it is possible to irrigate up to 6 hectares of land for certain crops. A two-horsepower SPV pump could irrigate about 2-3 hectares of land under many crops except paddy and sugar cane (again assuming a 10 m water table).

The cost of an SPV pump depends on the capacity and type of pump. For example, a DC surface pump with a 900 W array may cost about Rs. 150 000; a similar pump of 1800 W may cost about Rs. 300 000; and an 1800 W AC submersible pump may cost about Rs. 422 000.

Source : Ministry of New and Renewable Energy Sources, Government of India, Block No. 14, CGO Complex, Lodi Road, New Delhi-110 003.

Web Site : **www.mnes.nic.in**

SAQ 2

Describe Solar PV Power Plants.

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3.6 LET US SUM UP

Madhya Pradesh Urja Vikas Nigam (MPUVN) has been setting up decentralised solar photovoltaic applications in the rural areas of Madhya Pradesh. A capacity of 66 KW has already been installed in the rural areas spread over 80 remote locations. The largest solar photovoltaic plant in India (capacity 239 KW) has been set up in the private sector at Steel Tubes of India, Dewas near Indore.

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The photovoltaic power generation unit may be stand alone for supplying power to the scattered loads in the areas where it is difficult to take grid connected power. The output of a solar PV systems is DC. Therefore, solar PV systems could be used for DC loads as well as for AC loads by converting DC power to AC power. A photovoltaic array consists of several solar cell interconnected in series and parallel combination.

The cost of a stand-alone power plant depends on the PV array size, battery bank capacity, inverter, etc. The approximate cost of a standalone power plant is between Rs. 3.00 lakhs and Rs. 3.50 lakhs per KW of PV capacity.

3.7 KEY WORDS

Battery

A device that stores energy and produces electric current by chemical action.

Inverter

A device that converts direct current to alternating current.

Kilowatt (KW)

A unit of electric power (energy consumed per unit time) equivalent to 1,000 watts.

Kilowatt- hour (KWh)

A unit of energy; the energy consumed by 1 KW of power in 1 hour.

Solar Cell

A semiconductor device capable of converting solar radiations directly into electricity.

Solar Generators

A solar generator is a small capacity, stand-alone SPV power system based on a PV array, connected to a battery bank and an inverter of appropriate size.

Building Integrated PV Systems

PV panels are integrated into the roof or façade of a building. The SPV panels generate electricity during the daytime, which is used to meet a part of the electrical energy needs of the building.

Solar Photovoltaic Cell

A semi-conductor device capable of converting solar radiations directly into electricity.

3.8 ANSWERS TO SAQS

SAQ 1

A solar photovoltaic installation requires minimal and very easy maintenance. PV modules need very little or no maintenance due to their configuration. The rain eliminates the need for cleaning the modules, but if necessary they can be washed using water and non abrasive detergent. The batteries need more attention; their effective life will be dependent upon their correct use and maintenance. The electrolyte level should be checked every 6 months.

SAQ 2

The solar PV plants are the following :

(1) Stand-alone Solar Power Plant

A stand-alone SPV power plant is typically designed for specific requirements. The capacity of a stand-alone power plant usually varies from 1 KWp to 25 KWp.

(2) Solar Generators

A solar generator is a small capacity, stand-alone SPV power system based on a PV array, connected to a battery bank and an inverter of appropriate size. This system is designed to supply power to limited loads (such as lights and fans) for a period of two to three hours daily.

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(4) SPV Pumping System

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