UE8020200

PHOTOVOLTAIC SYSTEMS

OBJECTIVE

Investigate how partial shading affects photovoltaic systems

EXPERIMENT PROCEDURE

- **Measure and analyse the *I-U* characteristic and *P-R* characteristic for a series circuit containing two photovoltaic modules.**
- **Measure and analyse the characteristics with the modules partially in shade both with and without by-pass diodes.**
- **Demonstrate the reverse bias voltage for an unprotected module in shadow.**
- **Determine the loss of power resulting from partial shading.**

SUMMARY

In photovoltaic installations, multiple solar modules are usually connected in series in a long line. The modules themselves are made up of many solar cells connected in series. In practice, it is possible for such systems to be partially in shadow. Individual parts of the system are then exposed to less light and therefore generate little current, which then limits the current in the whole series circuit. This can be avoided by means of by-pass diodes. In this experiment, two modules each consisting of 18 solar cells are formed into a simple photovoltaic system. They can optionally be connected in series with or without by-pass diodes and are then illuminated with light from a halogen lamp.

REQUIRED APPARATUS

Quantity	Description	Number
1	SEK Solar Energy (230 V, 50/60 Hz)	**1017732 or**
	SEK Solar Energy (115 V, 50/60 Hz)	**1017731**

BASIC PRINCIPLES

In photovoltaic installations, multiple solar modules are usually connected in series in a long line. The modules themselves are made up of many solar cells connected in series.

Calculation of current and voltage for such a series circuit follows from Kirchhoff's laws, taking into account the current-voltage characteristic of the solar cells. The same current *I* flows through all the modules in the series circuit and the voltage is given by

(1) $$U = \sum_{i=1}^{n} U_i$$

n: Number of modules

This is the sum of all the voltages U_i between the terminals of the individual modules.

The current-voltage characteristic of a solar cell or module can be easily explained by means of an equivalent circuit diagram made up of a constant voltage source supplying a photoelectric voltage and a "semiconductor diode" connected in parallel with it but in reverse-bias direction. Resistive losses which occur are represented by a resistor, also connected in parallel in the system (see Experiment UE8020100 and Fig. 1). The photoelectric current is proportional to the intensity of the illuminating light. When the intensity is the same for all modules, then they all respond alike and individually supply the same voltage. Equation 1 then implies:

(2) $$U = n \cdot U_1$$

In practice, however, it is possible for such systems to be partially in shadow. Individual modules in the system are then exposed to less light and therefore generate little photoelectric current, which then limits the current in the whole series circuit. This limiting of current causes differing voltages U_i to be generated by the individual modules.

In the extreme case, the voltages across fully illuminated modules, even under short-circuit conditions ($U = 0$), can attain values going as far as the open-circuit voltage, see Fig. 2. The sum of these voltages is in reverse-bias direction across the modules in shadow. This can lead to enormous amounts of heating and can destroy the capsules in which the solar cells are contained or even the cells themselves. To protect against this, photovoltaic systems are equipped with by-pass diodes, which allow the current to by-pass elements which are in shadow.

In this experiment, two modules each consisting of 18 solar cells are formed into a simple photovoltaic system. They can optionally be connected with or without by-pass diodes in series and are then illuminated with light from a halogen lamp. Initially the two modules are both illuminated with the same bright intensity of light, but later one module is put into shadow such that it only supplies half the amount of current.

In all cases *I-U* characteristics are plotted from short-circuit to open-circuit range and compared. Power values are also calculated as a function of the load resistance to determine the amount of power loss as a result of the shading and to determine the effect of the by-pass diodes.

For the case of a short-circuit, the voltage across the shaded module is also measured separately. It reaches -9 V if the module is not protected by a by-pass diode.

EVALUATION

If a module only supplies half the amount of photoelectric current, for example, it will be responsible for determining the short-circuit current for the whole series circuit in the absence of any by-pass diodes.

With by-pass diodes, the fully illuminated module can supply its higher current until this starts to decrease when the open-circuit voltage of the individual module is reached.

The mathematical model for evaluating the measurements in Figs. 3 and 4 takes into account Kirchhoff's laws and utilises the current-voltage characteristic for the individual modules obtained in Experiment UE8020100 with parameters I_S, U_T and R_P. To take account of the by-pass diodes, their own characteristics are used.

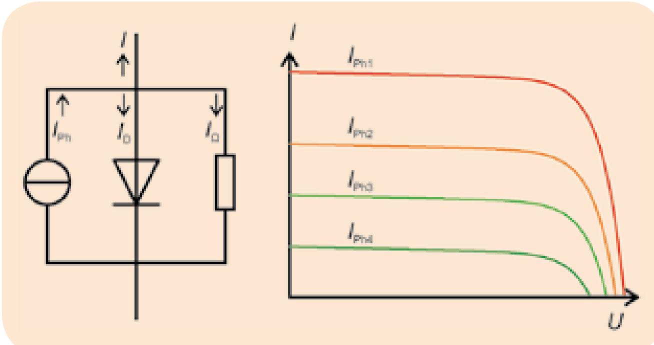

Fig. 1: Equivalent circuit diagram and characteristics of a solar cell

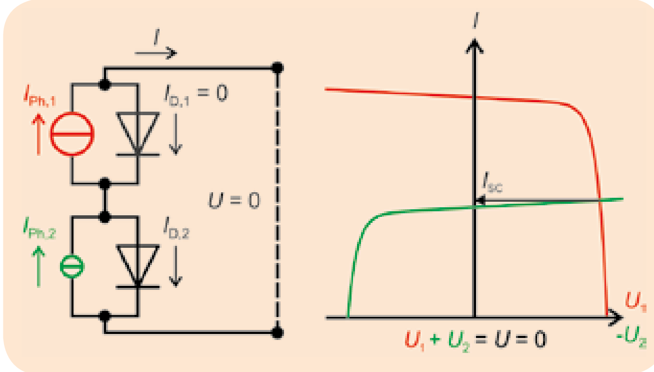

Fig. 2: Schematic diagram of partial shading of two modules with no by-pass diodes under short-circuit conditions ($U = 0$). The characteristic of the shaded model (green) is shown reversed. Here it represents a voltage of U_2 in the reverse-bias direction.

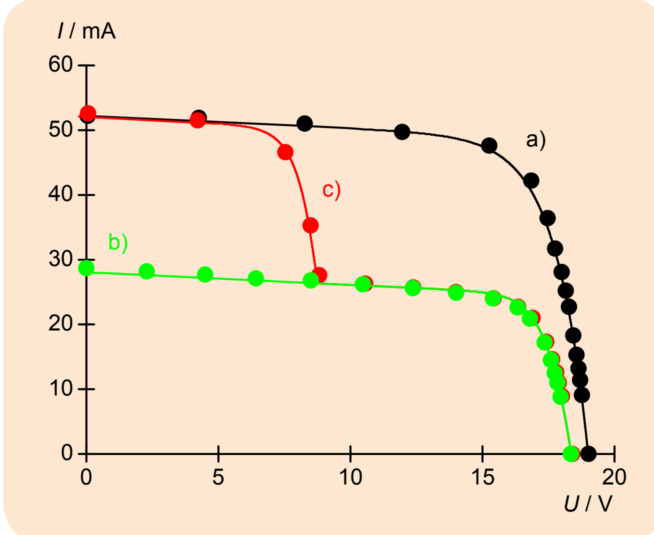

Fig. 3: *I-U* characteristic for series circuit containing two solar modules a) with no shading, b) partial shading without by-pass, c) partial shading with by-pass

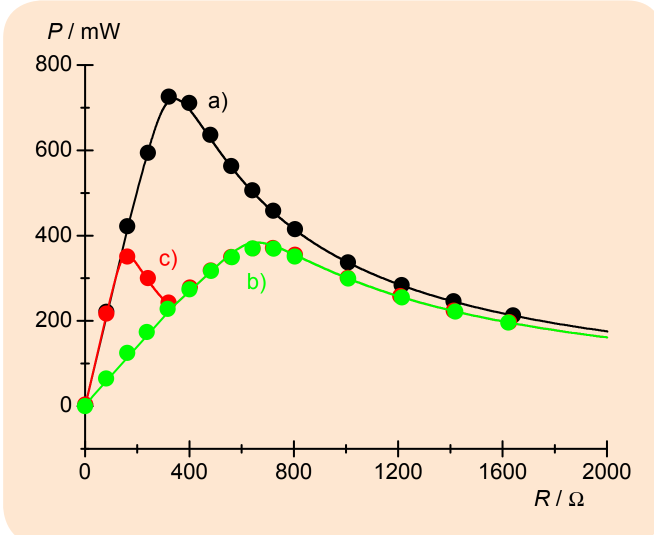

Fig. 4: *P-R* characteristic for series circuit containing two solar modules a) with no shading, b) partial shading without by-pass, c) partial shading with by-pass

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1