



SCHOOL OF COMPUTING AND ENGINEERING SCIENCES
MASTER OF SCIENCE IN SUSTAINABLE ENERGY TRANSITIONS
UNIVERSITY EXAMINATION - 2023
MSSET 8501: SOLAR PHOTOVOLTAIC SYSTEMS

DATE: 9th January 2023

Time: 2 Hours

Instructions

1. This examination consists of **FOUR** questions.
2. Answer **QUESTION ONE** and any other **TWO QUESTIONS**.

Question 1 (20 Marks)

You are asked to design a stand-alone PV system for a house in Kenya, where the annual insolation is 2190 kWh/m². The PV modules have to be placed horizontally on a flat roof. The PV system should operate at 24V and power both DC and AC devices listed in Table Q1(a). You buy the PV modules and batteries with the specifications given in Table Q1(b). The PV module consists of 48 c-Si PV cells with a nominal voltage of 0.5 V. The nominal current density of these c-Si cells is 35 mA/cm²

Table Q1(a)

Device	Rated power	Daily usage	Type
Lamps	20 W	6 hours	DC
Water pump	100 W	8 hours	DC
Laptop	50 W	4 hours	AC
TV	130W	5 hours	AC

Table Q1(b)

PV Module		Battery	
Nominal voltage	24.0 V	Nominal Voltage	24.0 V
Nominal current	5.5 A	Capacity	65 Ah

- (i) Calculate the total daily amount of current (expressed in Ah) that the PV system has to provide. In your calculation assume an inverter efficiency of 85% and additional system losses of 20%.
- (ii) What is the daily equivalent hours of sunshine for this location?
- (iii) Assuming that the PV cells are square, what is their size?
- (iv) How many PV modules do you need? Should they be connected in series or parallel?
- (v) You would like to have a reserve time of 2 days. How many batteries do you need?

Ignore seasonal variations and assume that the battery will be operated at 80% of its full capacity.

- (vi) Make a simple sketch to show how the PV modules, batteries, inverter and charge controller are connected. Also indicate where AC and DC devices will be connected to the system.

Question 2 (15 Marks)

You are asked to design a stand-alone PV system for a remote hospital in South Africa. Your PV system needs to power an important cooling system that has to keep the vaccines at a constant temperature of 5°C, every hour of the day, every day of the year. The cooling system is a DC system, operating at 48V. The power consumption (P_{cool}) in watts of the cooling system depends on the outside temperature (T_{out}) and is given by the equation:

$$P_{cool} = 60W + |T_{out} - 5^{\circ}C| \times 40W/^{\circ}C$$

The daily average outside temperature and the equivalent sun hours (ESH) for the location in South Africa vary with the seasons and are given in Table Q2:

Table Q2

Season	Winter	Spring	Summer	Autumn
T_{out} (°C)	8	14	32	17
ESH (kWh/m ² ·day)	1.8	7.0	7.6	4.5

- (i) For each season, calculate the power consumption of the cooling system P_{cool} and the corresponding daily amount of Ah that it requires for continuous operation.
 (ii) Explain why this PV system does not need an inverter.

You decide to power the PV system with modules that under Standard Test Conditions (STC) conditions have a nominal voltage (V_{mpp}) of 48V and a nominal current (I_{mpp}) of 5A. One PV module is 1.20 m long and 1.00 m wide. You do not have to take into account any safety factors or losses.

- (iii) What is the efficiency of these PV modules?
 (iv) For each season, how many PV modules do you need to power the cooling system? Should the PV modules be connected in series or parallel?

The system needs enough energy storage to achieve a reserve time of 7 days. Batteries with a nominal voltage of 48V and capacity of 100Ah are available. In order not to damage the batteries they should only be operated between 100% (full) and 20% state of charge.

- (v) How many of these batteries would you install?

Question 3 (15 Marks)

- (a) The working principle of a solar cell is based on the photovoltaic effect. What is the photovoltaic effect and which are the fundamental processes behind this effect? Sketch a schematic cross-section of a typical crystalline silicon solar cell to briefly explain these fundamental processes.
 b) The behaviour of a solar cell can be described by an equivalent circuit. Sketch the

equivalent circuit of a real, non-ideal solar cell and briefly explain what each element of the equivalent circuit represents in a real solar cell.

Question 4 (15 Marks)

- (a) The efficiency of solar cells is measured under standard test conditions (STC). Also indicate the external solar cell parameters and explain how the solar cell efficiency can be derived from this graph.
- (i) What are the standard test conditions?
 - (ii) Sketch a typical measurement graph and indicate which variables are on the x and y axis.
- (b) The solar cell external quantum efficiency (EQE) as a function of wavelength can be measured.
- (i) How is the external quantum efficiency (EQE) defined?
 - (ii) What is the approximate EQE in high-quality crystalline silicon solar cells at 1250nm. Briefly explain your answer.