Lappeenranta University of Technology

School of Energy Systems

BL20A1400 Renewable Energy Technology

EXAMINATION: 8th May 2026

C. Breyer/A. Gulagi

TIME: 08:30 – 10:30

- You are allowed to use one, double-sided sheet of A4-sized paper as a study aid during the exam. This study aid must be hand-written. No printouts or photocopies will be allowed. No other supplementary materials or dictionaries are allowed.
- Read and follow the instructions for each question carefully.
- Use the answer paper provided to show detailed calculations. Showing your formulas and calculations in detail will ensure that part marks can be awarded if minor calculation errors occur.
- Your name and student number must appear on all answer booklets.
- Calculators with empty memory/offline may be used.
- All questions should be answered in English and in a clear and legible handwriting.

EXAM TOTAL: 40 points

Answer **ALL** of the following questions. Showing your calculations in detail will ensure that part marks can be awarded if minor calculation errors occur.

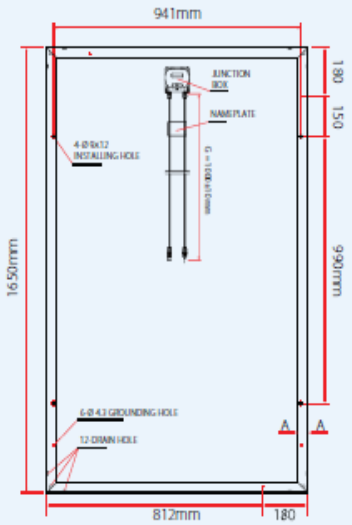
1. Use the manufacturer's specifications provided for the TSM-PC05 solar modules. **(Total 10 points)**

   a. Calculate the efficiency of the **TSM-240 PC/PA05** at Nominal Operating Cell Temperature (NOCT) **(2 points)**

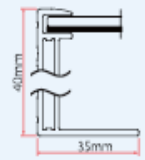
   b. Calculate the **Maximum Power Point (Mpp)**, **Short circuit current (Isc)**, **Open circuit voltage (Voc)** and **efficiency** of the **TSM-240 PC/PA05** panel at a cell temperature of 15 ºC lower than NOCT, assuming all other conditions are the same. **(8 points)**

TSM-PC05 / TSM-PA05 THE UNIVERSAL SOLUTION

DIMENSIONS OF PV MODULE TSM-PC/PA05

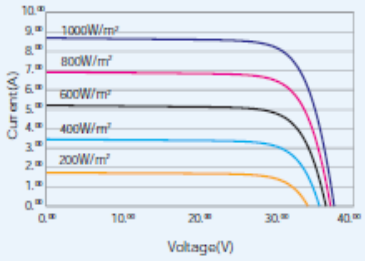


Back View



A-A

I-V CURVES OF PV MODULE TSM-245 PC/PA05



Average efficiency reduction of 4.5% at 200W/m² according to EN 60904-1.

CERTIFICATION

ELECTRICAL DATA @ STC	TSM-235 PC/PA05	TSM-240 PC/PA05	TSM-245 PC/PA05	TSM-250 PC/PA05
Peak Power Watts-P_{MAX} (Wp)	235	240	245	250
Power Output Tolerance-P_{MAX} (%)	0/+3	0/+3	0/+3	0/+3
Maximum Power Voltage-V_{MP} (V)	29.3	29.7	30.2	30.3
Maximum Power Current-I_{MPP} (A)	8.03	8.10	8.13	8.27
Open Circuit Voltage-V_{OC} (V)	37.2	37.3	37.5	37.6
Short Circuit Current-I_{SC} (A)	8.55	8.62	8.68	8.85
Module Efficiency η_m (%)	14.4	14.7	15.0	15.3

Values at Standard Test Conditions STC (Air Mass AM1.5, Irradiance 1000W/m², Cell Temperature 25°C).
Power measurement tolerance: ±3%

ELECTRICAL DATA @ NOCT	TSM-235 PC/PA05	TSM-240 PC/PA05	TSM-245 PC/PA05	TSM-250 PC/PA05
Maximum Power-P_{MAX} (Wp)	171	174	178	181
Maximum Power Voltage-V_{MP} (V)	26.4	26.6	26.8	27.0
Maximum Power Current-I_{MPP} (A)	6.48	6.55	6.64	6.70
Open Circuit Voltage (V)-V_{OC} (V)	34.0	34.1	34.2	34.3
Short Circuit Current (A)-I_{SC} (A)	6.97	7.04	7.10	7.25

NOCT: Irradiance at 800W/m², Ambient Temperature 20°C, Wind Speed 1m/s.
Power measurement tolerance: ±3%

MECHANICAL DATA	
Solar cells	Multicrystalline 156 × 156mm (6 inches)
Cell orientation	60 cells (6 × 10)
Module dimensions	1650 × 992 × 40mm (64.95 × 39.05 × 1.57 inches)
Weight	19.5kg (43.0 lb)
Glass	High transparency solar glass 3.2mm (0.13 inches)
Frame	Anodized aluminium alloy
J-Box	IP 65 rated
Cables	Photovoltaic Technology cable 4.0mm² (0.006 inches²), 1000mm (39.4 inches)
Connector	MC4

TEMPERATURE RATINGS	
Nominal Operating Cell Temperature (NOCT)	45°C (±2°C)
Temperature Coefficient of P_{MAX}	- 0.43%/°C
Temperature Coefficient of V_{OC}	- 0.32%/°C
Temperature Coefficient of I_{SC}	0.047%/°C

MAXIMUM RATINGS	
Operational Temperature	-40~+85°C
Maximum System Voltage	1000V DC(IEC)/ 600V DC(UL)
Max Series Fuse Rating	15A

WARRANTY
10 year workmanship warranty
25 year linear performance warranty

(Please refer to product warranty for details)

PACKAGING CONFIGURATION
Modules per box: 24 pcs
Modules per 40' container: 672 pcs

TSM_EN_Jun_2012

2. Consider the following data for Israel in 2030, where the components of the electricity system are assumed to be ground-mounted solar PV, stationary batteries, and a PtG system (including gas storage). Assume WACC is 5%. **(Total 14 points)**

Parameter	Unit	Electrolysis	Methanation	Carbon capture	CCGT	Solar PV
Capex	€/kW	380	278	335	775	390
Opex_fixed	€/kW	13	13	13	19	11
Opex_variable	€/kWh	0.0012	0.0015	0.0013	0.002	0
FLH	hours	1780	1780	1780		1700
Efficiency	%	70 %	85 %	95 %	58 %	
Lifetime	years	30	30	25	30	35

Parameter	Unit	Battery	Gas storage
Capex	€/kWh	134	0.05
Opex_fixed	€/kWh	4	0.001
Opex_variable	€/kWh	0.0002	0
Efficiency (round trip)	%	85 %	100 %
Lifetime	years	20	50

Parameter	Unit	Value
Average daily consumption	kWh_e	15
Number of households		300000
Hours of year	h	8760
Daily consumption	GWh_e	4.5
Annual consumption	GWh_e	1642.5
Average hourly power demand	kW_e	187500
Battery capacity	kWh_e	8
Battery E/P	h	6
Battery cycles/a		365
Number of batteries		300000

a) Calculate the total amount of energy that would be charged to the batteries in GWh_e. **(2 points)**

b) Calculate the total amount of energy that would be discharged from the batteries in GWh_e. **(2 points)**

c) Calculate the amount of electricity output that would come from the CCGT in GWh_e. **(2 points)**

d) Calculate the amount of gas that would be needed to produce the electricity output from CCGT in GWh_{gas}. **(1 points)**

e) Calculate the total amount of solar PV energy that would need to be generated over the year in GWh_e. (**2 points)**

f) Calculate the solar PV capacity needed to produce that energy in MW_p. **(1 points)**

g) Calculate the necessary charge power of the PtG system in MW_e. **(2 points)**

h) Calculate the amount of gas storage needed in GWh_{gas} if the equivalent of a 6-month supply of gas is to be stored. **(2 points)**

3. PtX: Methanol production (6 points)

Methanol production in the PtX process is defined by the following:

Methanol synthesis

$$CO_2 + 3H_2 \leftrightarrow CH_3OH + H_2O \quad \Delta H_{298K,50\,bar} = -40.9\ \frac{kJ}{mol}$$

Assume that an electrolyser can be operated at 84% efficiency to create hydrogen gas, and that CO_2 can be produced in a scrubber at an energy demand of 500 kWh/ton. The lower heating values of hydrogen and methanol are 120.21 and 20.094 MJ/kg, respectively. Calculate the efficiency of the PtX (here: power-to-methanol) process as a whole if only 80% of the raw materials are converted by the methanol synthesis process. Hint: assume 1000 mol production and calculate mass and energy flows.

Molar mass		
CO	g/mol	28
CO_2	g/mol	44
H_2	g/mol	2
CH_3OH	g/mol	32
H_20	g/mol	18

4. Examine the following data provided about rooftop solar PV systems in Finland and a battery storage system. Assume WACC of 2%. **(Total 10 points)**

Parameter	Unit	Rooftop solar PV 2020	Rooftop solar PV 2030
Capex	€/kW_p	1169	826
$Opex_{fixed}$	% of Capex per year	1.5%	1.5%
FLH	hours	1000	1000
Lifetime	years	30	35

Parameter	Unit	Value
Battery Capex	€	4000
Battery Opex	% of Capex/year	2.33%
Battery lifetime	years	15
Battery cycles per year	-	275
Round trip efficiency of battery	%	90%
Battery capacity	kWh_e	10
Capacity degradation factor	%	90%

a) Calculate the levelised cost of electricity for the rooftop solar PV system for 2030. **(3 points)**

b) Calculate the levelised cost of storage of the battery system using the 2030 LCOE for solar PV if the battery lifetime increased to 20 years, the round-trip efficiency increased to 95% and the capex of the battery decreased to €1800. **(4 points)**

c) How many doublings of battery capacity would need to occur in order to achieve this new capex of 1800€ if the learning rate were 20%? **(3 points)**