UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2022/2023

COURSE NAME	:	PHOTOVOLTAIC TECHNOLOGY
COURSE CODE	:	BNE 45303
PROGRAMME CODE	:	BNE
EXAMINATION DATE	:	JULY/AUGUST 2023
DURATION	:	3 HOURS
INSTRUCTIONS	1.	ANSWER ALL QUESTIONS
	2.	THIS FINAL EXAMINATION IS CONDUCTED VIA **CLOSED BOOK.**
	3.	STUDENTS ARE **PROHIBITED** TO CONSULT THEIR OWN MATERIAL OR ANY EXTERNAL RESOURCES DURING THE EXAMINATION CONDUCTED VIA CLOSED BOOK

THIS QUESTION PAPER CONSISTS OF **TEN (10)** PAGES

Q1 (a) Malaysia is aspiring to be a Low Carbon Nation by 2040. To achieve this, the government emphasizes on low carbon policies and investments to increase adoption and pursue selective leadership in low carbon sectors.

(i) Justify whether the policy of 'no new coal power plant' can be achieved in Malaysia.

(3 marks)

(ii) If you are a policy maker, suggest an alternative method for Malaysia to become a Low Carbon Nation by 2040.

(4 marks)

(b) Net Energy Metering (NEM) was as an initiative introduced in 2016 to replace the Feed-in Tariff scheme.

(i) Briefly explain the concept of Net Energy Metering.

(4 marks)

(ii) The take-up for NEM quota was very low which is less than 3% of the 500 MW allocated. To address this problem, MESTECC minister introduced an improvement to the scheme beginning of 1 January 2019. Discuss the problem with the old scheme and how the improved scheme aims to solve this.

(4 marks)

(c) If the annual maximum demand of a company is 10 MW. Suggest the maximum capacity of PV integration for NEM project in this company and determine the cost for mandatory study for this installation.

(3 marks)

(d) Photovoltaic cell consists of different layers of semiconductor.

(i) Explain the construction of N-type and P-type layers of PV cell.

(3 marks)

(ii) Draw and label the equivalent circuit of PV cell.

(4 marks)

Q2 (a) A site is located at a latitude of 18°N. Determine the best tilted angle for a PV array at solar noon:

(i) When the sun is over the equator.

(2 marks)

(ii) When the sun is over the tropic of cancer.

(4 marks)

(b) The shading profile for a site with latitude 7 deg N and longitude 103 deg E is shown on sun path chart in **Figure Q2(b)**. Using the monthly solar irradiation (H) data in **Table Q2(b)**, determine the following:

(i) Monthly shading factor (SF) for the location.

(3 marks)

(ii) Annual $PSH_{available}$ at the site.

(5 marks)

(iii) As a site advisor, do you recommend the site location to be installed with PV array and why?

(2 marks)

(c) A PV module is given with the electrical parameters as shown in **Table Q4(c)**.

(i) Sketch the I-V curve and P-V curve for this module and label all the electrical values on the curves correctly.

(4 marks)

(ii) Calculate the fill factor and efficiency of this module and discuss the results in your own words.

(5 marks)

Q3 As a technologies in a PV consultant company, you are given the task of designing a grid-connected photovoltaic (GCPV) system for a rooftop installation to generate maximum power. The rooftop is a flat concrete slab with dimensions 22 meters x 8.5 meters. You must use the PV module and inverter with the characteristics provided in **Table Q3(a)** and **Table Q3(b)**, respectively.

(i) Design an array configuration to fit the maximum number of modules possible. Assume the module gap is 20 mm. No clearance around the edges is required.

(6 marks)

(ii) Design the optimal array arrangement (Np and Ns) of PV module connection for one inverter together with the number of inverters required for the system.

(9 marks)

(iii) For the similar PV module in **Table Q3(a)**, if the client allocates a budget of RM70000 to invest in a complete GCPV system, determine the total number of modules if the cost of a similar complete system in the market is RM 31500 for a 5 kWp system.

(6 marks)

(iv) Evaluate the steps that can be taken to ensure a high performance ratio (PR) for the system.

(4 marks)

Q4 (a) **Table Q4(a)** shows the historical record of a client monthly consumption from the previous year. The client is requesting to have 90% of her electricity to be offset by energy produced from a PV system to be installed in her premise. As a PV technologies, you plan to design the system using **First Solar Series 6 model FS-6445** (refer appendix). Other information for your design are:

- Average daily PSH = 4.7 hours
- Average maximum ambient temperature = 34°C
- Cable loss = 1.5 %
- Inverter efficiency = 97 %

Show the necessary design steps and determine the minimum number of modules required to fulfill the client's request.

(10 marks)

(b) Provide the proper definition and relevant equations for the following terms:

(i) Yield

(2 marks)

(ii) Specific Yield

(2 marks)

(iii) Performance Ratio

(2 marks)

(c) A 5 MWp GCPV system in Alor Setar, Kedah uses the **First Solar Series 6 model FS-6445** (refer **Appendix A**). Here are the information available about the system and its location:

- Average daily PSH is 5 hours
- Average maximum ambient temperature is 33°C
- Dirt factor is 4%
- Cable losses 3%
- Inverter efficiency is 97.3%

Calculate the yield, specific yield and performance ratio of the system for the 3rd year.

(9 marks)

- END OF QUESTIONS –

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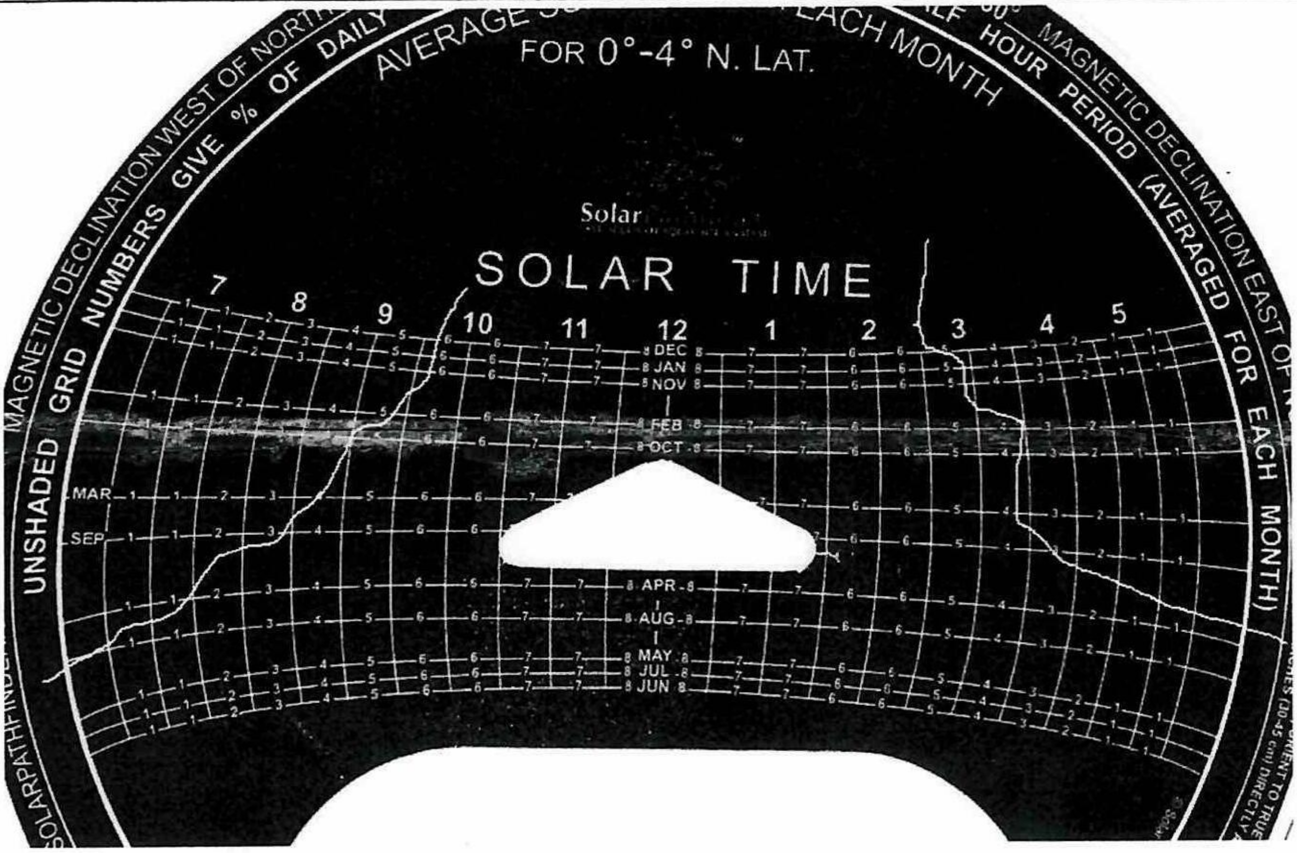

Figure Q2(b)

Table Q2(b)

Month	$kWhm^{-2}$	Month	$kWhm^{-2}$
Jan	125	Jul	139
Feb	121	Aug	156
Mac	130	Sep	149
Apr	150	Oct	135
May	159	Nov	125
Jun	146	Dec	124

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Table Q1(c)

Model: Ganfizky-250-PV		
Parameter	Unit	Value
Maximum power	W	250
Short circuit current	A	8.14
Open circuit voltage	V	45.2
Current at maximum power	A	6.39
Voltage at maximum power	V	39.1
No of cells		72
Cell size	mm x mm	125 x 125

Table Q3(a)

Electrical Values	
Parameter	Value
Maximum Power (W)	370
Open circuit voltage (V)	40.9
Short-circuit current (A)	11.52
Voltage at maximum power (V)	34.4
Current at maximum power (A)	10.76
Temperature coefficients (%/°C)	
k_{temp_Isc}	+0.05
k_{temp_Voc}	–0.265
k_{temp_Pmp}	–0.34
Dimensions (mm)	
Length	1755
Width	1038

Table Q2 (d)

Input Values (DC)	
Parameter	Value
Maximum Input Power (W)	8900
Vmpp-range (V)	335 - 800
V_{dc_max} (V)	900
I_{dc_max} (A)	25.4
Max no. of DC inputs (parallel)	4
Output Values (AC)	
Power (W)	8000
Nominal current (A)	34.8
Nominal voltage (V)	230
Efficiency (%)	97.1

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Table Q4(a)

Month	Energy (kWh)	Month	Energy (kWh)
Jan	921	Jul	1,054
Feb	1,023	Aug	**N/A**
Mar	1,045	Sep	937
Apr	**N/A**	Oct	898
May	985	Nov	**N/A**
Jun	907	Dec	915

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APPENDICES

LIST OF EQUATIONS

CSA of DC cable	$A_{\min\_dc\_cable} = \dfrac{2 \times L_{dc\_cable} \times I_{dc} \times \rho}{Loss \times V_{\min\_string}}$
Lowest voltage of maximum power	$V_{mp\_min} = V_{mp_{stc}} \times \left\{1 + \left(\dfrac{\beta_{voltage}}{100\%}\right) \times \left(T_{cell\_max} - T_{stc}\right)\right\}$
Voltage drop in cables	$V_{drop\_dc} = \dfrac{2 \times L_{dc\_cable} \times I_{dc} \times \rho}{A_{dc\_cable}}$
Power Loss in cable	$P_{dc} = \dfrac{2 \times L_{dc\_cable} \times (I_{dc})^2 \times \rho}{A_{dc\_cable}}$

GCPV System Protection

1. Bypass diode

Have a voltage rating of at least 2 x $V_{OC\ STC\ MOD}$ of the protected module.
Have a current rating of at least 1.3 x $I_{SC\ STC\ MOD}$

2. Overcurrent Protection

DC rated trip current: 1.5 x $I_{SC\ STC\ MOD} \leq I_{\_TRIP} \leq$ 2 x $I_{SC\ STC\ MOD}$
DC voltage rating: ≥ 1.2 x $V_{OC\ STC\ ARRAY}$

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GCPV System Design Calculation

$$V_{max\_oc} = V_{oc\_stc} \times \left[1 + \frac{\gamma_{Voc}(\% / °C)}{100}\left(T_{cell\_min} - 25°C\right)\right]$$

$$\text{Max no of modules} = \frac{V_{max\_inv} \times 0.95}{V_{max\_oc}}$$

$$V_{min\_mp} = V_{mp\_stc} \times \left[1 + \frac{\gamma_{Pmp}(\% / °C)}{100}\left(T_{cell\_max} - 25°C\right)\right]$$

$$\text{Min no of modules} = \frac{V_{min\_inv} \times 1.1}{V_{min\_mp}}$$

$$I_{max} = I_{sc\_stc} \times \left[1 + \frac{\gamma_{Isc}}{100}\left(T_{cell\_max} - 25°C\right)\right]$$

$$\text{Max no of strings} = \frac{I_{max\_dc\_inv}}{I_{max} \times 1.2}$$

PV Design based on energy requirement

$$E_{req} = \frac{\%\,\text{energy to be supplied}}{100} \times \frac{12}{\text{no of months with data}} \times \sum_{m=1}^{12} \text{energy consumption}$$

$$k_{temp} = 1 + \left[\frac{\gamma}{100} \times \left(T_{cell} - T_{stc}\right)\right]$$

$$P_{array\_stc} = \frac{E_{req}}{PSH_{poa} \times k_{deration}}$$

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APPENDIX A

First Solar Series 6 model FS-6445 (*for Q4)

MODEL TYPES AND RATINGS AT STANDARD TEST CONDITIONS (1000W/m², AM 1.5, 25°C)[2]							
NOMINAL VALUES		FS-6420 FS-6420A	FS-6425 FS-6425A	FS-6430 FS-6430A	FS-6435 FS-6435A	FS-6440 FS-6440A	FS-6445 FS-6445A
Nominal Power[3] (-0/+5%)	P_{MAX} (W)	420.0	425.0	430.0	435.0	440.0	445.0
Efficiency (%)	%	17.0	17.2	17.4	17.6	17.8	18.0
Voltage at P_{MAX}	V_{MAX} (V)	180.4	181.5	182.6	183.6	184.7	185.7
Current at P_{MAX}	I_{MAX} (A)	2.33	2.34	2.36	2.37	2.38	2.40
Open Circuit Voltage	V_{OC} (V)	218.5	218.9	219.2	219.6	220.0	220.4
Short Circuit Current	I_{SC} (A)	2.54	2.54	2.54	2.55	2.55	2.56
Maximum System Voltage	V_{SYS} (V)	1500[5]					
Limiting Reverse Current	I_R (A)	6.0					
Maximum Series Fuse	I_{CF} (A)	6.0					
RATINGS AT NOMINAL OPERATING CELL TEMPERATURE OF 45°C (800W/m², 20°C air temperature, AM 1.5, 1m/s wind speed)[2]							
Nominal Power	P_{MAX} (W)	317.2	320.9	324.7	328.5	332.4	336.0
Voltage at P_{MAX}	V_{MAX} (V)	168.7	169.8	170.9	172.0	173.1	174.1
Current at P_{MAX}	I_{MAX} (A)	1.88	1.89	1.90	1.91	1.92	1.93
Open Circuit Voltage	V_{OC} (V)	206.3	206.6	207.0	207.3	207.7	208.0
Short Circuit Current	I_{SC} (A)	2.04	2.05	2.05	2.06	2.06	2.06

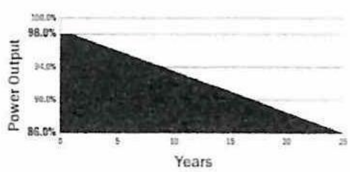
TEMPERATURE CHARACTERISTICS		
Module Operating Temperature Range	(°C)	-40 to +85
Temperature Coefficient of P_{MAX}	T_K (P_{MAX})	-0.32%/°C [Temperature Range: 25°C to 75°C]
Temperature Coefficient of V_{OC}	T_K (V_{OC})	-0.28%/°C
Temperature Coefficient of I_{SC}	T_K (I_{SC})	+0.04%/°C

420-445 Watts
17%+ Efficiency

INDUSTRY-LEADING MODULE WARRANTY[4]

98% WARRANTY START POINT

0.5% WARRANTED ANNUAL DEGRADATION RATE



- 25-Year Linear Performance Warranty
- 10-Year Limited Product Warranty