# UNIVERSITI TUN HUSSEIN ONN MALAYSIA

## FINAL EXAMINATION
## SEMESTER II
## SESSION 2023/2024

| | | |
|---|---|---|
| COURSE NAME | : | PHOTOVOLTAIC TECHNOLOGY |
| COURSE CODE | : | BNE 45303 |
| PROGRAMME CODE | : | BNE |
| EXAMINATION DATE | : | JULY 2024 |
| DURATION | : | 3 HOURS |
| INSTRUCTION | : | 1. ANSWER ALL QUESTIONS<br>2. THIS FINAL EXAMINATION IS CONDUCTED VIA<br>☐ Open book<br>☒ Closed book<br>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 **ELEVEN (11)** PAGES

**Q1** (a) For each of the following statements, indicate **True (T)** or **False (F)**.

(i) The implementation of the Feed-in Tariff (FiT) in Malaysia started in 2012.
(ii) The large scale solar (LSS) with capacity 29.99 MWac needs to be connected to the grid system through the transmission line.
(iii) Malaysia launched the LSS and Net-Metering (NEM) programs in 2016.
(iv) NEM 3.0 starts from December 2020 until December 2023.
(v) In the morning the hour angle is negative, in the afternoon the hour angle is positive.
(vi) The point where earth is farthest to the sun occurs on July 3rd. This point is called the perihelion.

(6 marks)

(b) Malaysia is aspiring to be a Low Carbon Nation by 2040. To achieve this, the government emphasizes 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.

(5 marks)

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

(4 marks)

(c) **Figure Q1.1** shows the sun path diagram for one location on 18/4/2024. From the diagram:

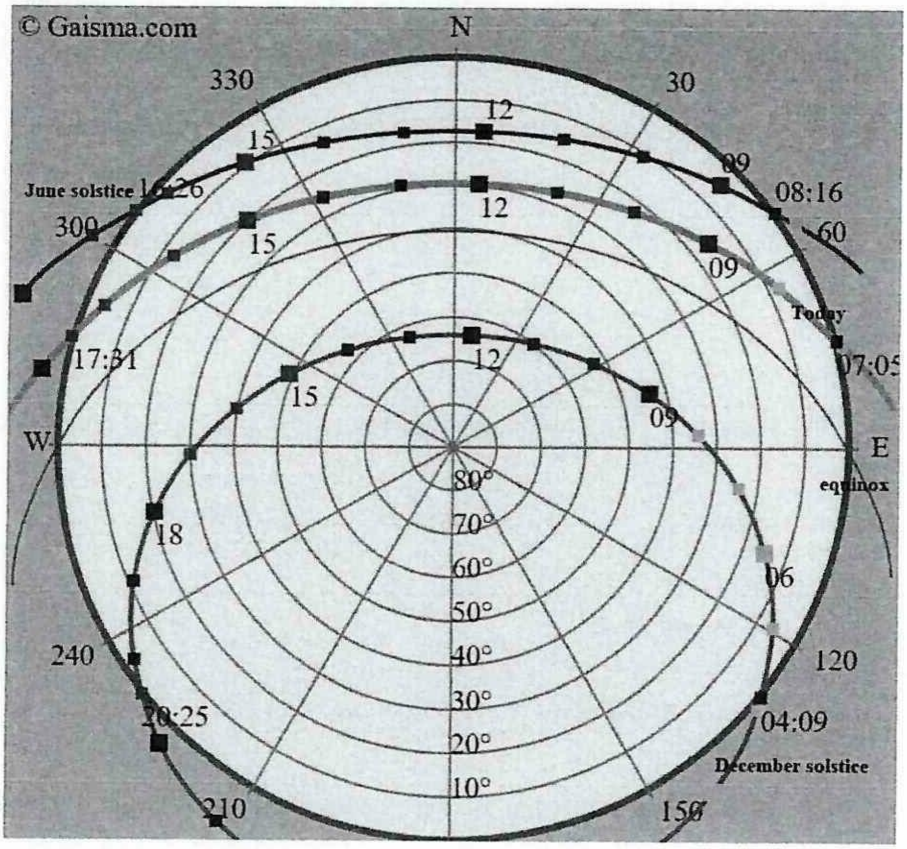



**Figure Q1.1** Sun Path for a Location

(i) Find the time when the azimuth is equal to 330° during the shortest day of the year.

(1 mark)

(ii) Throughout the year, determine the date on which the sun reaches its maximum altitude and find the corresponding elevation.

(2 marks)

(iii) The location located at the northern hemisphere. Is the statement true or false and explain why.

(3 marks)

(iv) Based on the sun path in **Figure Q1.1**, suggest **TWO (2)** photovoltaic (PV) system design that are suitable for this location with justifications.

(4 marks)

**Q2** (a) Feed in Tariff (FiT) and Net Energy Metering (NEM) schemes are an initiative introduced by government to support renewable energy technology. Briefly explain the concept of FiT and NEM.

(5 marks)

(b) A domestic customer's energy import and energy export from his rooftop PV system are shown in **Table Q2.1 (i)**. Use the tariff structure in **Table Q2.1 (ii)**. (The displaced cost of the old formula is 31 cents/kWh)

**Table Q2.1 (i)** Domestic Customer Energy Profile

| **Month** | **Energy Import (kWh)** | **Energy Export (kWh)** |
|---|---|---|
| February | 300 | 300 |
| March | 670 | 550 |

**Table Q2.1 (ii)** Domestic Tariff Structure

| **Tariff Category** | **Rates (cents/kWh)** |
|---|---|
| For the first 200 kWh (1 – 200 kWh) per month | 21.80 |
| For the next 100 kWh (201 – 300 kWh) per month | 33.40 |
| For the next 300 kWh (301 – 600 kWh) per month | 51.60 |
| For the next 300 kWh (601 – 900 kWh) per month | 54.60 |
| For the next kWh (901 kWh onwards) per month | 57.10 |

(i) Calculate the bill for each month using both the old and improved scheme of NEM.

(10 marks)

(ii) Compare the difference between the old and new scheme and compute the percentage of savings of the improved scheme compared to the old one.

(4 marks)

(c) Discuss the role of large-scale solar energy projects in Malaysia's renewable energy transition. Highlight **THREE (3)** key benefits of large-scale solar projects for the Malaysian energy sector and evaluate **THREE (3)** challenges or obstacles that may hinder the widespread adoption and effectiveness of large-scale solar initiatives in the country.

(6 marks)

**Q3** You have been appointed by Berjaya Holding company to design and install a grid-connected PV system for one of their officer's rooftops as shown in **Figure Q3.1**. The system will utilize PV-MJT250GB modules of which the data are as shown in **Figure Appendix A.**

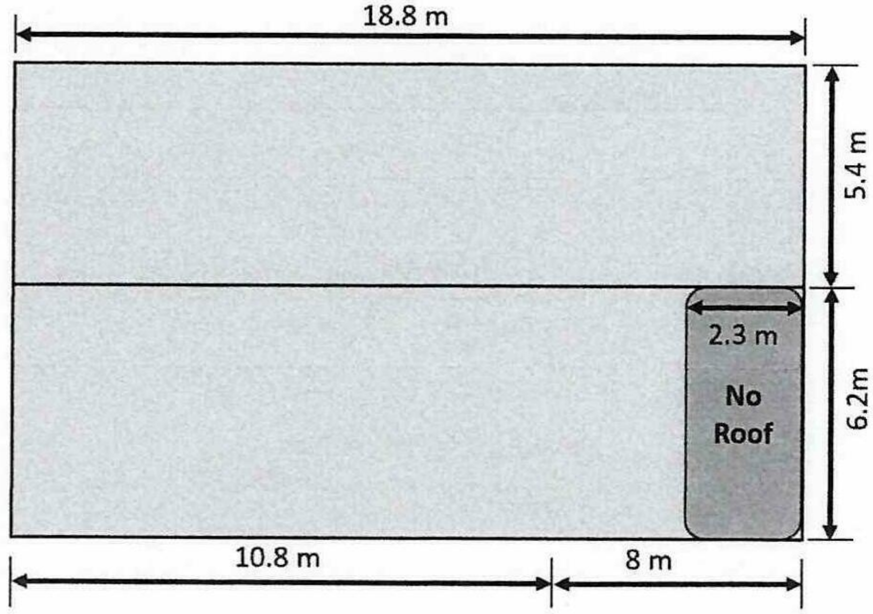



**Figure Q3.1** Top View of Rooftop

(a) You intend to use 100% of the rooftop space with the PV modules, calculate the maximum number of modules that can be installed and its total capacity in kWp. The gap between modules is 10 mm.

(7 marks)

(b) You are required to determine the minimum number of modules based on annual energy consumption listed in **Table Q3.1**. The premises operating at 66.67 % capacity annually, with a consistent of 5 % annual increment in energy consumption. Starting from 2024, the company set the offset at 80 % of the usage through energy generated from a PV system to be installed on the premises. Assume the following parameters:

- Average daily PSH = 3.5 hours
- Average maximum ambient temperature = 33.2 °C
- Cable losses = 1.05 %
- Inverter efficiency = 97.5 %

(9 marks)

**Table Q3.1** Annual Energy Consumption

| Year | Energy (kWh) |
|---|---|
| 2018 | 6240 |
| 2020 | 6864 |
| 2022 | 7488 |

(c) Based on **Q3(b)**, determine the optimal array arrangement (Np and Ns) of PV module connection for one inverter together with the number of inverters required for the system. Refer to **Figure Appendix B** for inverter characteristics. Choose 18.0 TR3 type.

(9 marks)

**Q4** As a technology specialist at a solar energy consultancy firm, your assignment involves solving several issues for a grid-connected photovoltaic (GCPV) system tailored for a rooftop setup.

(a) The solar panel with specifications as stated in **Table Q4.1** having 48-cell modules are connected in series connection and operated under STC. The solar panel has 4 diodes, with each diode connected in parallel to a string consisting of 12 cells. Sketch the most suitable connection diagram of the diodes and the PV module. Also estimated the voltage and current rating of the diode, string fuse and dc switch for solar module at STC.

(6 marks)

**Table Q4.1** Specifications of Solar Module at STC

| Parameter at STC | Value |
|---|---|
| Open circuit voltage | 50.4 V |
| Short circuit current | 9.4 A |
| Voltage at maximum power | 41.2 V |
| Current at maximum power | 7.5 A |

(b) Based on **Table Q4.1**, you are required to propose minimum cost for cable sizing for the system if the voltage drop and cable length are 2.25% and 15 m, respectively. Discuss your answer.

(4 marks)

(c) The design of a system uses the solar panel and an AMO-7K inverter as stated in **Figure Appendix A** and **Table Q4.2**, respectively. Given $PSH_{poa}$= 7h at house's location; cable losses of 3 %. Neglect all other derating factors.

**Table Q4.2** Specifications of AMO-7K inverter

| DC input | Value | AC output | Value |
|---|---|---|---|
| Nominal Power | 7,500 W | Nominal power | 7,300 VA |
| Maximum Power | 8,173 W | Max power | 7,955 VA |
| Max input voltage | 930 V | Operating AC voltage | 230 V |
| MPPT input voltage | 340-820 V | Operating frequency | 50 Hz |
| Min input voltage | 310 V | Power factor | +0.8 – 0.8 |
| Max input current | 2 x 11 A | $\eta_{max}$ | 97.3 % |

Using the information given, determine the following expected key performance indices at the end of the first year:

(i) Yield

(4 marks)

(ii) Specific Yield

(4 marks)

(iii) Performance ratio

(4 marks)

(d) What would happen if the performance ratio calculated in **Q4(c)(iii)** is less than 0.75 under testing period? Briefly describe your answer.

(3 marks)

- **END OF QUESTIONS** -

## APPENDIX A

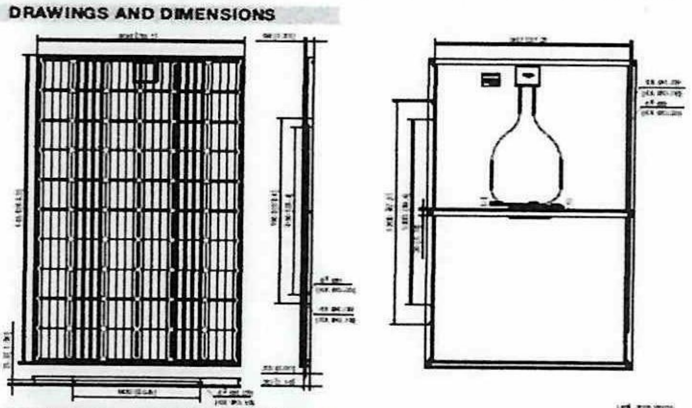
### MITSUBISHI ELECTRIC PHOTOVOLTAIC MODULES

#### SPECIFICATIONS SHEET

| | | |
|---|---|---|
| Manufacturer | MITSUBISHI ELECTRIC | |
| Model name | PV-MJT250GB | PV-MJT245GB |
| Cell type | Monocrystalline silicon, 156 mm × 156 mm | |
| Number of cells | 60 cells in a series | |
| Performance at STC | | |
| Maximum power rating (Pmax) | 250 W | 245 W |
| Warranted minimum Pmax | 242.5 W | 237.7 W |
| Tolerance of maximum power rating | +/-3 % (The average Pmax of each pair of modules has a positive tolerance) | |
| Open circuit voltage (Voc) | 37.4 V | 37.2 V |
| Short circuit current (Isc) | 8.80 A | 8.69 A |
| Maximum power voltage (Vmp) | 30.2 V | 30.0 V |
| Maximum power current (Imp) | 8.28 A | 8.17 A |
| Normal operating cell temperature (NOCT) | 47 °C | |
| Performance at NOCT (at 800 W/m²)* | | |
| Maximum power rating (Pmax) | 182 W | 177 W |
| Open circuit voltage (Voc) | 34.0 V | 33.8 V |
| Short circuit current (Isc) | 7.13 A | 7.04 A |
| Maximum power voltage (Vmp) | 27.2 V | 27.0 V |
| Maximum power current (Imp) | 6.62 A | 6.54 A |
| Maximum system voltage | 1000 V | |
| Fuse rating | 15 A | |
| Dimensions | 1658 × 994 × 46 mm (65.3 × 39.1 × 1.81 inches) | |
| Weight | 20 kg | |
| Output terminal | (+) 800 mm/(-) 1250 mm with MC connector (PV-KTB4/6I-UR, PV-KST4/6I-UR) Cable conforms with TÜV Specification 2 PfG 1169/08.2007 | |
| Module efficiency | 15.17 % | 14.87 % |
| Packing condition | 2 pcs / 1 carton | |
| Certificates | IEC 61215 Second Edition, IEC 61730 | |
| Product Warranty | 10 years | |
| Output Warranty | 90% of minimum rated Pmax for 10 years, 80% of minumum rated Pmax for 25 years | |

*Measured at 800W/m², ambient temp. 20 °C, wind speed 1 m/s

#### DRAWINGS AND DIMENSIONS

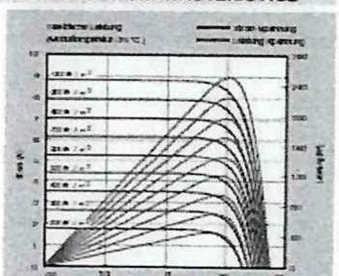


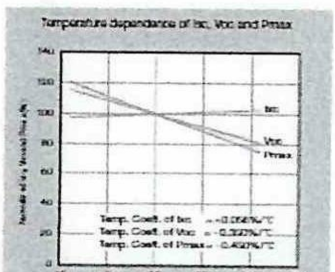
Unit: mm (inch)

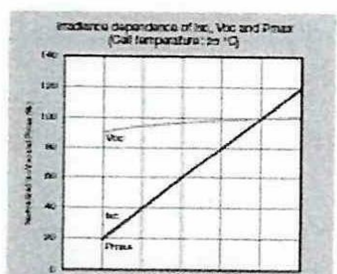
PV CYCLE

• Periodic Inspection
• Qualified IEC 61215
• Safety tested IEC 61730

#### ELECTRICAL CHARACTERISTICS




| 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 |

**APPENDIX B**

# Technical data

## Powador 16.0 TR3 | 18.0 TR3

| Electrical data | 16.0 TR3 | 18.0 TR3 |
|---|---|---|
| **Input variables** | | |
| PV max. generator output | 16000 W | 18000 W |
| MPP range | 200 V ... 510 V | 200 V ... 510 V |
| No-load voltage | 600 V* | 600 V* |
| Max. input current | 3 x 26 A | 3 x 26 A |
| Number of MPP trackers | 3 | 3 |
| Number of strings | 3 x 3 | 3 x 3 |
| **Output variables** | | |
| Rated output | 13500 VA | 15000 VA |
| Supply voltage | acc. to local requirements | acc. to local requirements |
| Rated current | 3 x 19.5 A | 3 x 21.7 A |
| Rated frequency | 50 Hz / 60 Hz | 50 Hz / 60 Hz |
| cos phi | 0.80 inductive ... 0.80 capacitive | 0.80 inductive ... 0.80 capacitive |
| Number of grid phases | 3 | 3 |
| **General electrical data** | | |
| Max. efficiency | 96.2 % | 96.2 % |
| European efficiency | 95.6 % | 95.7% |
| Night consumption | 1.9 W | 1.9 W |
| Switching plan | self-commutated, galvanically isolated, HF transformer | self-commutated, galvanically isolated, HF transformer |
| Grid monitoring | acc. to local requirements | acc. to local requirements |
| **Mechanical data** | | |
| Display | graphical display + LEDs | graphical display + LEDs |
| Control units | 4-way navigation + 2 buttons | 4-way navigation + 2 buttons |
| Interfaces | Ethernet, USB, RS485, S0 output | Ethernet, USB, RS485, S0 output |
| Fault signalling relay | potential-free NOC max. 230 V / 1 A | potential-free NOC max. 230 V / 1 A |
| Connections | screw terminals within the device (max. cross section: 16 mm² flexible) cable supply via cable connections (DC-connection M16, AC-connection M40) | screw terminals within the device (max. cross section: 16 mm² flexible) cable supply via cable connections (DC-connection M16, AC-connection M40) |
| Ambient temperature | -25 °C ... +60 °C** | -25 °C ... +60 °C** |
| Cooling | fan | fan |
| Protection class | IP54 | IP54 |
| Noise emission | < 45 dB (A) (noiseless when operated without fan) | < 45 dB (A) (noiseless when operated without fan) |
| DC-switch | integrated | integrated |
| Casing | aluminium casting | aluminium casting |
| H x W x D | 948 x 510 x 269 mm | 948 x 510 x 269 mm |
| Weight | 80 kg | 80 kg |

* To protect the hardware, the inverter starts up only at < 550 V / ** Power derating at high ambient temperatures
Applicable standards and regulations are taken into account for each country version that is set.

## 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: $\geq$ 1.2 x $V_{OC\ STC\ ARRAY}$

3. DC Main Switch

DC Voltage : $\geq$ 2 x $V_{OC\ STC\ ARRAY}$
DC Current : $\geq$ 1.2 x $I_{SC\ STC\ ARRAY}$

**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**

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

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

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

TERBUKA