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# UNIVERSITI TUN HUSSEIN ONN MALAYSIA

## FINAL EXAMINATION
## SEMESTER I
## SESSION 2022/2023

| | | |
|---|---|---|
| COURSE NAME | : | PHOTOVOLTAIC SYSTEMS |
| COURSE CODE | : | BEE 41503 |
| PROGRAMME CODE | : | BEV & BEJ |
| EXAMINATION DATE | : | FEBRUARY 2023 |
| DURATION | : | 3 HOURS |
| INSTRUCTION | : | 1. ANSWER ALL QUESTIONS<br>2. THIS FINAL EXAMINATION IS CONDUCTED VIA **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 **EIGHT (8)** PAGES



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**Q1** (a) List down the environmental factors that can affect the output of a PV panel.
(3 marks)

(b) Describe **three (3)** impacts of high temperature of PV cells towards the output of PV panel.
(3 marks)

(c) The datasheet of SuriaCinta 315 PV panel is tabulated in **TableQ1(c)**. Determine the expected maximum power output the PV panel when it is exposed to the following real operating condition:

- Operating PV cell temperature of 65°C.
- Irradiance of $800Wm^{-2}$
- Dirt 2%, no shading
- LID degradation is 2.5% on the zeroth year.

(14 marks)

**Q2** (a) Sketch the indirect feed-in grid connected photovoltaic (GCPV) system in low voltage system.
(3 marks)

(b) Draw and label the single-phase GCPV schematic diagram according to the MS1837.
(7 marks)

(c) Differentiate the advantages and disadvantages of the micro-inverter and central inverter.
(4 marks)

(d) Explain the **three (3)** main features of the GCPV inverter.
(6 marks)

**Q3** (a) A house has PV space area of 20m in length and 6 m in width. By using the QCells solar module shown in **FigureQ3(a)** and assuming the inter-module gap of 10mm,

(i) Determine the number of panels can be installed in landscape orientation.
(5 marks)

(ii) Determine the number of panels can be installed in portrait orientation.
(5 marks)

(iii) Justify the best orientation to maximize the energy harvesting for this house.
(2 marks)

(b) Mr. Razali plans to have a GCPV system that is capable for reducing annual energy consumption up to 80%. The monthly electricity consumption of his house is presented in **TableQ3(b)**. He plans to design the system with the following details:

- New QCells PV module 420W, datasheet is shown in **FigureQ3(a)**
- Average daily peak sun hour (PSH) of 4.5 h
- 4 % loss due to dirt
- 2.5 % cable loss
- 98 % inverter efficiency
- No shading
- Power degradation factor is 2%
- Average cell temperature is 55° C

Calculate the total number of PV modules to meet his target.

(8marks)

**Q4** (a) After considering several constraints, a client planned to install 27 units of QCells 430 W PV modules (datasheet given in **Figure 3(a)**) and an inverter in **Table 4 (a).** Given the maximum and minimum cell temperatures are 75° C and 20° C respectively.

(i) Determine the suitable inverter nominal power rating required if the DC/AC ratio set to 1.2.

(1 mark)

(ii) Determine the maximum number PV modules in series per string that will not damage the inverter.

(3 marks)

(iii) Determine the maximum number of PV modules in series per string based on the MPPT mode.

(3 marks)

(iv) Determine the maximum number of PV modules in series per string based on the maximum system voltage.

(3 marks)

(v) Find the maximum number of PV modules that can be connected in series.

(1 marks)

(vi) Determine the minimum number of PV modules in series per string based on MPPT mode. Given cable efficiency is 0.97.

(3 marks)

(vii) Determine the minimum number of PV modules in series per string that shall start up the inverter from the OFF mode.

(3 marks)

(viii) Find the minimum number of PV modules to connected in series.

(1 mark)

(ix) Find the maximum number of string per MPPT.

(2 marks)

**Q5** (a) List the importance of system performance and evaluations of a PV system

(4 marks)

(b) Differentiate between global monitoring and analytical monitoring for PV systems.

(6 marks)

(c) Your company has installed one GCPV system at Site A and another GCPV system at Site B. As the head of the project, you are instructed to evaluate which GCPV system is better in terms of acceptance ratio (AR) and energy performance index (EPI). The information for both sites is tabulated in **TableQ5(c)**.

(10 marks)

**-END OF QUESTIONS**

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| Parameter | Value | Parameter | Value |
|---|---|---|---|
| Maximum power | 315 W | $\gamma_{Pmax}$ | -0.37% °C$^{-1}$ |
| Power tolerance | 0 ~ +3% | $\beta_{Voc}$ | -0.28% °C$^{-1}$ |
| Short circuit current | 10.05 A | $\alpha_{Isc}$ | 0.048% °C$^{-1}$ |
| Open circuit voltage | 40.5 V | NOCT | 47 °C |
| Current at maximum power | 9.49 A | Efficiency | 18.9% |
| Voltage at maximum power | 33.2 V | Max. system voltage | 1 500 V DC |

**TableQ1(c)**

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| | | | |
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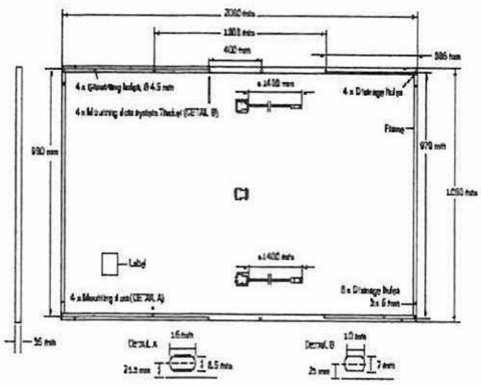
**PV Modules Datasheet (QCells)**

### MECHANICAL SPECIFICATION

| | |
|---|---|
| Format | 2080 mm × 1030 mm × 35 mm (including frame) |
| Weight | 24.5 kg |
| Front Cover | 3.2 mm thermally pre-stressed glass with anti-reflection technology |
| Back Cover | Composite film |
| Frame | Anodised aluminium |
| Cell | 6 × 24 monocrystalline Q.ANTUM solar half cells |
| Junction box | 53-101 mm × 32-60 mm × 15-18 mm Protection class IP67, with bypass diodes |
| Cable | 4 mm² Solar cable; (+) ≥1400 mm, (−) ≥1400 mm* |
| Connector | Stäubli MC4-Evo2, Hanwha Q CELLS HQC4, Amphenol UTX, Renhe 05-8, JMTHY JM601A, Tongling Cable01S-F; IP68 or Friends PV2e; IP67 |

*Short cables (+) ≥700 mm, (−) ≥ 350 mm are available upon request.



### ELECTRICAL CHARACTERISTICS

| POWER CLASS | | | | 420 | 425 | 430 | 435 |
|---|---|---|---|---|---|---|---|
| MINIMUM PERFORMANCE AT STANDARD TEST CONDITIONS, STC[1] (POWER TOLERANCE +5 W / −0 W) | | | | | | | |
| Minimum | Power at MPP[1] | $P_{MPP}$ | [W] | 420 | 425 | 430 | 435 |
| | Short Circuit Current[1] | $I_{SC}$ | [A] | 10.74 | 10.78 | 10.83 | 10.87 |
| | Open Circuit Voltage[1] | $V_{OC}$ | [V] | 48.84 | 49.09 | 49.33 | 49.58 |
| | Current at MPP | $I_{MPP}$ | [A] | 10.22 | 10.27 | 10.31 | 10.36 |
| | Voltage at MPP | $V_{MPP}$ | [V] | 41.08 | 41.39 | 41.70 | 42.00 |
| | Efficiency[1] | $\eta$ | [%] | ≥19.6 | ≥19.8 | ≥20.1 | ≥20.3 |
| MINIMUM PERFORMANCE AT NORMAL OPERATING CONDITIONS, NMOT[2] | | | | | | | |
| Minimum | Power at MPP | $P_{MPP}$ | [W] | 314.5 | 318.3 | 322.0 | 325.8 |
| | Short Circuit Current | $I_{SC}$ | [A] | 8.65 | 8.69 | 8.72 | 8.76 |
| | Open Circuit Voltage | $V_{OC}$ | [V] | 46.05 | 46.29 | 46.52 | 46.76 |
| | Current at MPP | $I_{MPP}$ | [A] | 8.05 | 8.08 | 8.12 | 8.15 |
| | Voltage at MPP | $V_{MPP}$ | [V] | 39.09 | 39.38 | 39.67 | 39.96 |

[1]Measurement tolerances $P_{MPP}$ ±3%; $I_{SC}$; $V_{OC}$ ±5% at STC: 1000 W/m², 25±2 °C, AM 1.5 according to IEC 60904-3 • [2]800 W/m², NMOT, spectrum AM 1.5

**TEMPERATURE COEFFICIENTS**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Temperature Coefficient of $I_{SC}$ | $\alpha$ | [%/K] | +0.04 | Temperature Coefficient of $V_{OC}$ | $\beta$ | [%/K] | −0.27 |
| Temperature Coefficient of $P_{MPP}$ | $\gamma$ | [%/K] | −0.35 | Nominal Module Operating Temperature | NMOT | [°C] | 43±3 |

Maximum system voltage = 1000 V

**FigureQ3(a)**

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| Month | Jan | Feb | Mar | Apr | May | Jun | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Energy (kWh) | 800 | N.A | 900 | 850 | N.A | 910 | 870 | 900 | 800 | 850 | 900 | 850 |

N.A – Not available

**TableQ3(b)**

**Inverter Datasheet**

| Technical Data | Rating |
|---|---|
| Input (DC) | |
| Maximum input voltage | 1100 V |
| Start Voltage | 150 V |
| MPPT Voltage Range | 160 V-1000 V |
| Maximum Input Current per MPPT | 11 A |
| Max DC Short Circuit Current | 20 A |
| Number of MPPT | 2 |
| Number of Input per MPPT | 2 |
| Output (AC) | |
| Nominal or Rated Power | 10,000 W |
| Rated Voltage | 230 V / 50 Hz |
| Efficiency | 98 % |

**TableQ4(a)**

| Site A | | Site B | |
|---|---|---|---|
| Pout measured | 32 280 W | Pout measured | 23 156 W |
| Pout expected | 31 305 W | Pout expected | 28 880 W |
| Eout measured | 59.01 MWh | Eout measured | 43.16 MWh |
| Eout expected | 56.17 MWh | Eout expected | 48.88 MWh |

**TableQ5(c)**

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**List of Formulae**

$$P_{max} = P_{maxSTC} \times f_{mm} \times f_{degrad} \times f_{temp\ p} \times f_g \times f_{clean} \times f_{unshade}$$

$$f_{degrade} = f_{LID} \times f_{age}$$

$$f_g = \frac{G_i}{1\,000}$$

$$f_{temp\_p} = 1 + \left[\left(\frac{\gamma_{Pmax}}{100}\right) \times (T_{mod} - T_{STC})\right]$$

$$E_{Req} = \frac{\varepsilon}{100\%} \times \frac{12}{n} \times \sum_{m=1}^{12} E_m$$

$$P_{Array\_STC} = \frac{E_{req}}{PSH \times k_{\det eration} \times n_{sub\_system}}$$

$$f_{temp\_ave} = 1 + \left[\left(\frac{\gamma_{p\max}}{100}\right) \times \left(T_{\mathrm{mod\_}ave} - T_{STC}\right)\right]$$

$$P_{nom\_inv} \geq \frac{P_{A\_STC}}{f_1}$$

$$V_{oc\_\max} = V_{oc\_STC} \times \left\{1 + \left[\left(\frac{\beta_{Voc}}{100}\right) \times (T_{\mathrm{mod\_min}} - T_{STC})\right]\right\}$$

$$V_{P\max\_\max} = V_{P\max \times STC} \times \left\{1 + \left[\left(\frac{\beta_{Vp\max}}{100}\right) \times (T_{\mathrm{mod\_min}} - T_{STC})\right]\right\}$$

$$V_{OC\_\max} = V_{OC\_STC} \times \left\{1 + \left[\left(\frac{\beta_{voc}}{100}\right) \times (T_{\mathrm{mod\_min}} - T_{STC})\right]\right\}$$

$$V_{p\max\_\min} = V_{p\max\_STC} \times \left\{1 + \left[\left(\frac{\beta_{vp\max}}{100}\right) \times (T_{\mathrm{mod\_max}} - T_{STC})\right]\right\}$$

$$V_{OC\_\min} = V_{OC\_STC} \times \left\{1 + \left[\left(\frac{\beta_{voc}}{100}\right) \times (T_{\mathrm{mod\_max}} - T_{STC})\right]\right\}$$

$$N_{p\max\_per\_mppt} = r.d\left[\frac{I_{SC\_\max\_mppt}}{I_{SC\_STC} \times sf}\right]$$

$$AR = \frac{P_{out\ measured}}{P_{out\ expected}} \qquad EPI = \frac{E_{out\ measured}}{E_{out\ expected}}$$