
TAKE SOME REST & SEE U TOMORROW

KURSUS DESIGNING OF GRID CONNECTED SOLAR PV SYSTEMS (11 – 13 OKTOBER 2021)

MASA HARI	8.30 Pg - 9.00 Pg	9.00 Pg - 10.30 Pg	10.30 pg - 11.00 Pg	11.00 Pg - 1.00 tgh	1.00 ptg - 2.30 Ptg	2.30 Ptg - 4.30 Ptg
HARI PERTAMA	PEMBUKAAN & PRE TEST	**SLOT 1** Fundamental of RE Technology Kandungan: - Background - RE Technology - Solar PV system Kaedah : Ceramah Penceramah : (Ir Dr Abdul Muhaimin)	REHAT : MINUM PAGI	**SLOT 2** Asas kejuruteraan Sistem Solar Photovoltaic (PV) Kandungan : - Spesifikasi & standard MS1837 - Basic earth geography - Solar-earth-collector geometry - Availability of solar energy Kaedah: Ceramah Penceramah : (Ir Dr Abdul Muhaimin)	REHAT : MAKAN TENGAHARI	**SLOT 3** Teknologi Solar PV & Balance of System (BOS) Kandungan : - Spesifikasi & standard MS62093 - PV cells, modules, string & array - Electrical performance - Balance of System components Kaedah : Ceramah Penceramah : (Ir Dr Abdul Muhaimin)
HARI KEDUA	**SLOT 4** Teknologi Solar PV & Balance of System (BOS) – (sambungan) Kandungan: - Connection to the grid - Interconnection issues Kaedah : Ceramah Penceramah : (Ir Dr Abdul Muhaimin)			**SLOT 5** Rekabentuk sistem grid connected solar PV Kandungan: - Dimensioning of PV array - Sizing of PV array to inverter Kaedah : Ceramah & latihan Penceramah : (Ir Dr Abdul Muhaimin) Fasilitator : (Mohd Quyyum)		**SLOT 6** Rekabentuk sistem grid connected solar PV - (sambungan) Kandungan: - Dimensioning of PV array - Sizing of PV array to inverter Kaedah : Ceramah & latihan Penceramah : (Ir Dr Abdul Muhaimin) Fasilitator : (Mohd Quyyum)
HARI KETIGA	**SLOT 7** Rekabentuk sistem grid connected solar PV - (sambungan) Kandungan: - Sizing of BOS components - Penyediaan lukisan skematik - System performance & evaluation - Key performance indices Kaedah : Ceramah & latihan Penceramah : (Ir Dr Abdul Muhaimin) Fasilitator : (Mohd Quyyum)			**SLOT 8** Kerja berkumpulan Kandungan: - Case study of solar PV grid connected design Kaedah : Latihan berkumpulan Penceramah : (Ir Dr Abdul Muhaimin) Fasilitator : (Mohd Quyyum)		**SLOT 9** Pemasangan sistem (hands-on), operasi & penyelenggaraan Kandungan: - Spesifikasi & standard MS2692 - Testing and commissioning - Operation and maintenance Kaedah : Ceramah & Latihan Hands-on di lapangan Penceramah : (Ir Dr Abdul Muhaimin) Fasilitator : (Mohd Quyyum)

Connection to the Grid

- GCPV can be categorised as:
  - Distributed system
    - Small to medium sized systems, eg: residential houses & industrial premises
    - Connected to LV side of grid supply
  - Centralised system
    - Large scale GCPV, eg: solar farm
    - Connected at MV side of grid supply

Balance of System (BOS) Components

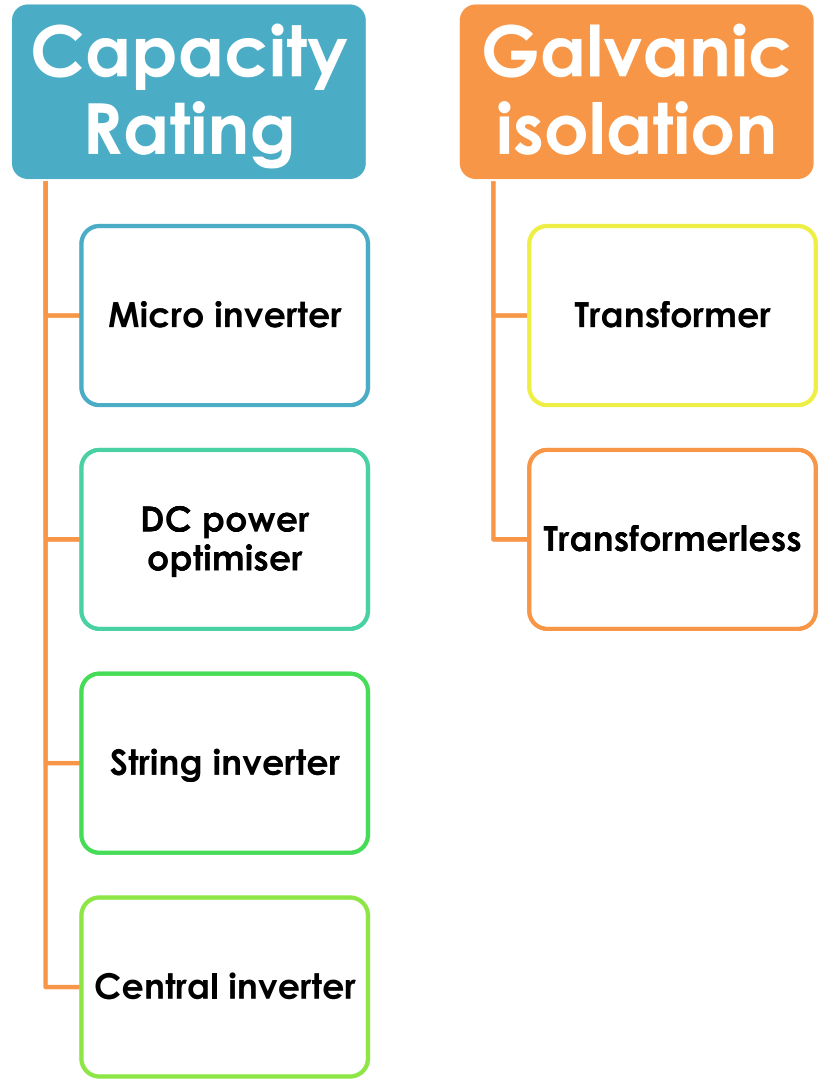
Grid Inverter

- DC to AC conversion
- Works with the presence of grid voltage
- Standard Features
  - – Maximum input voltage
  - – Input voltage window (MPP voltage window)
  - – Rated & maximum AC power
  - – Operating frequency
  - – Range of operating grid voltage
  - – Anti-islanding detection
  - – Etc…refer to data sheet

Grid Inverter
Types of GCPV inverter

String Inverter

- Single phase grid inverter
- Multiple PV string can be combined in the Array Junction Box (AJB) before connected to string inverter
- Maximum DC current should not be exceeded



Grid Inverter

Types of GCPV inverter

Central Inverter

- Three phase grid inverter
- Usually used for large scale GCPV as power rating for an inverter can reach up to a few megawatts

Capacity Rating

- Micro inverter
- DC power optimiser
- String inverter
- Central inverter

Galvanic isolation

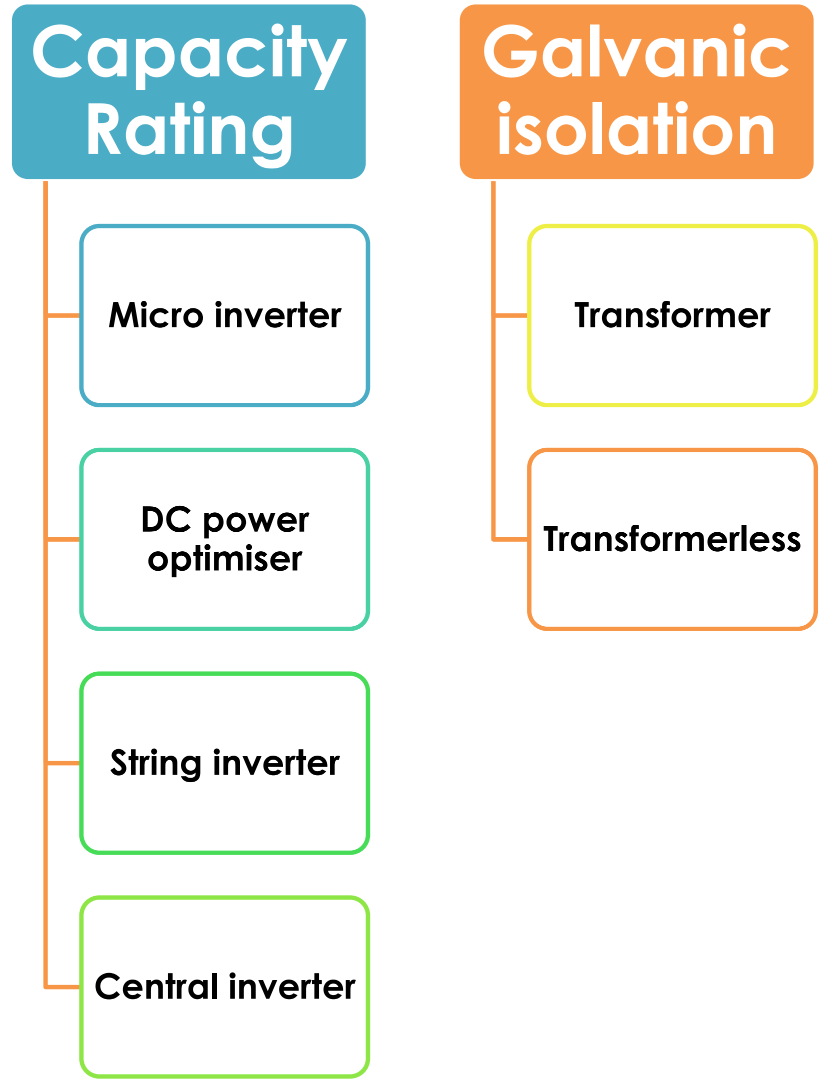
- Transformer
- Transformerless

Grid Inverter

Types of GCPV inverter

Micro Inverter

- A small (micro) inverter for each solar panel
- Suitable for installation with different orientation
- Not practical for large solar PV system
- AC voltage & AC current are produced from each panel

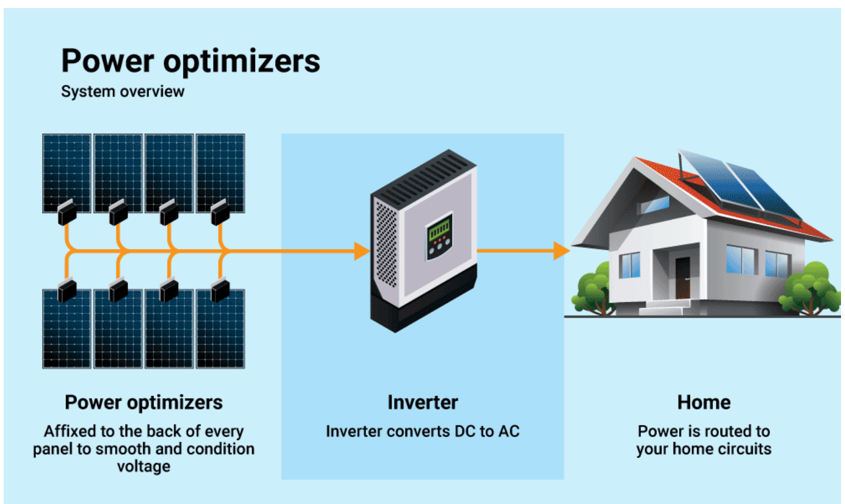


Grid Inverter

Types of GCPV inverter

DC power optimiser

- Some inverters may have Multiple MPPT for optimum power generation from each strings
- DC power optimiser brings the MPPT close to solar panel
- Reduce the effect of partial shading across the system



- **Capacity Rating**
  - Micro inverter
  - DC power optimiser
  - String inverter
  - Central inverter
- **Galvanic isolation**
  - Transformer
  - Transformerless

Derating Power of Inverters

- Input voltage variation
- Ambient temperature

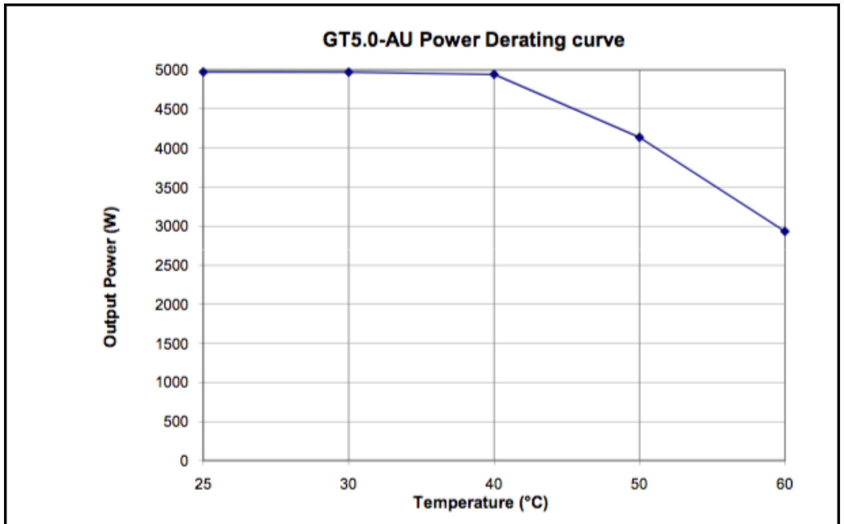
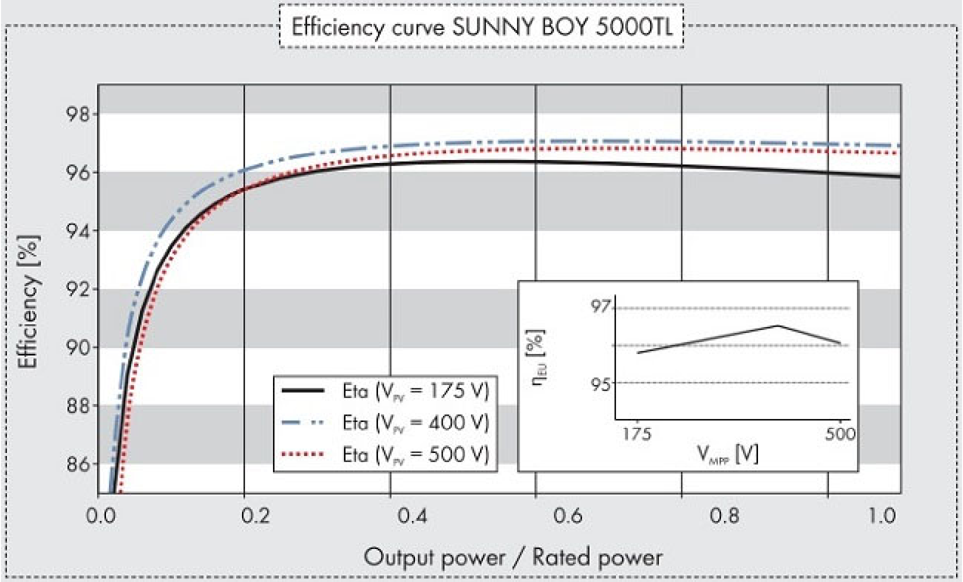


Figure A-2 Output Power vs. Ambient Temperature (GT5.0-AU)



Balance of System (BOS) Components

Other components

- AC & DC Cables
- Fuses or OC protection unit
- AC & DC switches
- Array (DC & AC) junction box & combiner box
- Structure
- Connectors
- AC & DC SPD
- Earthing system
- LPS

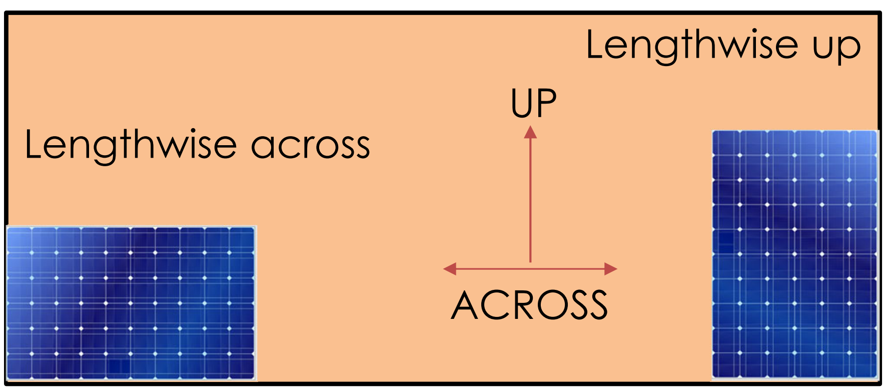
Types of Connection

- Direct connection
  - Used for Feed-in-Tarif (FiT)
  - Export all generated power/energy into the grid network
- Indirect connection
  - Used for Net Energy Metering (NEM)
  - Connected to MSB or SSB or DB
  - Energy generated for PV used for building consumption, excess to be exported into the grid network

CHAPTER 4
: GCPV system design

Dimensioning of PV Array

- Architectural constraint
  - Numbers of modules depends on the orientation of the utilisable area



Dimensioning of PV Array

- Lengthwise across
  - $N_{\max\_module\_across} = N_{across\_up} X N_{across\_across}$
  - $N_{across\_up} = round\ down\ [\frac{W_{roof}}{W_{mod} + \Delta}]$
  - $N_{across\_across} = round\ down\ [\frac{L_{roof}}{L_{mod} + \Delta}]$
  - Δ is the allowed inter-module gap (m)

- Lengthwise up
  - $N_{\max\_module\_up} = N_{up\_up} X N_{up\_across}$
  - $N_{up\_up} = round\ down\ [\frac{W_{roof}}{L_{mod} + \Delta}]$
  - $N_{up\_across} = round\ down\ [\frac{L_{roof}}{W_{mod} + \Delta}]$
  - Δ is the allowed inter-module gap (m)

This step would give an idea to the designer of how much (maximum) modules can be installed

Exercise

- An area has utilisable dimension of 30m in length by 15m in width. Inter-module gap is 10mm. Use Q-Cell panel of 420 W to determine the arrangement of maximum panels.

Dimensioning of PV Array

- Energy constraint
  - How much energy required to be generated by the PV (daily, weekly, monthly or annually)
    1. Determine the amount of energy supplied by solar PV
    2. Determine the minimum power of PV array required
    3. Determine the minimum number of PV modules needed

1. $$E_{req} = \frac{\varepsilon}{100\%} \, X \, \frac{12}{n} \, X \, \sum_{n=1}^{12} E_n$$

E_{req} is energy required per annum

Dimensioning of PV Array

2. The minimum power of PV array required can be calculated as:

$$P_{array\_stc} = \frac{E_{req}}{PSH \ x \ f_{deration} \ x \ \eta_{sub\_system}}$$

P_{array_stc} is power of PV array at STC

PSH is peak sun hour received on plane of array per annum (h)

$\eta_{sub_{system}} = \eta_{cable} \ x \ \eta_{inv}$

Dimensioning of PV Array

3. Minimum number of solar PV modules needed

$$N_{\min\_module} = round\ up\ [\frac{P_{array\_stc}}{P_{module\_stc}}]$$

Exercise

Monthly recorded energy consumption

Month	Jan	Feb	Mac	Apr	Mei	Jun
Energy (kWh)	900	935	NA	600	885	850
Month	**Jul**	Aug	**Sept**	**Oct**	**Nov**	**Dec**
Energy (kWh)	NA	1,020	950	915	NA	NA

- 70% energy from solar PV
- PSH is 5 hrs daily
- Max ambient Temperature is 36 oC
- 4% loss due to dirt
- 3% cable loss
- 97% inverter efficiency

Dimensioning of PV Array

- Budget constraint
  - Total modules also depends on investment
    1. Set a ceiling for budget
    2. Establish the affordable total PV power
    3. Determine the maximum number PV affordable

$$B = P_{array\_stc}\, x\, k_{index}$$

B is allocated total investment cost

k_{index} is unit rate price for complete PV system (RM/Wp)

Dimensioning of PV Array

- $N_{\max\_module} = round\ down\ [\frac{P_{array\_stc}}{P_{module\_stc}}]$

- **Exercise**
  - Budget available is RM37,500 for GCPV system
  - Determine the maximum array capacity, per unit cost is RM5,000/kWp, using Q-Cell 420 Wp

- At this point, designer may have preliminary info in term of area, energy & budget to explain to the client

Sizing of PV array to Inverter

- Selection of inverter
  - Now we have established the numbers of PV modules required.
  - Next step is to match with the inverter specification.

$$P_{array}\ x\ f_2 \ \leq P_{nom\_inv} \ \leq \ P_{array}\ x\ f_1$$

f_1 & f_2 *are the derating factors of PV array* $(0.9\ and\ 1.0)$

Exercise

Based on previous exercise, determine the required inverter range.

Sizing of PV array to Inverter

- Range of numbers of modules
  - Nominal power rating of inverter determines the number of PV modules that can be connected to the inverter

$$N_{min} = round\ up\ [\frac{P_{inv\_nom}}{f_1\ x\ P_{module\_stc}}]$$

$$N_{max} = round\ down\ [\frac{P_{inv\_nom}}{f_2\ x\ P_{module\_stc}}]$$

Exercise

- Based on previous exercise (budget constraint), determine:
  - the suitable inverter
  - Minimum number of PV modules
  - Maximum number of PV modules

Sizing of PV array to Inverter

- Limits on voltages of PV module
  - Range of input voltage values ie, $V_{oc\_max}, V_{mp\_max}\ and\ V_{mp\_min}$ are required for safety and functionality of inverter & optimum operation
  - These limits would define the voltage output of PV modules and strings

$$V_{oc\_max} = V_{oc\_stc}\ x\ \left\{1 + [\left(\frac{\beta_{Voc}}{100\%}\right) x\ (T_{cell}\ -\ T_{stc})]\right\}$$

V_{oc_max} *is the maximum open circuit voltage at real operating condition*

Sizing of PV array to Inverter

- Limits on voltages of PV module
  - The highest allowable voltage of maximum power PV should generate

$$V_{mp\_max} = V_{mp\_stc}\ x\ \left\{1 + [\left(\frac{\beta_{Vmp}}{100\%}\right) x\ (T_{cell}\ -\ T_{stc})]\right\}$$

  - The lowest voltage of maximum power from PV module

$$V_{mp\_minx} = V_{mp\_stc}\ x\ \left\{1 + [\left(\frac{\beta_{Vmp}}{100\%}\right) x\ (T_{cell}\ -\ T_{stc})]\right\}$$

Exercise

- Based on previous exercise, determine:
  - Maximum voltage open circuit
  - Maximum voltage PV module
  - Minimum voltage PV module

Sizing of PV array to Inverter

- Limits on voltages of PV string (series)
  - The voltage generated by PV string must comply with input window of the inverter
  - Maximum number of PV modules:

$$N_{s\_max} = round\ down\ [\frac{V_{\max\_inv}}{V_{mp\_max}}]$$

$$N_{s\_min} = round\ up\ [\frac{V_{\max\_inv}}{V_{mp\_min}}]$$

- **Exercise:** Determine the series configuration of PV modules

Sizing of PV array to Inverter

- Parallel string
  - The inverter limits certain number of parallel PV strings, to ensure maximum input current is not exceeded.

$$N_{p\_max} = round\ down\ [\frac{I_{\max\_inv}}{I_{sc\_string}}]$$

- **Exercise**: Determine the maximum parallel string can be connected to the inverter

Sizing of PV array to Inverter

- Array Configuration
  - At this stage, we now know the PV modules configuration in series & parallel:

$$N_t = N_s \, x \, N_p$$