Designing of Grid Connected Solar PV system

11 – 13 Oktober 2021

Unit Perunding Tenaga Lestari
Cawangan Kejuruteraan Elektrik

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)

Objektif Latihan

- Mengenalpasti komponen sistem "grid-connected solar PV", spesifikasi dan standard pemasangan sistem selaras dengan MS1837;
- Merekabentuk sistem grid-connected solar PV termasuk komponen "Balance of System" (BOS) seperti inverter, Net Energy Metering (NEM) dan pendawaian selaras dengan MS62093
- Menganalisis tahap prestasi sistem grid-connected solar PV selaras dengan MS61724
- Membuat pengujian terhadap pemasangan sistem grid-connected solar PV selaras dengan spesifikasi dan standard MS2692

LATARBELAKANG

- Unit Perunding Tenaga Lestari (UPTL) ditubuhkan untuk memberi khidmat pakar dalam bidang Tenaga Boleh Baharu (TBB) & Kecekapan Tenaga
- 17 tahun pengalaman & kepakaran dalam bidang teknologi solar

KHIDMAT PAKAR UPTL

Pengkhususan kepada bidang Tenaga Boleh Baharu (TBB) & Kecekapan Tenaga

- Rekabentuk, pengurusan projek & penyelenggaran sistem TBB
- Audit Tenaga bangunan
- Audit Prestasi system TBB
- Khidmat nasihat teknikal
- Penyediaan garis panduan & spesifikasi

ANTARA PENGLIBATAN UPTL DALAM BIDANG TEKNOLOGI SOLAR

- Sistem Solar Hibrid untuk sekolah luar bandar Semenanjung, Sabah & Sarawak dengan jumlah kapasiti 10 MW (316 buah sekolah)
- Program Solar Energy Purchasing (SEP) untuk Bangunan Kerajaan
- Penyelenggaraan Sistem Solar Hibrid
- Menaiktaraf Stesen Solar Hibrid Pulau Kapas, Marang
- Sistem Solar untuk kawasan pelancongan Tasik Kenyir
- Sistem Solar Hibrid untuk Klinik Kesihatan luar bandar

PENCAPAIAN & MANFAAT PENGLIBATAN UPKTE

- ASEAN ENERGY AWARD 2016 – 2^{nd} Runners Up (Best Practice Off-Grid Solar PV System)
- Mewujudkan pasukan pakar - #teamsolarJKR
- Penyelidikan & Pembentangan kertas kerja – dalam & luar negara

Sistem Solar Hibrid di SK Pulau Omadal, Semporna, Sabah

Sistem Solar Hibrid Sekolah luar bandar

316 sekolah di Semenanjung, Sabah & Sarawak

10 MegaWatt (MW)

Capaian bekalan elektrik 24 jam kepada lebih **20,000** murid dan guru

Powering a Sustainable Future in Malaysia

Solar Power Initiatives

1 Solar Energy Purchasing (SEP)

Rooftop solar PV installation for buildings

2 Integrated Solar PV System (ISPV)

Off-grid power system solution for remote areas

3 Solar PV Integrated Management System (SPV-IMS)

IoT based information management system for solar PV system

4 Energy Storage System (ESS)

Energy storage as a backup for buildings energy supply

Senarai Projek UPTL

Sepanjang tempoh Pandemic COVID-19

RM675 juta

32 projek

687 tapak projek

Skop Perlaksanaan

- Rekabentuk
- Perolehan
- Penyeliaan tapak
- Operasi & Penyelenggaraan
- Pelupusan Aset

680 sekolah luar bandar, 2 Klinik Kesihatan, 3 perkampungan, 2 pusat pelancongan

1

Projek Operasi & Penyelenggaraan Genset

Sekolah Luar Bandar Sarawak

763 buah genset

Rektifikasi, pembaikan, penggantian, pembekalan minyak, operasi & penyelenggaraan

2 Projek Lampu Solar LED
Kg Orang Asli, Royal Belum, Gerik, Perak

2 Projek Lampu Solar LED
Kg Orang Asli, Royal Belum, Gerik, Perak

30 unit lampu solar LED
Penyerahan projek pada 4 September 2021

3 Projek Solar Hibrid

Sekolah Luar Bandar Sarawak

5.02 MW

Sistem solar hibrid – konsep ISPV

SODIUM & LITHIUM Battery

Energy Storage System

5 Program Solar Energy Purchasing (SEP) untuk Bangunan Kerajaan

SEP

- Program Solar Energy Purchasing (SEP) untuk bangunan KKR dan JKR Malaysia telah dilancarkan oleh **YB Dato' Sri Haji Fadillah bin Haji Yusof, Menteri Kanan Kerja Raya** pada 16hb Mac 2021.
- Program SEP berkonsep *zero upfront cost dan zero capex* ini mensasarkan pemasangan sistem solar di 12 buah bangunan KKR & JKR Malaysia dengan **kapasiti 1.2 MW**, penjimatan bil elektrik sebanyak **RM9.3 juta** untuk tempoh 21 tahun dan pengurangan pelepasan karbon sebanyak **819 tan CO_2 setahun**.
- KKR dan JKR Malaysia akan menjadi **peneraju untuk perlaksanaan program SEP yang lebih menyeluruh** untuk bangunan-bangunan Kerajaan yang lain ke arah penggunaan tenaga yang lebih cekap dengan penerapan elemen lestari dalam aspek pembinaan.

CHAPTER 1

- Background & Review on Solar PV System Technology

Energy Resources

- The world energy demand is still dependen on fossil fuel base energ generation
  - Gas & oil
  - Coal
  - Diesel

KAPASITI TERPASANG SISTEM GRID
GRID SYSTEM INSTALLED CAPACITY

2018	2019
24,418MW	**26,132MW**
- Gas (11,537MW) Gas (11,537MW)	- Gas (11,000MW) Gas (11,000MW)
- Arang Batu (10,066MW) Coal (10,066MW)	- Arang Batu (12,066MW) Coal (12,066MW)
- Hidro (2,536MW, termasuk 296MW yang dianggap sebagai hidro mini) Hydro (2,536MW, which is inclusive of 296MW that is considered as mini hydro)	- Hidro (2,240MW) Hydro (2,240MW)
- TBB (179MW)* *LSS (179MW di rangkaian penghantaran) RE (179MW)* *LSS (179MW at transmission network)	- TBB (725MW)* *LSS (429MW di rangkaian penghantaran) + Hidro Mini (296MW) RE (725MW)* *LSS (429MW at transmission network) + mini hydro (296MW)
- Sambungtara (100MW) Interconnection (100MW)	- Sambungtara (100MW) Interconnection (100MW)

Source: ST Annual Report 2019

Energy Resources

	2018 Semenanjung Malaysia / Peninsular Malaysia	2018 Sabah dan Labuan / Sabah and Labuan	2019 Semenanjung Malaysia / Peninsular Malaysia	2019 Sabah dan Labuan / Sabah and Labuan
Kapasiti Terpasang / Installed Capacity	24,418MW	1,277MW	26,132MW	1,277MW
SAIDI / SAIDI	48.22 minit /pelanggan/tahun minutes/customer/year	267.87 minit /pelanggan/tahun minutes/customer/year	48.13 minit /pelanggan/tahun minutes/customer/year	205.31 minit /pelanggan/tahun minutes/customer/year
Kapasiti LSS / LSS Capacity	179MW	50MW	429MW	50MW
Margin Rizab / Reserve Margin	32%	29%	38%	23%
Permintaan Maksimum / Maximum Demand	18,338MW	955MW	18,566MW	1,001MW

Source: ST Annual Report 2019

Energy Emission Overview

- Every day we damage our climate by using fossil fuels for energy & transport

- Malaysia emitted 208 mill. tonnes of CO_2 or 7.1 tonnes per capita in 2009

- Projected total emissions – 285.73 mill tonnes CO_2 (2020). Largest emitting sector – electricity generation (43.4%)

Source : Energy Revolution, Greenpeace

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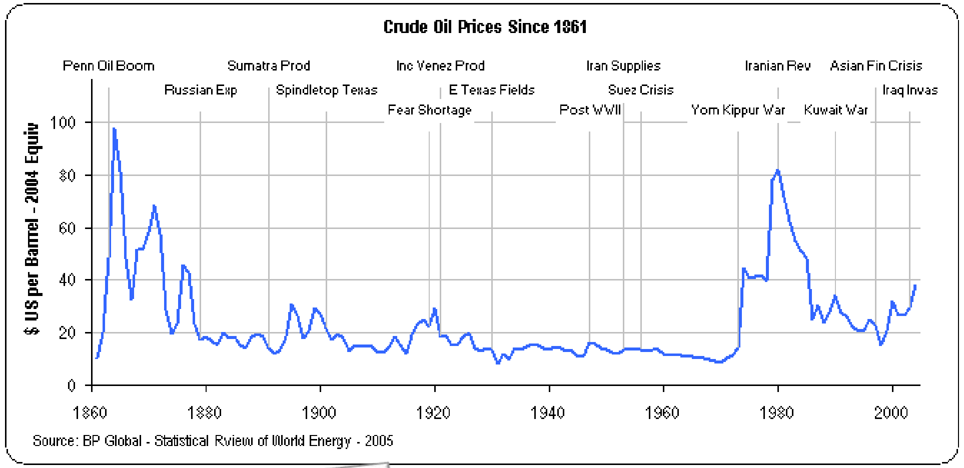
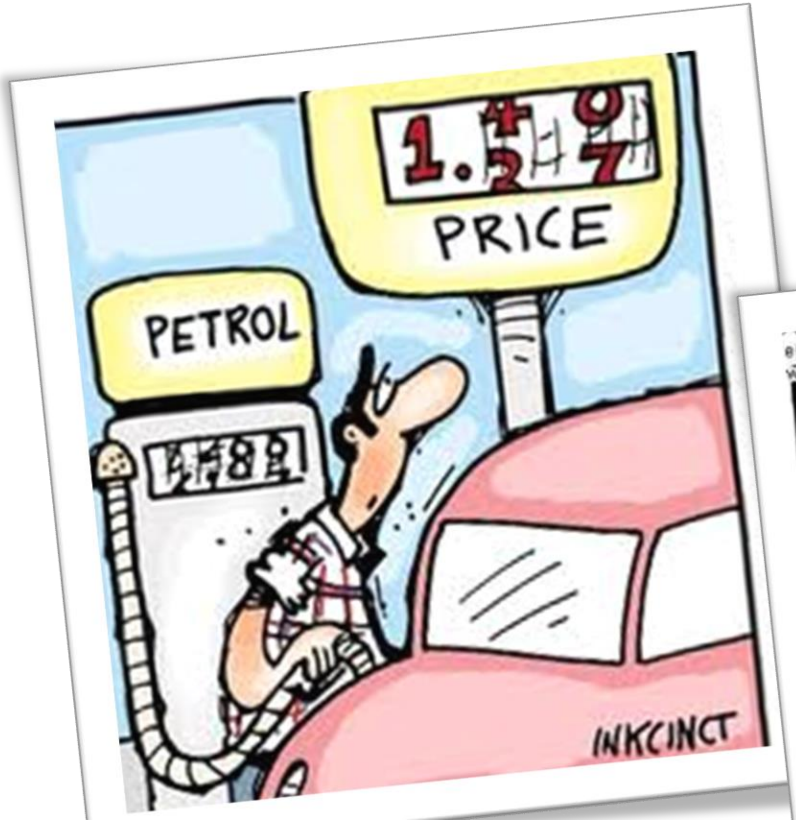
- Fossil fuel based energy will be depleted by time

  – **Malaysia's energy reserve**

    - Oil reserve of three billion barrels. Crude oil production 750,000 barrel/day
    - Natural gas produced 80,000 barrels/day, with 2.12 trillion cubic meter reserves
    - The current reserve amount for oil may last for 19 years & natural gas for 33 years

- Fluctuation of global oil price





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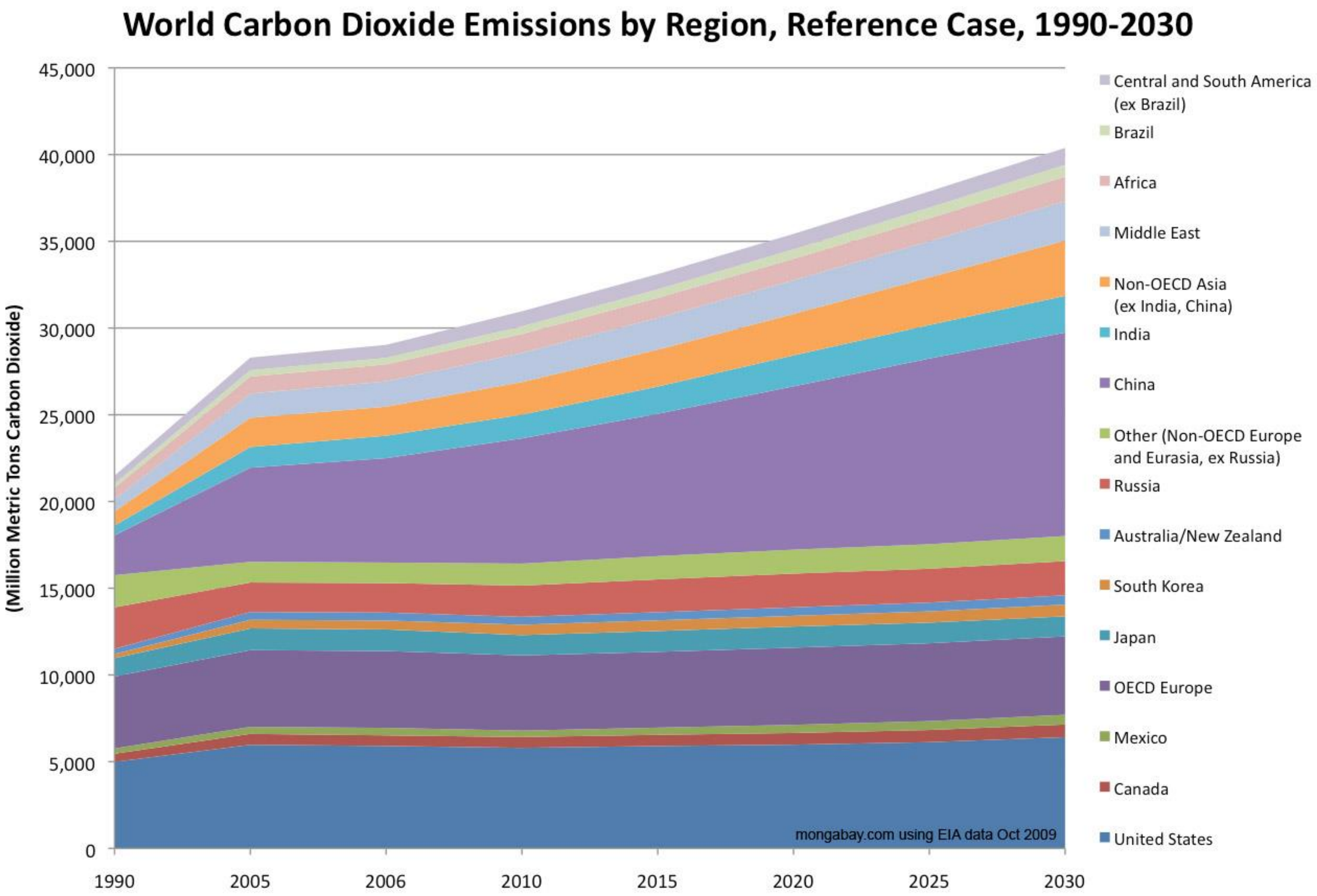
- World population growth requires more energy
- Environmental pollution

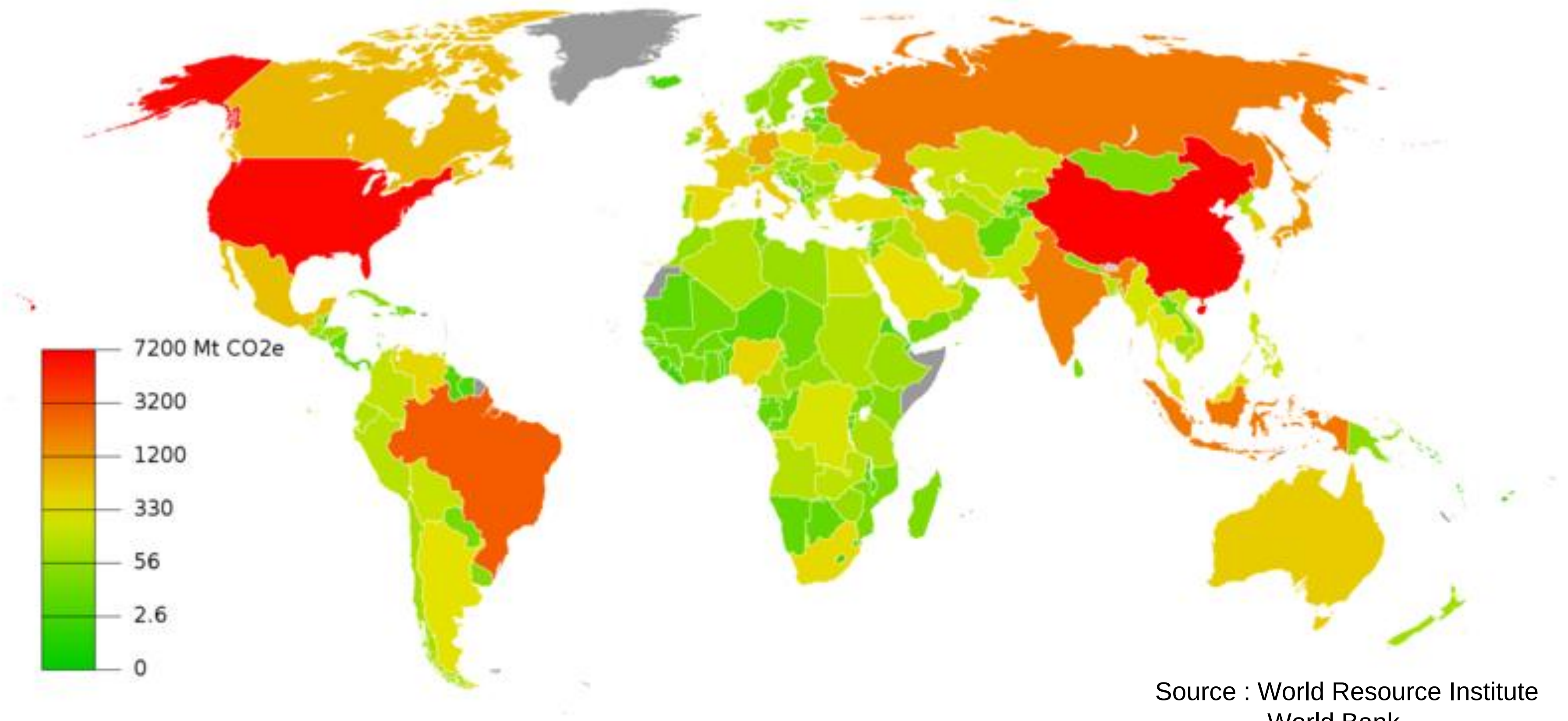
19

Environmental Effect

- Green House Gasses
  - Global warming & climate change



Annual CO_2 emission (2005) including land use

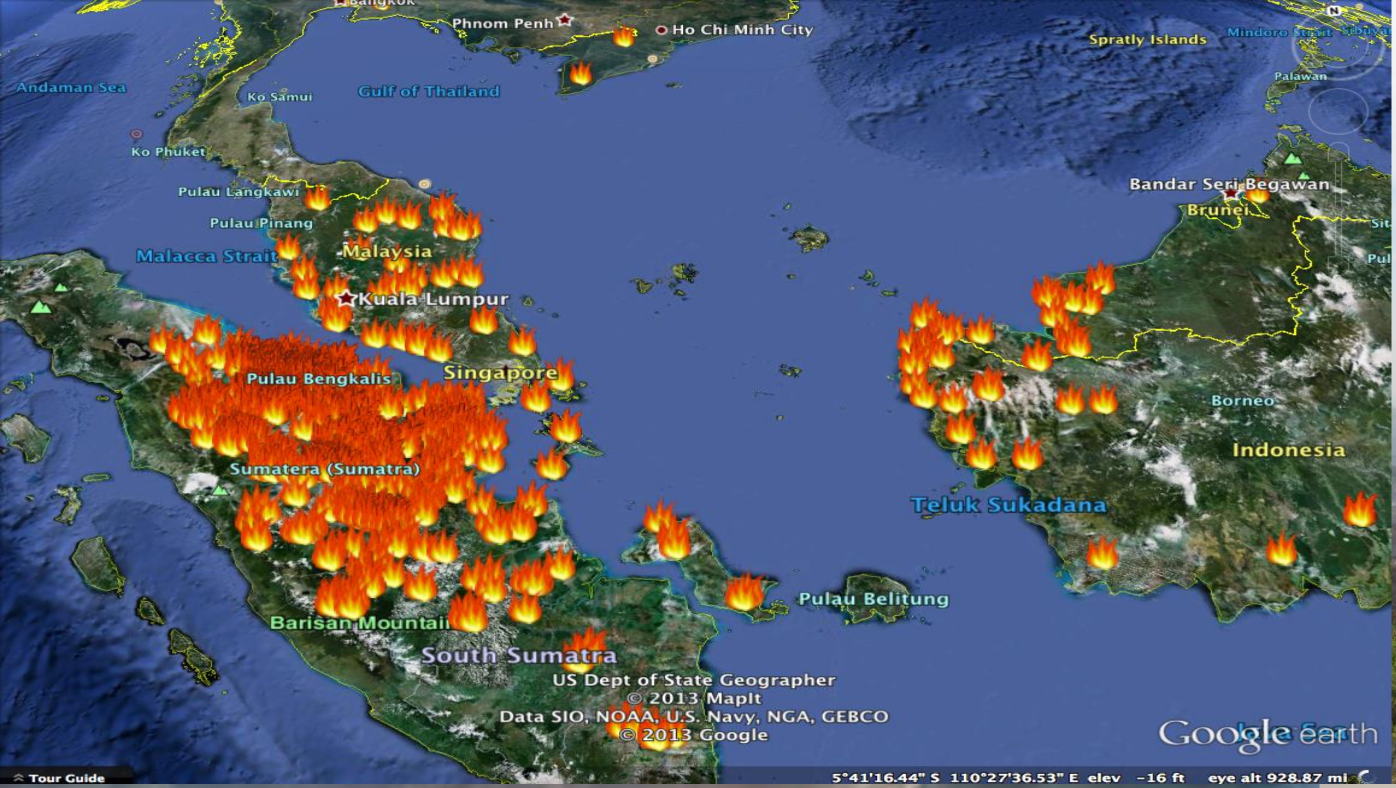


Source : World Resource Institute
World Bank

Malaysia

• Annual CO2 emission (2008) = 208,267,000 metric tons (0.7% of world emission)

• Annual CO2 emission per capita (2009) = 7.1 metric tons per capita (not including land use)


Phnom Penh
Ho Chi Minh City
Spratly Islands
Andaman Sea
Ko Samui
Gulf of Thailand
Ko Phuket
Pulau Langkawi
Pulau Pinang
Malacca Strait
Malaysia
Kuala Lumpur
Bandar Seri Begawan
Brunei
Pulau Bengkalis
Singapore
Borneo
Indonesia
Sumatera (Sumatra)
Teluk Sukadana
Pulau Belitung
Barisan Mountai
South Sumatra
US Dept of State Geographer
© 2013 MapIt
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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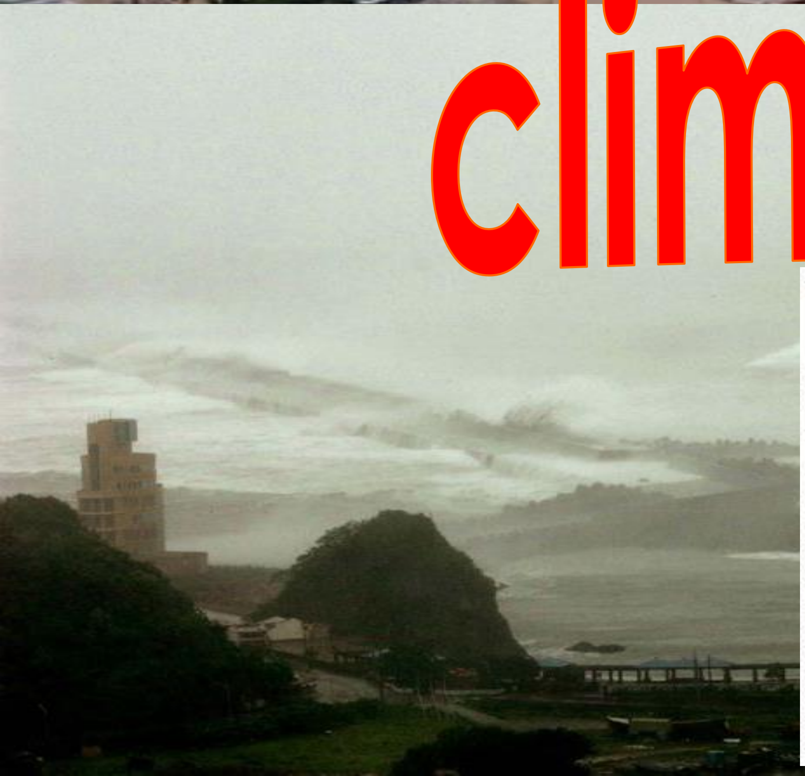
Google earth
Tour Guide


DIMANAKAH INSAN
DIKALA BUMI DINODAI


climate change !!!



The earth needs to be healed….

- Sustainable energy is the answer…

RENEWABLE ENERGY

ENERGY EFFICIENCY

Definition of Renewable Energy

Renewable Energy (RE) is any form of primary energy from recurring and non-depleting indigenous resources such as agricultural produce, hydro-power, solar, wind, solid-waste, etc.

Biomass

Wind Energy

Hydro

Biogas

Geothermal

Solar PV

Solar Energy Application

Solar Photovoltaic

Solar Thermal

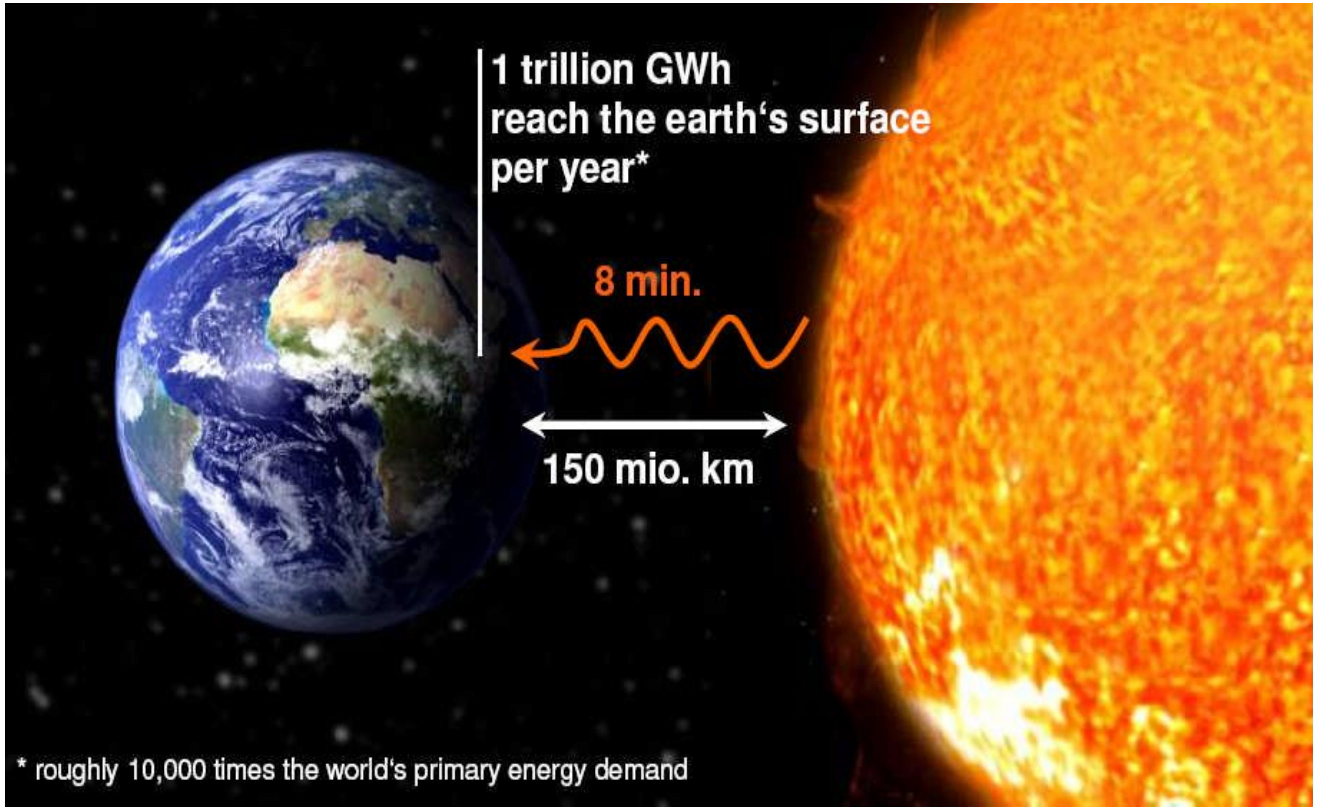
Major applications :

1) Electricity

2) Heat

Solar Photovoltaic (PV)

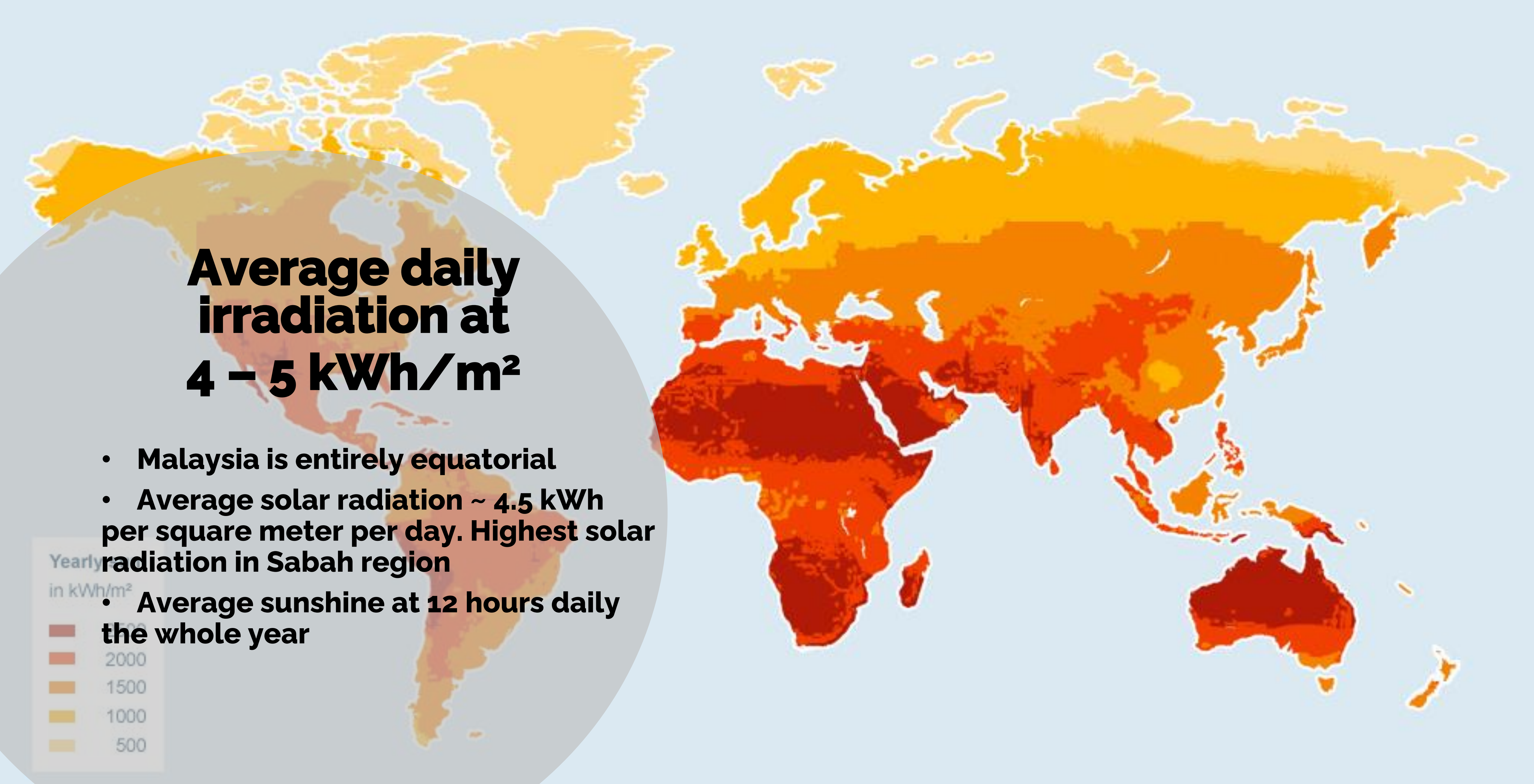
- Convert solar radiation into electric power



Maximum irradiance that can reach earth surface is ~1,000 W/m2

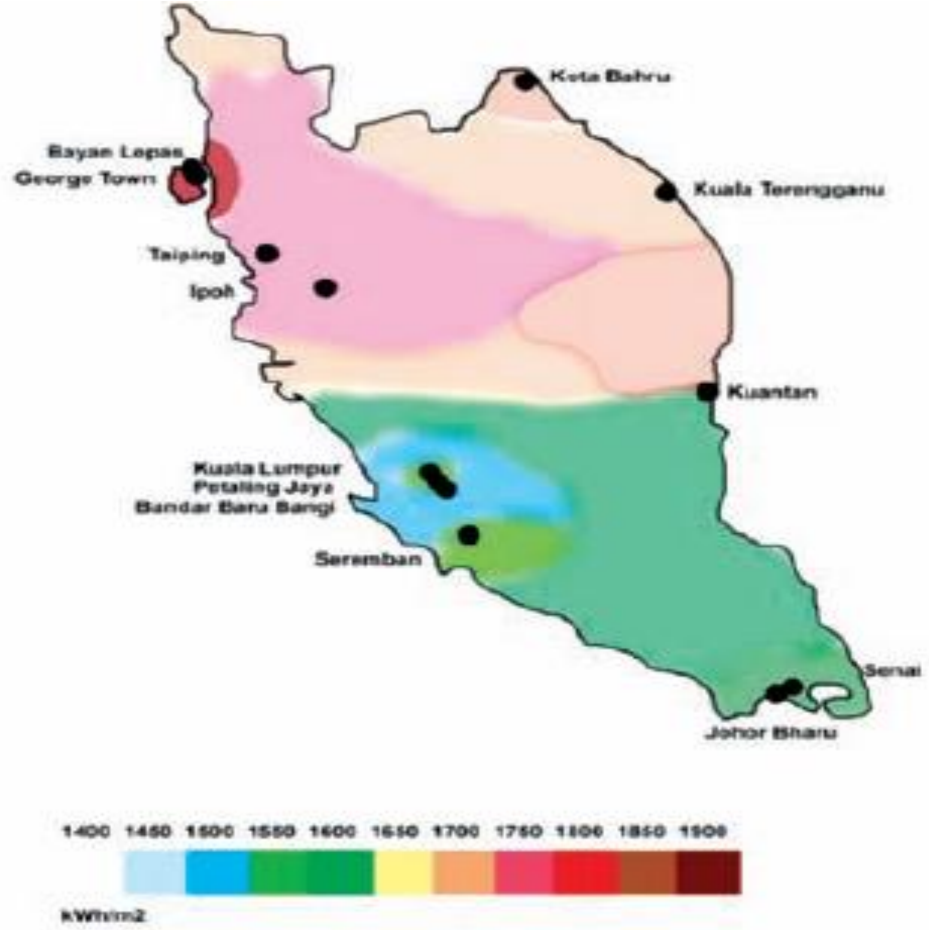
Average daily irradiation at 4 – 5 kWh/m²

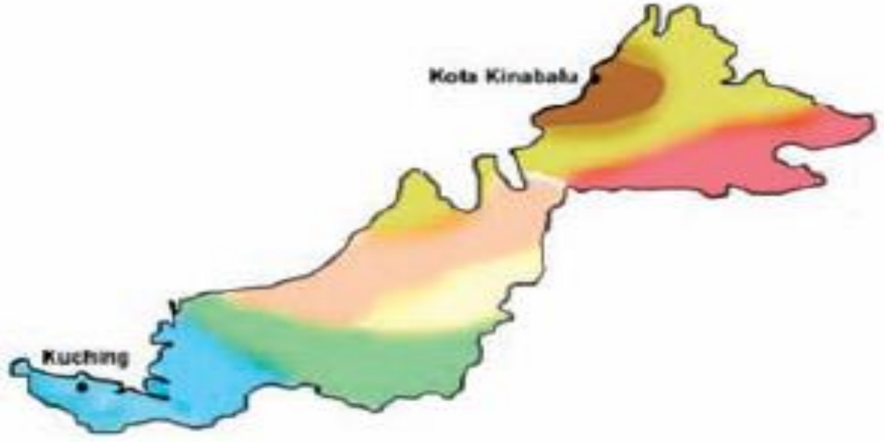
- Malaysia is entirely equatorial
- Average solar radiation ~ 4.5 kWh per square meter per day. Highest solar radiation in Sabah region
- Average sunshine at 12 hours daily the whole year



Irradiance in Malaysia

Annual irradiation in
Peninsula & Borneo

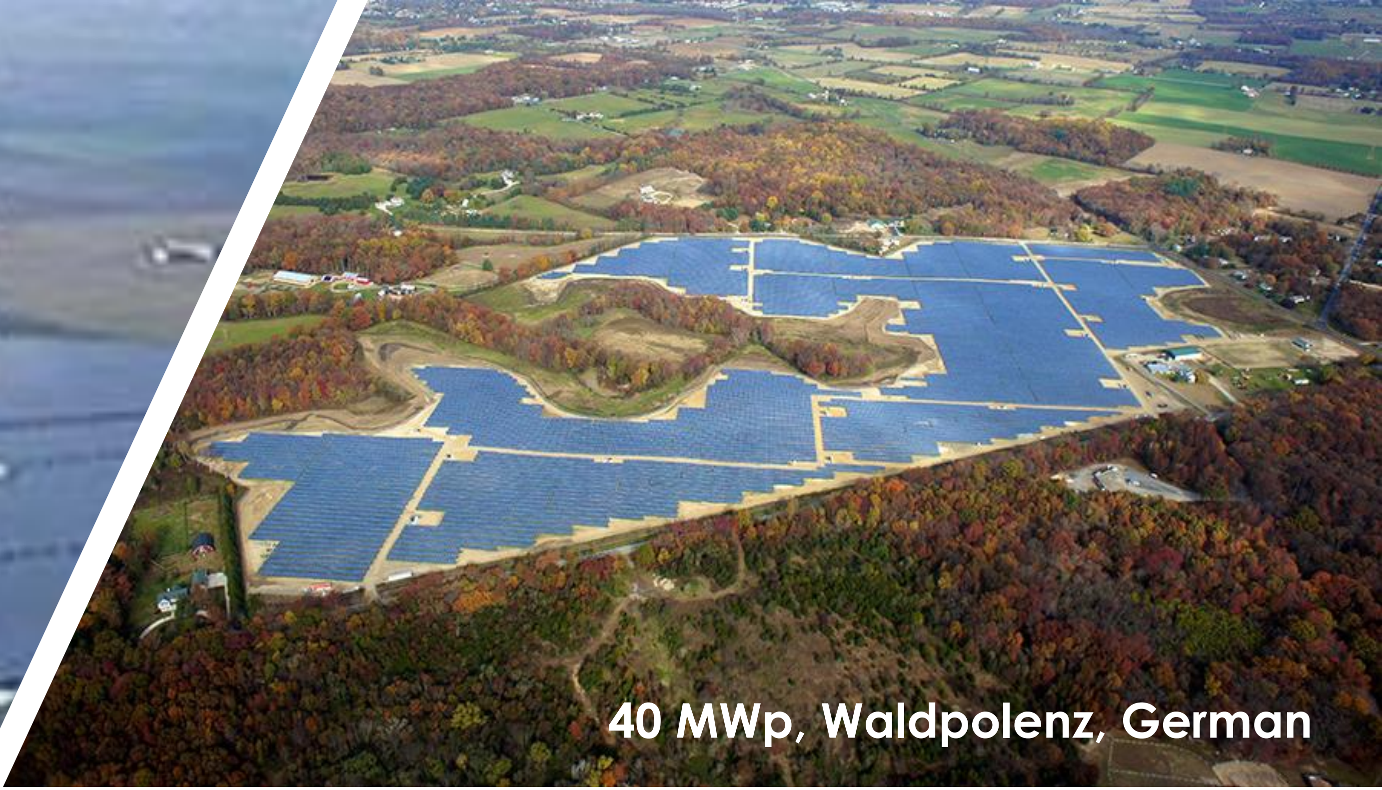




Average daily irradiation at 4 – 5 kWh/m^2

Source : NREPAP 2009


80 MWp, Revigo, Italy


40 MWp, Waldpolenz, German


20 MWp, Pilgrove
Township, New Jersey

World's largest solar park Shakti Sthala launched in Karnataka

The world's largest solar park, Shakti Sthala, has a capacity of 2,000 MW and has set up at an investment of Rs16,500 crore at Pavagada in Karnataka's Tumakuru district

Last Published: Fri, Mar 02 2018. 06 35 AM IST

Sharan Poovanna

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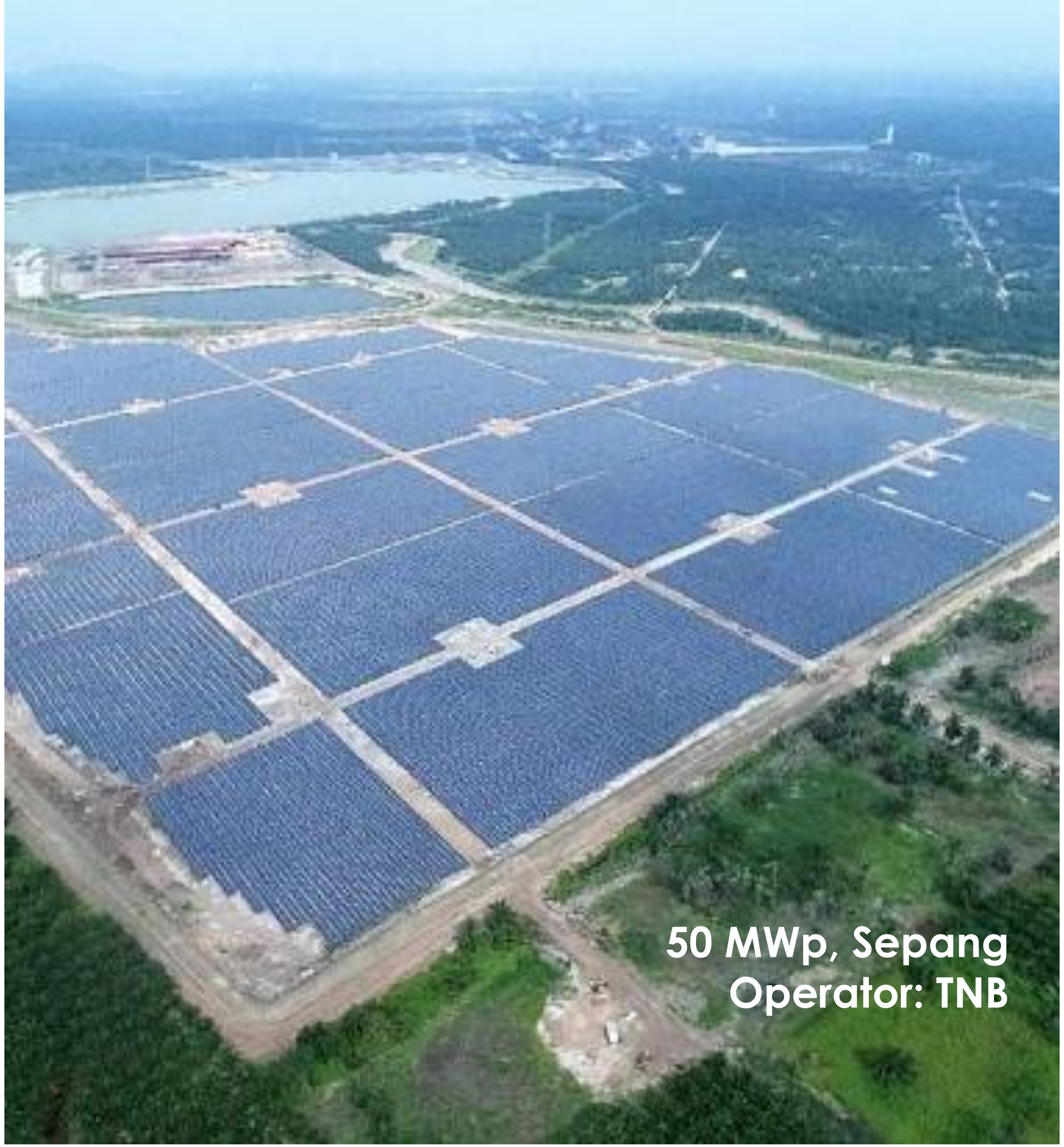
China Turns On the World's Largest Floating Solar Farm

Floating on a lake over a collapsed coal mine, the power station in Anhui province can produce 40 megawatts of energy


30 MWp, Bidor,
Operator: Gading
Kencana


50 MWp, Sepang
Operator: TNB

Renewable Energy in Malaysia

Development of Energy Policies in Malaysia

National Petroleum Policy (1975)

National Energy Policy (1979)

National Depletion Policy (1980)

4-Fuel Diversification Policy (1981)

5-Fuel Policy (2001)

RE Policy and Action Plan (2010)

POLISI TEKNOLOGI HIJAU NEGARA

2011 — Feed In Tariff

- Tarif untuk solar PV
  2013 – RM0.68 – RM1.1316/kWh
  ** Degression rate 8% setahun*

2016 — Net Energy Metering (NEM)

- Konsep *Net billing*
- *Self consumed*, lebihan penjanaan tenaga dijual ke pihak utiliti pada kadar tarif belian tenaga
- Contoh:
  Tarif B = RM0.509/kWh
  ** Rate telah disemak semula tahun 2018*

2018 — Supply Agreement for Renewable Energy (SARE)

- *Self consumed*,
- Tarif penjanaan tenaga daripada solar PV rendah daripada tarif grid utiliti
- Contoh:
  Grid = RM0.509/kWh
  Solar = RM0.43/kWh

POLISI TEKNOLOGI HIJAU NEGARA

KEMENTERIAN TENAGA & SUMBER ASLI

EMBARGO SEHINGGA 10.00AM 29 DISEMBER 2020

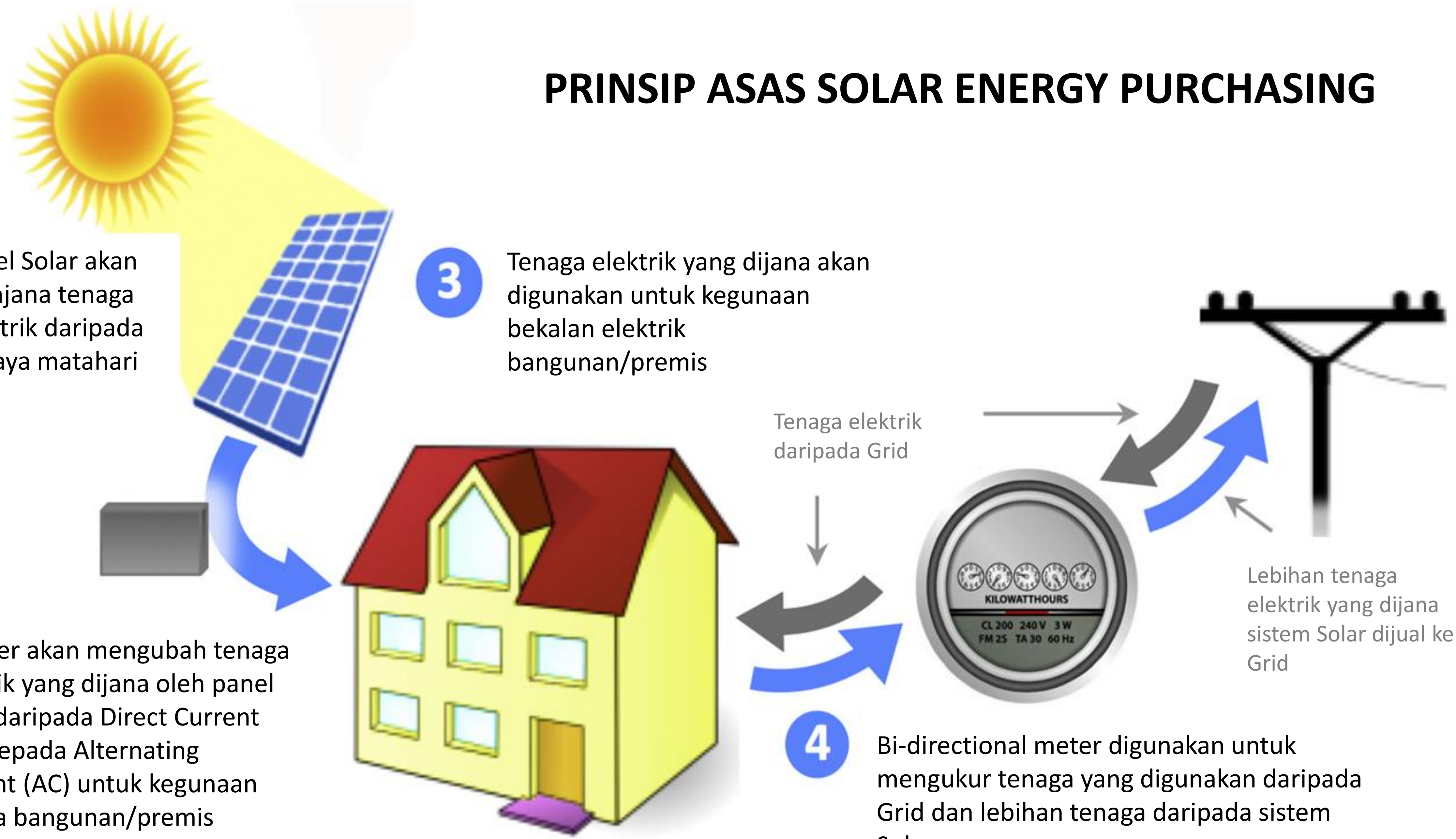
MEKANISME PELAKSANAAN *NET ENERGY METERING* 3.0

PERKARA	NEM 3.0		
	NEM RAKYAT	NEM GoMEn	NOVA
	Domestik	Bangunan Kerajaan	Komersial & Industri
Kuota ditawarkan (MW)	100	100	300
Mekanisme (*roll-over*)	NEM 1:1 (12 bulan)	NEM 1:1 (12 bulan)	SELCO+ (1 bulan)
Tarikh mula ditawarkan	1 Februari 2021		1 April 2021
Tempoh tawaran	3 tahun		
Kadar *offset*	Tarif Semasa	Tarif Semasa	*System Marginal Price*
Tempoh *offset*	10 tahun		
Ketetapan selepas 10 tahun	*Self-Consumption (SelCo)*	*Self-Consumption (SelCo)*	*Self-Consumption (SelCo)*
Had Kapasiti Pepasangan	*Single Phase*: 4kWac *Three Phase*: 10kWac	1 MWac/ 1 Akaun	*Nett offset*: 1MWac *Net offset +Virtual aggregation*: 5MWac
Kelayakan	Pemegang Akaun Domestik	Jabatan/Agensi Kerajaan	Pemegang Akaun Bukan Domestik

KAEDAH PERLAKSANAAN PEMASANGAN SISTEM SOLAR PV DI ATAS BUMBUNG BANGUNAN

KAEDAH	Pemasangan sendiri melalui peruntukan sendiri	SEP — Program SEP tanpa kos pemasangan & penyelenggaraan *(Zero upfront & maintenance cost)*
OPERASI	• Tiada tarif untuk setiap penjanaan tenaga solar yang digunakan • Penjimatan bil elektrik bulanan > 20% (bergantung kepada kapasiti sistem) • Hak milik sepenuhnya • Memerlukan peruntukan tahunan untuk kos operasi & penyelenggaran	• Tarif khas tenaga solar yang lebih rendah daripada tarif TNB • Tarif khas solar adalah tidak berubah sepanjang masa • Penjimatan bil elektrik sehingga 20% sebulan (bergantung kepada kapasiti sistem) • Tempoh perjanjian sehingga 21 tahun, hak milik sepenuhnya selepas tamat tempoh perjanjian • Tiada kos operasi & penyelenggaraan

PRINSIP ASAS SOLAR ENERGY PURCHASING



1. Panel Solar akan menjana tenaga elektrik daripada cahaya matahari

2. Inverter akan mengubah tenaga elektrik yang dijana oleh panel Solar daripada Direct Current (DC) kepada Alternating Current (AC) untuk kegunaan tenaga bangunan/premis

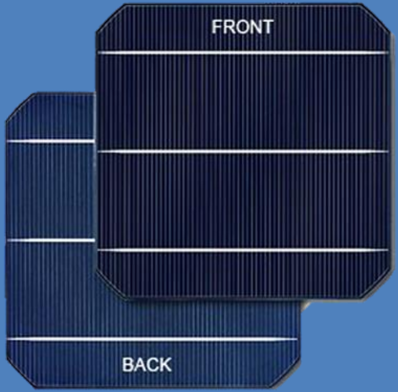
3. Tenaga elektrik yang dijana akan digunakan untuk kegunaan bekalan elektrik bangunan/premis

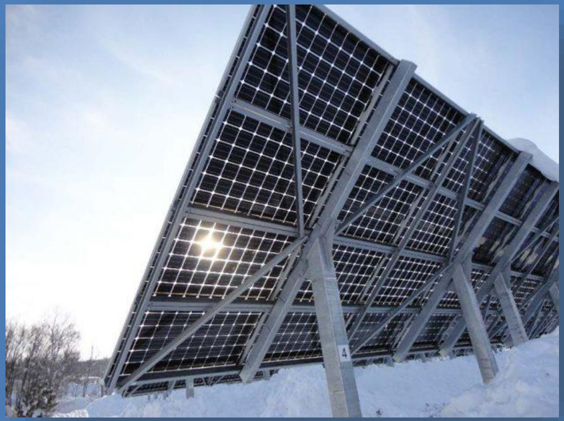
4. Bi-directional meter digunakan untuk mengukur tenaga yang digunakan daripada Grid dan lebihan tenaga daripada sistem Solar

Way forward

New solar panel design & aesthetics

- Frameless solar panel
- Clear solar panels
- Solar tiles





Solar panel products improvement

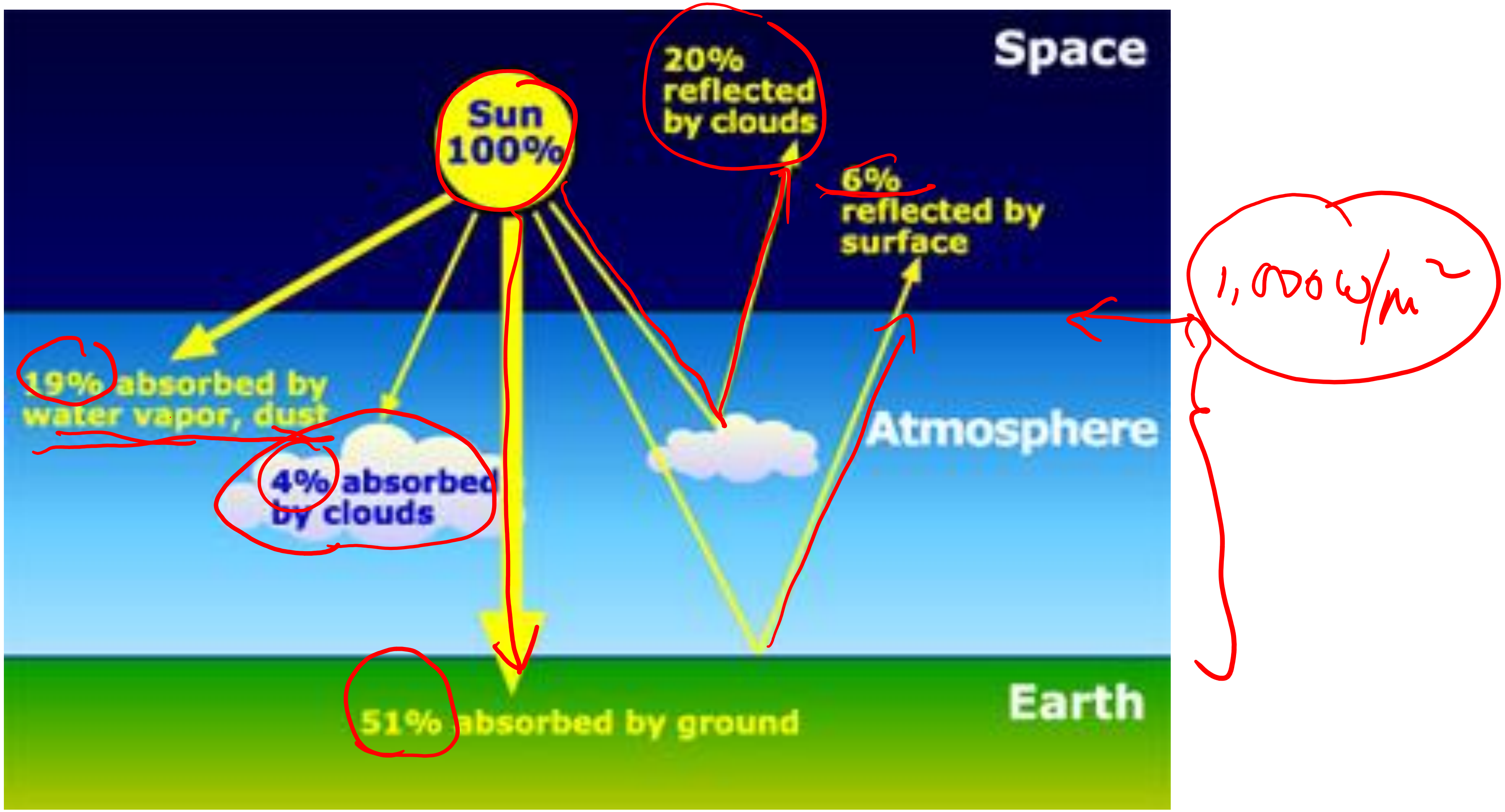
- Double sided solar panels
- PV integration – micro inverter

Training & Certification

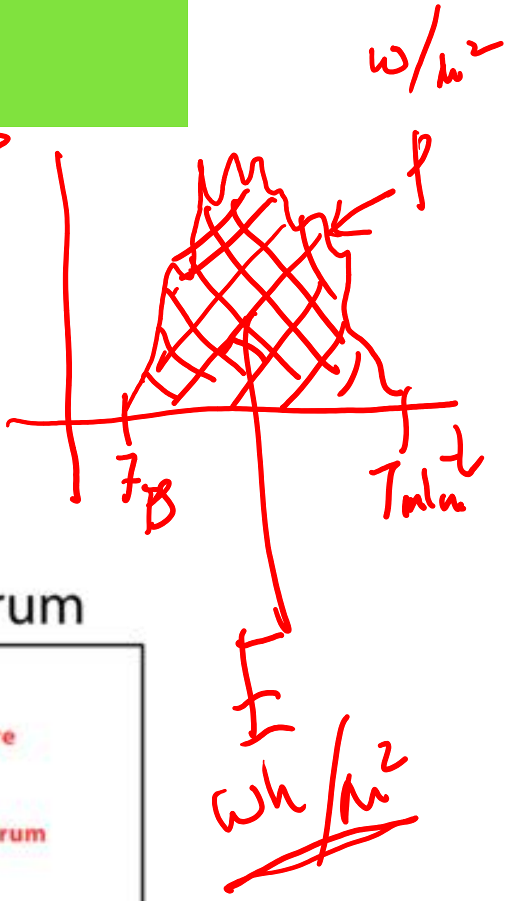
- Training for certification is provided by SEDA
- Training is held at UiTM and SHRDC
- Refer to SEDA website at www.seda.gov.my

BREAK

Availability of Solar Energy



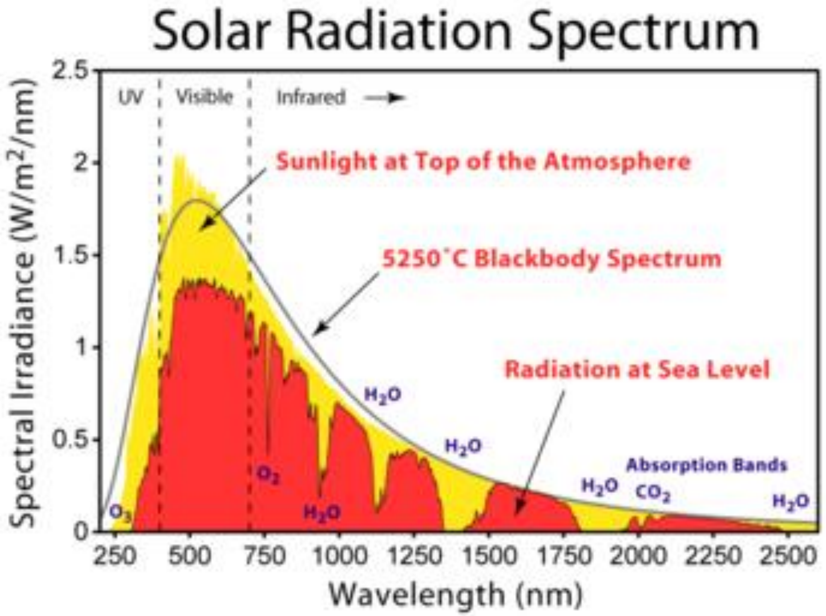
Irradiance & irradiation



Irradiance

The **power** per **unit area** received from the Sun in the form of electromagnetic **radiation** in the wavelength range of the measuring instrument.

Unit of irradiance in W/m²



Irradiation

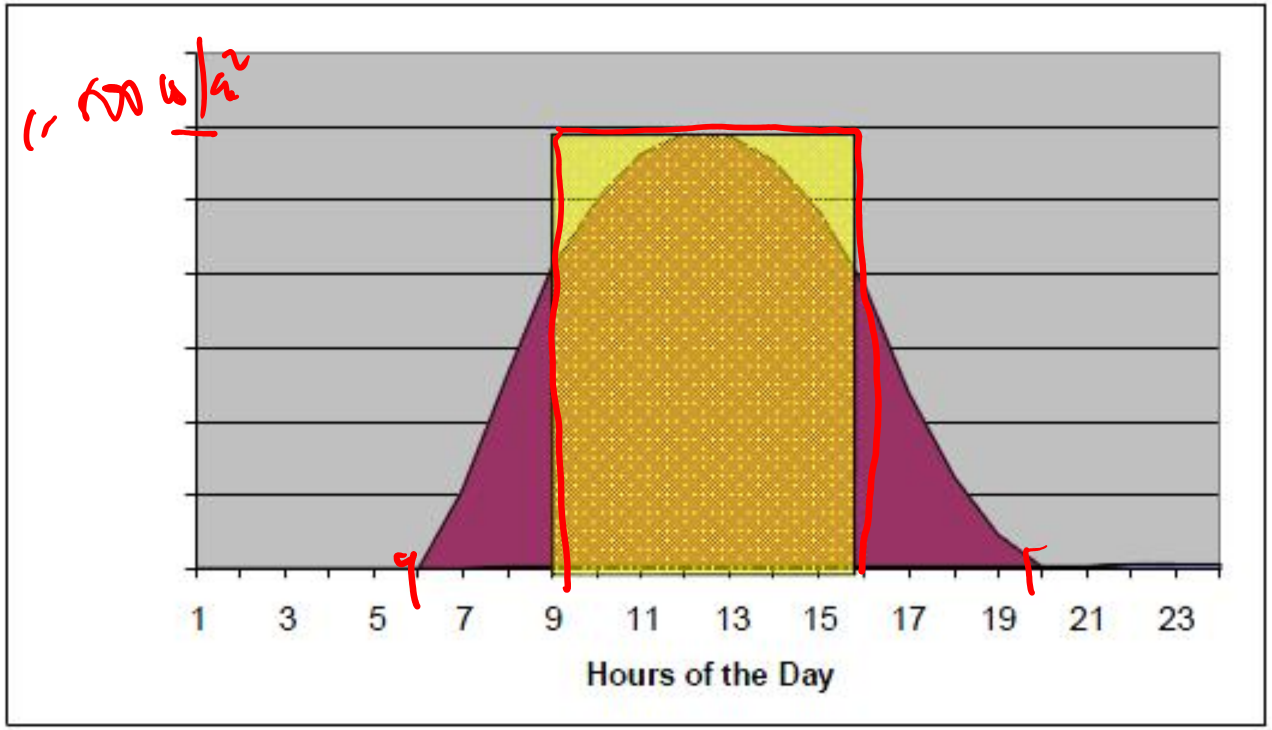
The **energy** per **unit area** received from the Sun in the period of daylight time

Unit of irradiation in Wh/m²

Availability of Solar Energy

Peak Sun Hour (PSH)

- The number of hour solar irradiance at 1,000Wm^{-2} gives the equivalent amount of solar irradiation (H) for the day



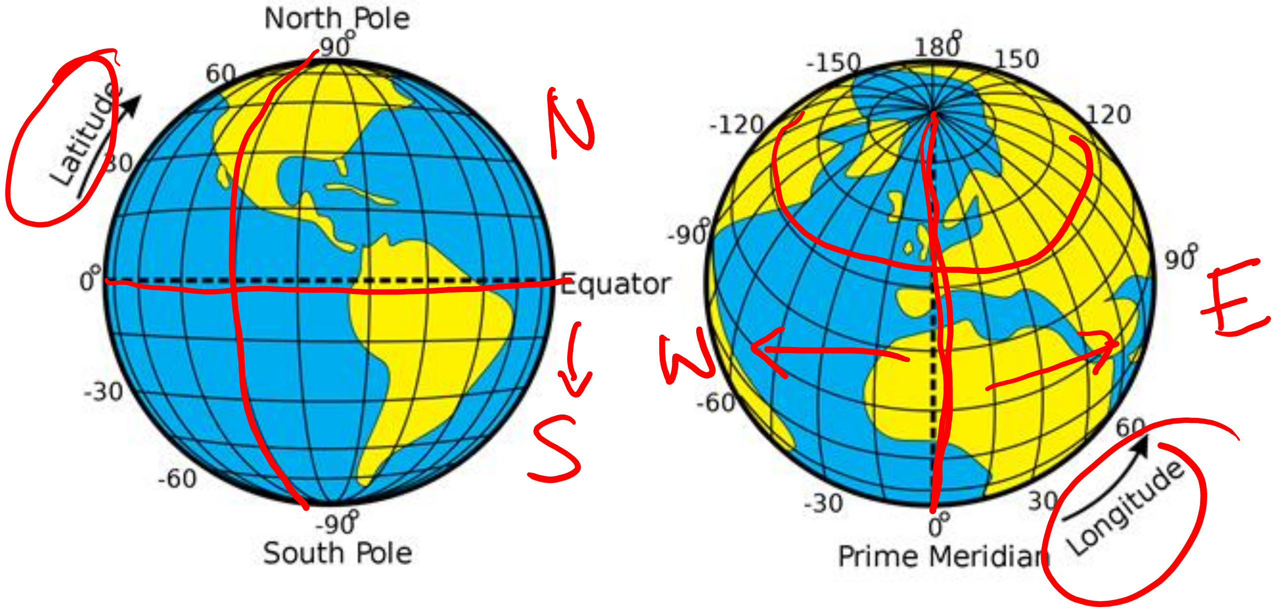
Exercise 1: (10 minutes & 5 minutes discussion)

Location	Irradiation (Wh/m²/day)
A	2,580
B	4,660
C	4,090
D	4,150
E	5,380

1) Calculate the PSH at each location
2) Calculate the annual (365 days) energy generation of 10 kWp solar PV system at each location, assuming irradiation is constant everyday and consider no losses

$$E_{PV_{annual}} = P_{PV} \text{ X } \frac{H}{G_{stc}} \text{ X } 365 \text{ days}$$

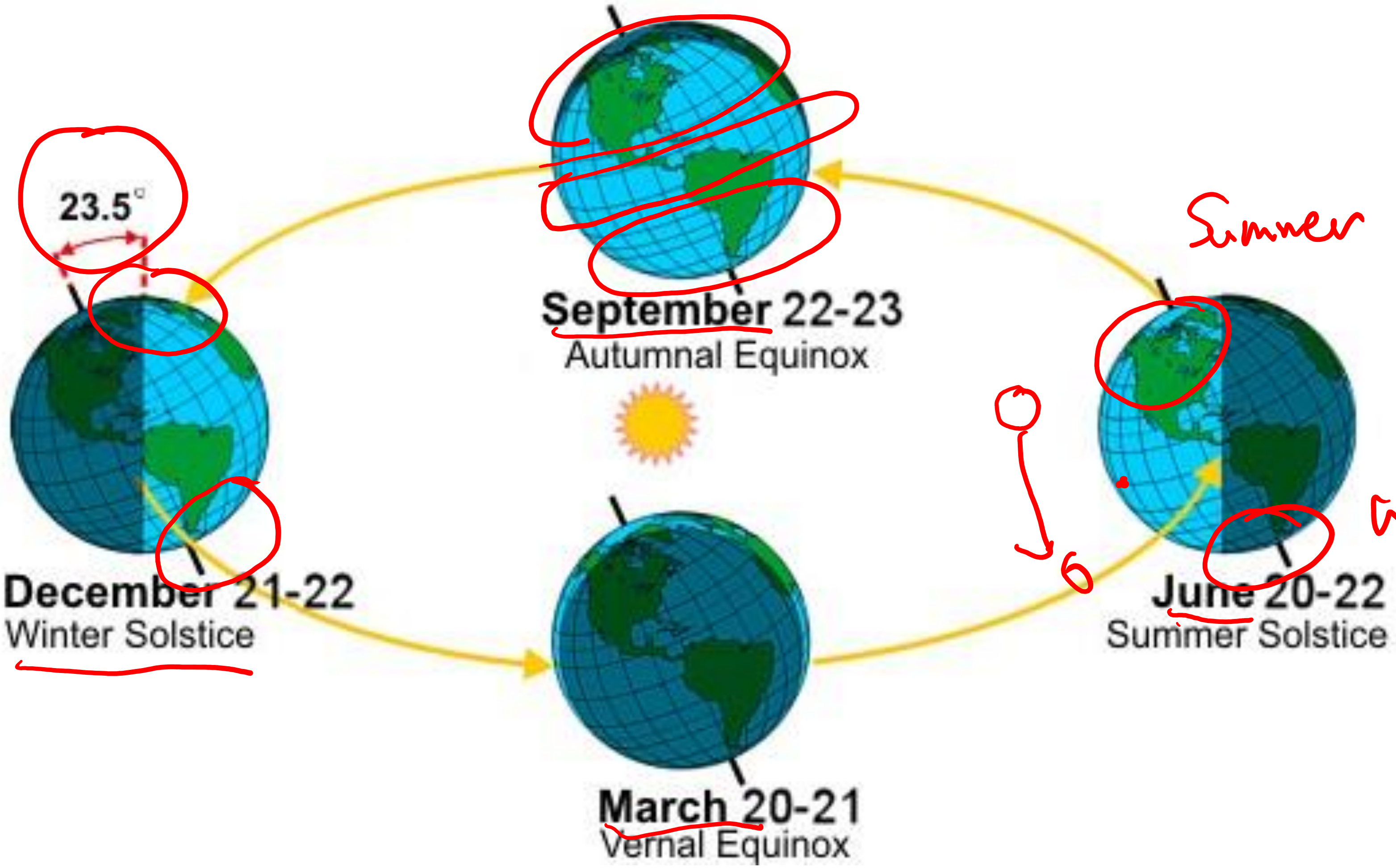
Geographic Coordinate System



- Main lines/latitude of reference:
- Malaysia:
  - Latitude: 1^0 to 7^0 N
  - Longitude : 99^0 to 120^0 E

Earth geography

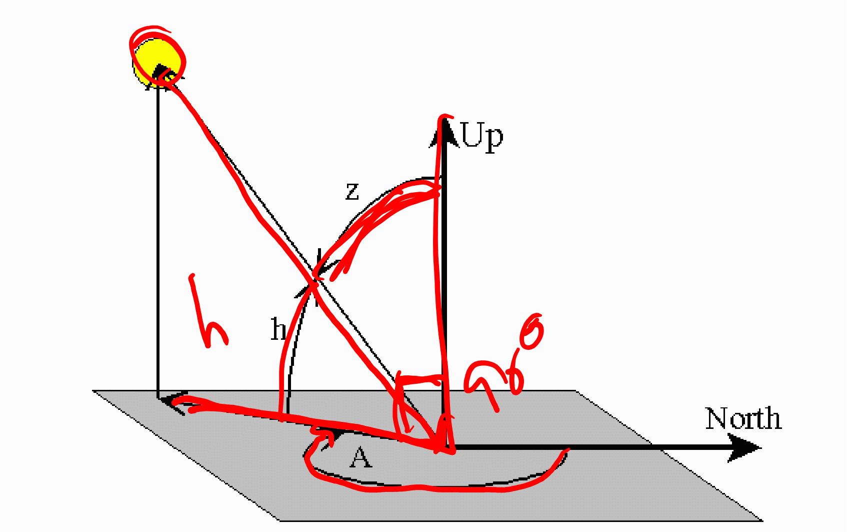
Tilt angle and revolution around the Sun



Sun Path Coordinate

Describing Location of the Sun

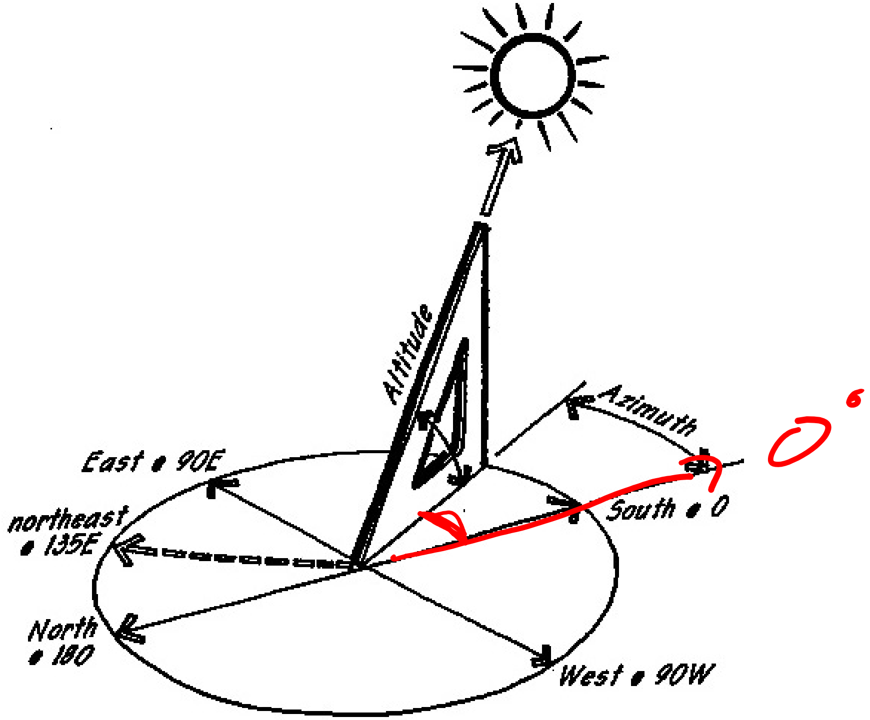
- Azimuth – horizontal angle of sun east or west of due south
- Elevation / altitude - angle of sun above the horizon
- Zenith angle – angle of the sun measured from vertical
- Azimuth and altitude describe the location of the sun in the sky at a given time.



h = elevation angle, measured up from horizon

z = zenith angle, measured from vertical

A = Azimuth angle, measured clockwise from North



Availability of Solar Energy

- How to quantify solar radiation?

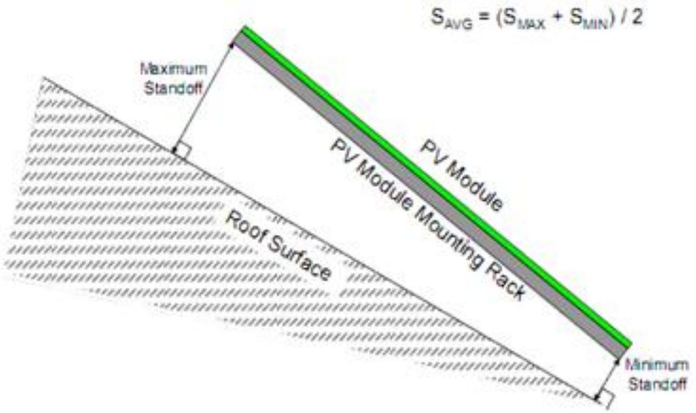
Solar cell sensor

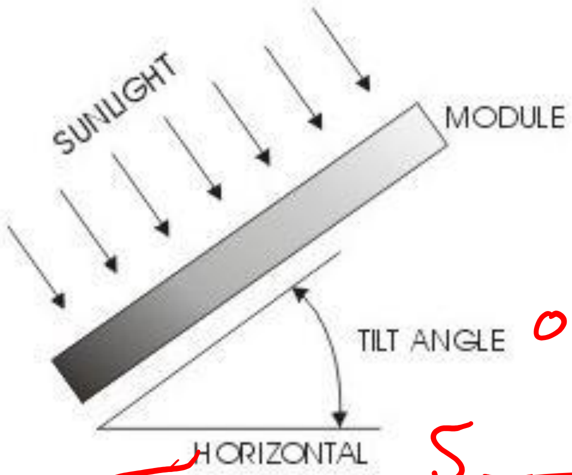
pyranometer

Sun Earth Collector Geometry

Tilt angle of solar collector

- Tilt angle is the angle between a collector plane and the ground plane





LANGKAH BERJAGA-JAGA DAN KESELAMATAN

- **Sistem solar PV adalah selamat** jika dioperasikan dengan **cara dan kaedah yang betul**, tetapi **berpotensi untuk mendatangkan bahaya** jika cuai
- Sila patuhi **langkah-langkah keselamatan** dan **prosedur operasi dan senggara** yang ditetapkan
- Hanya **orang kompeten sahaja dibenarkan** untuk menjalankan kerja-kerja operasi dan senggaraan

- **AC Voltage**
  - **240V AC power** adalah merbahaya dan boleh mengakibatkan maut jika 'live wires/terminal' terdedah dan boleh juga mengakibatkan kebakaran

LANGKAH BERJAGA-JAGA DAN KESELAMATAN

- **Solar PV array**
  - ➢ Electric shock (V_{oc} = 696.9 V_{dc})
  - ➢ Kemalangan disebabkan kedudukan pemasangan di tempat tinggi

DANGER

NOTE
maintenance can only be undertaken by a suitably licensed electrical worker or contractor.

- **PERINGATAN!!**
  - ➢ Sentiasa pastikan **bekalan kuasa suis utama** dan **suis-suis di solar PV array** dan **bilik inverter dimatikan** sebelum sebarang kerja-kerja penyenggaraan dan pembaikan dan seumpamanya dijalankan

CHAPTER 3
: Solar PV Technology & Balance of System (BOS)

KATEGORI SISTEM SOLAR PV

GRID CONNECTED SOLAR PV

LARGE SCALE SOLAR (LSS)

ROOFTOP SOLAR

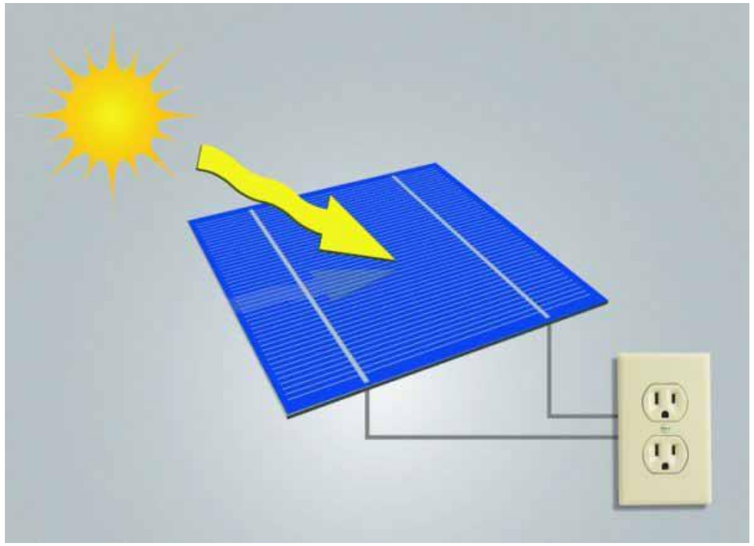
OFF-GRID SOLAR PV

Bekalan tenaga elektrik 24 jam untuk Kawasan di luar liputan rangkaian Grid

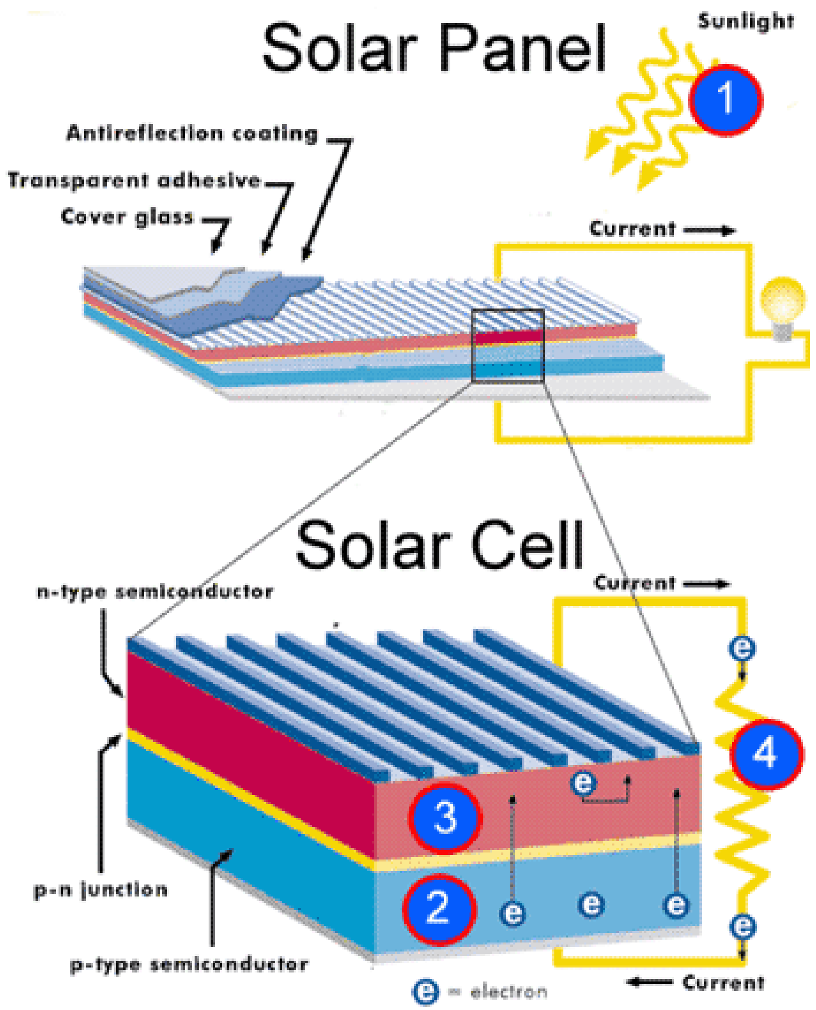
Solar PV + Sistem Inverter + Sistem simpanan tenaga + Genset

Solar Electricity

- **Photovoltaic Effect**
  - photo = light; voltaic = produces voltage
  - Photovoltaic (PV) systems convert light directly into electricity (using semiconductors)



Solar Photovoltaic fundamental



- Usually produced with semiconductor grade Silicon
- Dopants create positive and negative regions
- P/N junction results in 0.5 volts per cell
- Wire grid provides path for current

PV Terminology

Cell

Module

Array

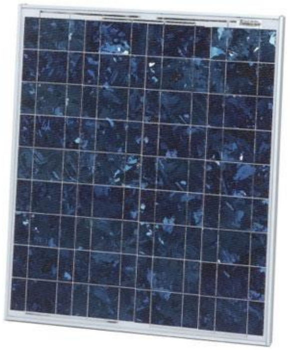
<u>PV System Sizing:</u>

4 kWp PV system: means that 4,000 watts (4 kW) is the MAXIMUM it will produce in full sunlight, ie at 1,000 W/m^2, 25^{o}C & 1.5 Air Mass

Types of Solar PV cell

- **Crystalline Silicon PV**

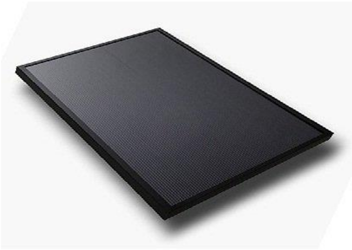
Mono crystalline

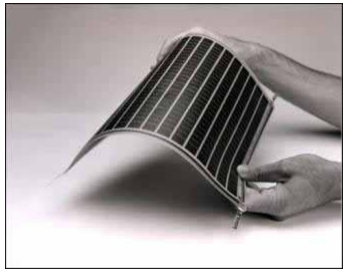


Polycrystalline

- Firm, like crystals
- Longest track record, over 50 years
- Most common, over 85% of the market
- Highest efficiencies: avg. 15%, up to 22%

- **Thin-Film PV**





- Can be applied on many different materials
- Longevity still to be proven
- Production growing at high rate
- Lower efficiencies: avg. 7%, up to 15%
- Has potential for big cost reduction
- Requires about 200 sf. per kilowatt

- Types of Thin-film : Amorphos Silicon, CIS/CIGS, Dye-sensitisized, Organic, CdTe, Micro-crystalline & Micromorphous

- Others like Hetero-junction intrinsic thin layer (HIT), Organic & Gallium Arsenide

Types of Solar PV cell…cont'd

Cell Technology	Crystalline Silicon	Thin Film
Types of Technology	• Mono-crystalline silicon (c-Si) • Poly-crystalline silicon (pc-Si/ mc-Si)	• Amorphous silicon (a-Si) • Cadmium Telluride (CdTe) • Copper Indium Gallium Selenide (CIG/ CIGS) • Organic photovoltaic (OPV/ DSC/ DYSC)
Temperature Coefficients	Higher	Lower (Lower is beneficial at high ambient temperatures)
Module construction	With Anodized Aluminum	Frameless, sandwiched between glass; lower cost, lower weight
Module efficiency	14% - 22%	4% - 12%
Required Area	Industry standard	May require up to %50 more space for a given project size
Example Brands	Kyocera, Evergreen,Q-Cell Sanyo, Schuco, Canadian Solar, Sharp, Yingli, ET Solar, Solon, Schott, Conergy, REC, Solarworld	First Solar, Solyndra, UniSolar, Konarka, Dye Solar, Bosch Solar, Sharp, Abound Solar

Thin-film needs about twice as much space for the same-size system.

Photovoltaic Modules…cont'd

Datasheets

- The electrical ratings of a PV module are normally rated at a Standard Test Conditions (STC), i.e. the PV module has been tested under this condition
- The STC refers to
  - Irradiance of 1,000 Wm^{-2}
  - Cell temperature of 25 deg C
  - Solar spectrum of Air Mass (AM) 1.5 (48.2^o)
- The electrical ratings of a PV module are also sometimes rated at Nominal Operating Cell Temperature (NOCT) conditions, i.e. the PV module has been tested under several conditions.
- The NOCT conditions refer to:
  - Irradiance of 800 Wm-2
  - Ambient temperature of 20 deg C
  - Solar spectrum of Air Mass (AM) 1.5
  - Wind speed of 1.0 ms^{-1}

powered by Q.ANTUM DUO

Q.PEAK DUO L-G8.3

415-430

ENDURING HIGH PERFORMANCE

Photon — Q.PRO-G2 235 Best polycrystalline solar module 2014 — Q CELLS — 174 modules tested

pv magazine award 2017 top innovation

EUPD RESEARCH TOP BRAND PV MODULES EUROPE 2019

Q CELLS YIELD SECURITY: ANTI PID TECHNOLOGY (APT); HOT-SPOT PROTECT (HSP); TRACEABLE QUALITY (TRA.Q™); ANTI LID TECHNOLOGY (ALT)

Q.ANTUM TECHNOLOGY: LOW LEVELISED COST OF ELECTRICITY
Higher yield per surface area, lower BOS costs, higher power classes, and an efficiency rate of up to 20.3%.

INNOVATIVE ALL-WEATHER TECHNOLOGY
Optimal yields, whatever the weather with excellent low-light and temperature behaviour.

ENDURING HIGH PERFORMANCE
Long-term yield security with Anti LID Technology, Anti PID Technology[1], Hot-Spot Protect and Traceable Quality Tra.Q™.

EXTREME WEATHER RATING
High-tech aluminium alloy frame, certified for high snow (5400 Pa) and wind loads (2400 Pa).

A RELIABLE INVESTMENT
Inclusive 12-year product warranty and 25-year linear performance warranty[2].

STATE OF THE ART MODULE TECHNOLOGY
Q.ANTUM DUO combines cutting edge cell separation and innovative 12-busbar design with Q.ANTUM Technology.

[1] APT test conditions according to IEC/TS 62804-1:2015, method B (−1500V, 168h)
[2] See data sheet on rear for further information.

THE IDEAL SOLUTION FOR:

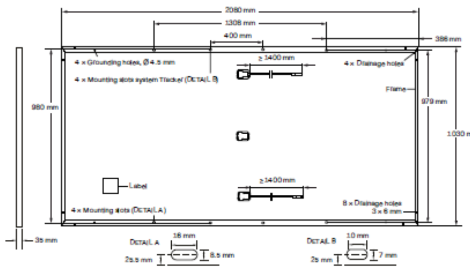
- Rooftop arrays on commercial/ industrial buildings
- Ground-mounted solar power plants

Engineered in Germany

Q CELLS

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

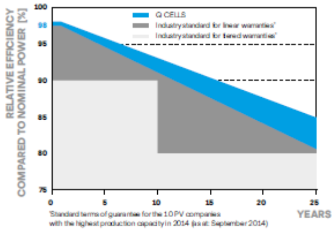


ELECTRICAL CHARACTERISTICS

POWER CLASS			415	420	425	430
MINIMUM PERFORMANCE AT STANDARD TEST CONDITIONS, STC[1] (POWER TOLERANCE +5 W / −0 W)						
Minimum — Power at MPP[1]	P_{MPP}	[W]	415	420	425	430
Short Circuit Current[1]	I_{SC}	[A]	10.69	10.74	10.78	10.83
Open Circuit Voltage[1]	V_{OC}	[V]	48.59	48.84	49.09	49.33
Current at MPP	I_{MPP}	[A]	10.18	10.22	10.27	10.31
Voltage at MPP	V_{MPP}	[V]	40.77	41.08	41.39	41.70
Efficiency[1]	η	[%]	≥19.4	≥19.6	≥19.8	≥20.1
MINIMUM PERFORMANCE AT NORMAL OPERATING CONDITIONS, NMOT[2]						
Minimum — Power at MPP	P_{MPP}	[W]	310.8	314.5	318.3	322.0
Short Circuit Current	I_{SC}	[A]	8.61	8.65	8.69	8.72
Open Circuit Voltage	V_{OC}	[V]	45.82	46.05	46.29	46.52
Current at MPP	I_{MPP}	[A]	8.01	8.05	8.08	8.12
Voltage at MPP	V_{MPP}	[V]	38.79	39.09	39.38	39.67

[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

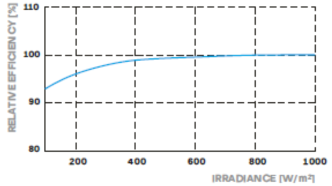
Q CELLS PERFORMANCE WARRANTY



At least 98% of nominal power during first year. Thereafter max. 0.54% degradation per year. At least 93.1% of nominal power up to 10 years. At least 85% of nominal power up to 25 years.

All data within measurement tolerances. Full warranties in accordance with the warranty terms of the Q CELLS sales organisation of your respective country.

PERFORMANCE AT LOW IRRADIANCE



Typical module performance under low irradiance conditions in comparison to STC conditions (25 °C, 1000 W/m²).

TEMPERATURE COEFFICIENTS							
Temperature Coefficient of I_{SC}	α	[%/K]	+0.04	Temperature Coefficient of V_{OC}	β	[%/K]	−0.27
Temperature Coefficient of P_{MPP}	γ	[%/K]	−0.35	Normal Module Operating Temperature	NMOT	[°C]	43±3

PROPERTIES FOR SYSTEM DESIGN

Maximum System Voltage	V_{SYS}	[V]	1500 (IEC) / 1500 (UL)	Safety Class	II
Maximum Reverse Current	I_R	[A]	20	Fire Rating based on ANSI / UL 1703	C / TYPE 1
Max. Design Load, Push / Pull		[Pa]	3600 / 1600	Permitted Module Temperature on Continuous Duty	−40 °C - +85 °C
Max. Test Load, Push / Pull		[Pa]	5400 / 2400		

QUALIFICATIONS AND CERTIFICATES

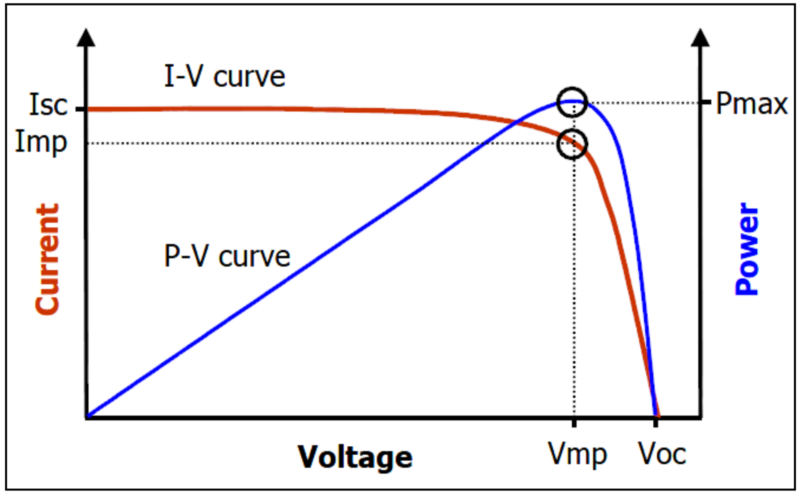
PACKAGING INFORMATION

PEAK DUO L-G8.3_415-430_2019-06_Rev01_EN

Photovoltaic Modules

Characterization of PV modules

- A PV module is characterized based on current-voltage performance of the string (s) of solar cells on the PV module
- The current-voltage performance is characterized using an I-V curve and power curve
- The I-V curve and power curve are valid at a particular irradiance and cell temperature only



Characteristics of a PV modules

Legend :

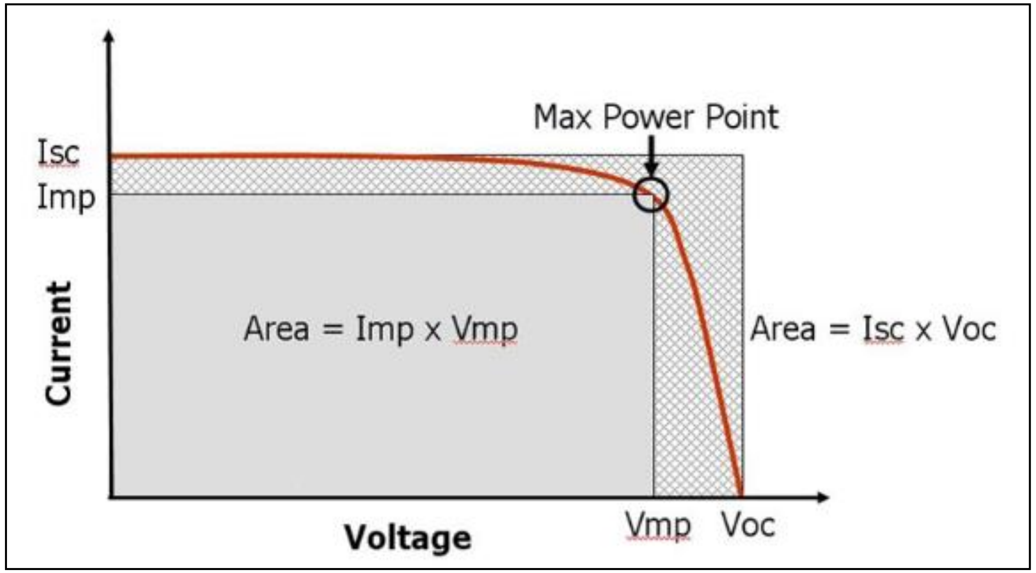
P_{mp} = Maximum power in W
V_{oc} = Open circuit voltage in V
V_{mp} = Voltage at maximum power in V
I_{sc} = Short circuit current in A
I_{mp} = Current at maximum power in A

Photovoltaic Modules…cont'd

Characterization of PV modules

- Fill Factor (FF) represents the degree of squareness of the IV curve
- The FF of a PV module or string is an important performance indicator

$$FF = \frac{I_{mp} \times V_{mp}}{I_{sc} \times V_{oc}}$$



Where :

V_{oc} = Open circuit voltage in V
V_{mp} = Voltage at maximum power in V
I_{sc} = Short circuit current in A
I_{mp} = Current at maximum power in A

Photovoltaic Modules…cont'd

Characterization of PV modules

- Efficiency, η represents the efficiency

$$\eta = \frac{I_{mp} \times V_{mp}}{G \times A} = \frac{P_{mp}}{G \times A}$$

Where :

P_{mp} = Maximum power in W
V_{mp} = Voltage at maximum power in V
I_{mp} = Current at maximum power in A
G = Irradiance in Wm^{-2} at STC (1,000 W/m^2)
A = Area of solar PV module in m^2

Efficiency of a solar PV modules only describes the ability of the module to produce maximum power at its surface area at STC level (G = 1,000 W/m^2).
It should not be used as the only parameter in determining the quality of the module.

Exercise 2: (10 minutes & 5 minutes discussion)

- Refer to datasheet solar PV module:
  - Determine FF of the module
  - Determine efficiency of the module
  - Base on the efficiency of the modules, what can you summarize?

415 W

$FF = \frac{40.77 \times 10.18}{48.55 \times 10.69} = 0.799$

430 W

$FF = 0.805$

P_{total}


LUNCH TIME

Standard & Test Conditions

- The electrical rating of PV module are rated at Standard Test Condition (STC)
  - Irradiance 1,000W/m^2
  - Cell temperature 25 ^{o}C
  - Solar Spectrum AM1.5
- Also, can be referred at Nominal Operating Cell Temperature (NOCT)
  - Irradiance 800 W/m^2
  - Ambient temperature 20 ^{o}C
  - Solar Spectrum AM1.5
  - Wind Speed 1.0 m/s

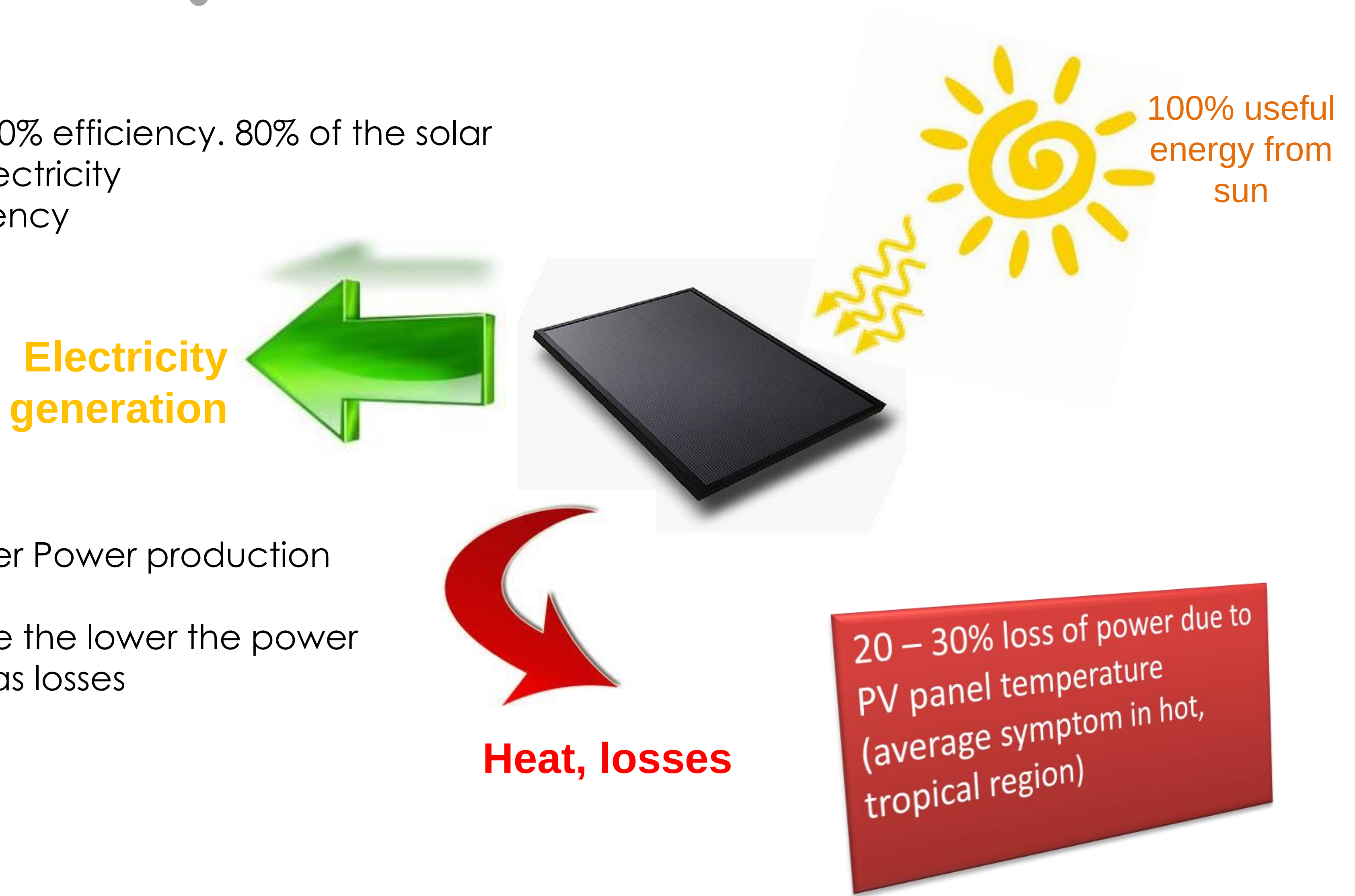
Electrical Performance

- Outputs of Installed PV system at site may differ from STC and operated at Real Operating Condition (ROC)
  - Irradiance
  - Temperature
  - Site conditions – due to location

Issues of PV Technology

Low efficiency

- Most solar panel have less than 20% efficiency. 80% of the solar radiation is not converted into electricity
- Current highest solar panel efficiency
  - *SunPower (22.2%)*
  - *LG (21.1%)*
  - *Solartech Universal (20.2%)*
  - *Silfab (20%)*
  - *Solaria (19.4%)*



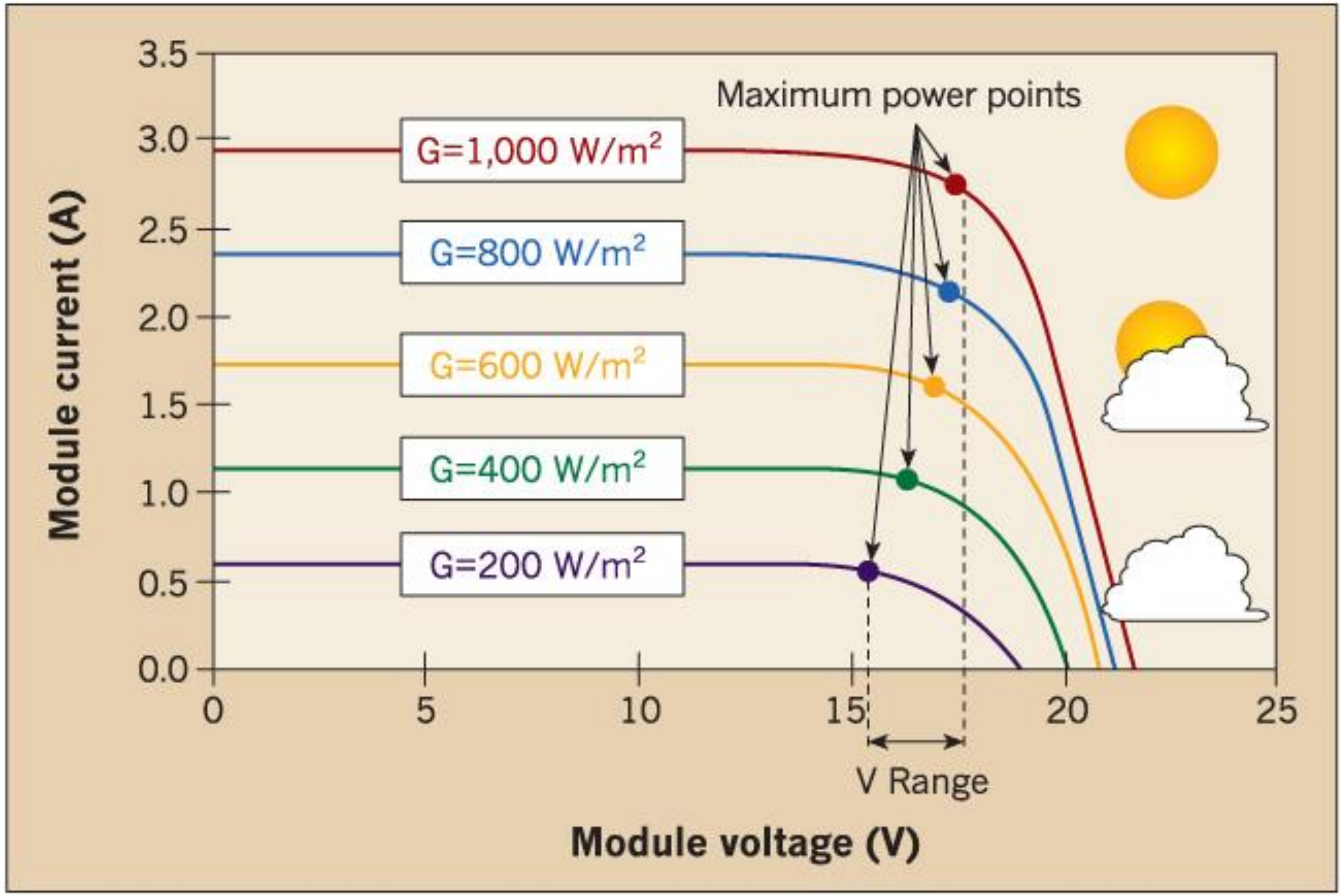
Effect on Temperature

- High temperature resulted in lower Power production
- Temperature coefficient
- The higher the panel temperature the lower the power generated. More heat produce as losses

Land requires

Photovoltaic Modules…cont'd

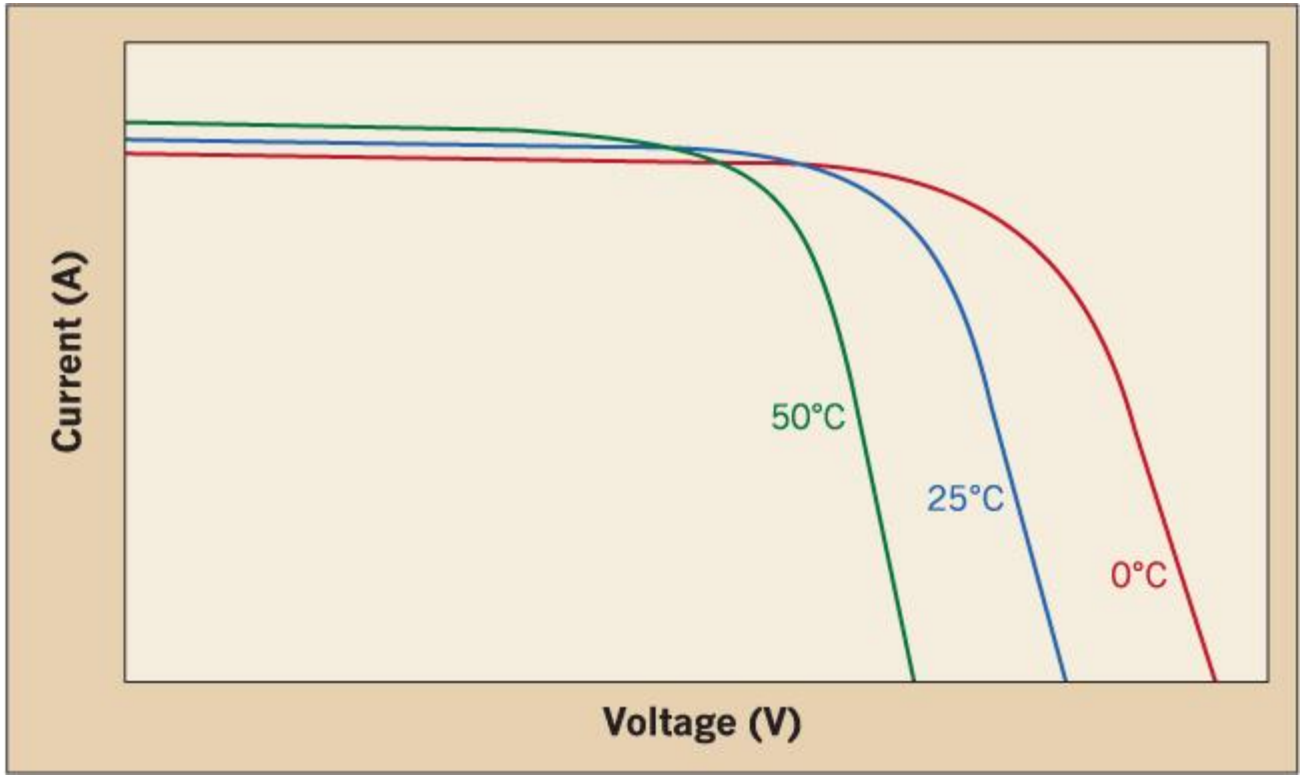
Effect of Irradiance



I-V curve of a PV module at different levels of irradiance

Photovoltaic Modules…cont'd

Effect of temperature



I-V curve of a PV module at different cell temperatures

- The output of PV module is affected by temperature:
  - Current marginally increases with module temperature increases
  - Voltage significantly decreases with increase in module temperature
  - Power significantly decreases with increase in module temperature

Temperature coefficient

- Temperature coefficients are used to determine the correct output values in different climate conditions
- Temperature coefficient can be in 2 forms:
  - Percentage values; eg, (%/°C)
  - Absolute values; eg, (mV/°C)

  } P_{real} =
- y_{Pmp} (Temperature coefficient for Maximum Power)
- y_{Isc} (Temperature coefficient for short circuit current)
- y_{Voc} (Temperature coefficient for open circuit voltage)
- y_{Vmp} (Temperature coefficient for voltage at maximum power)
- y_{Imp} (Temperature coefficient for current at maximum power)

Temperature correction factor

- Percentage values

$$f_{temp\_x} = 1 + [\frac{y_x}{100} \text{ x } (T_{cell} - T_{stc})]$$

- Absolute values

$$f_{temp\_x} = y_x \text{ x } (T_{cell} \text{ - } T_{stc})$$

x can be I_{sc}, V_{oc}, V_{mp}, I_{mp} or P_{mp}

Determining cell operating temperature

- Formula to calculate cell or module temperature:

$$T_{cell} = T_{amb} + \left[\frac{NOCT - 20}{800\ W/m^2} X\ G\right]$$

T_{cell} = temperature of cell during operation (°C)
NOCT = given by manufacturer (°C)
T_{amb} = ambient average temperature during operation (°C)
G = irradiance at ambient temperature (W/m²)

If NOCT is not available;

$$T_{cell} = T_{amb} + 25^{o}C$$

For Irradiance

- Derating factor due to irradiance effect
  - $f_g = \frac{G}{1{,}000\ W/m2}$
  - f_g is peak sun factor (decimal)
- Hence, by combining the factors;
  - $P_{roc} = P_{stc}\ x\ f_{power\_deration}$
- $f_{power\_deration} = f_{mm\_p}\ x\ f_{temp\_p}\ x\ f_g\ x\ f_{dirt}\ x\ f_{age}$
- $f_{current\_deration} = f_{mm\_i}\ x\ f_{temp\_i}\ x\ f_g\ x\ f_{dirt}$
- $f_{voltage\_deration} = f_{mm\_v}\ x\ f_{temp\_v}$

Exercise 4: 15 minutes

- Refer to the datasheet given, G is given at 900 W/m²;
  - Calculate the T_{cell} given the T_{amb} is 30°C
  - Calculate the f_{temp} of I_{sc}, V_{oc}, V_{mp}, I_{mp} or P_{mp}
  - The corrected Power output
  - If you have to consider dirt factor of 2%, determine the corrected Power output

$$T_{cell} = 30^\circ C + \left[\frac{43-20}{800}\right] \times 900$$

$$= 55.88^\circ C$$

$$f_g = 0.9$$

$$f_{temp.Pmp} = 1 + \left[-\frac{0.35}{100} \times (55.88 - 25)\right]$$

$$= 1 - 0.108 = 0.8919$$

f_{tag} – P_{mp} (V_{mp}, I_{mp})

f – I_{sc}

V_{oc}

$$P_{r6C} = P_{STC} \times f_{temp} \times f_{dirt} \times f_s$$

$$= 430 \times 0.8919 \times 0.98 \times 0.9$$

$$= \text{~~363.2~~}\ Wp \quad 326.88\ Wp$$

$$f_{temp.I_{sc}} = 1 + \left[\frac{0.04}{100} \times (55.88 - 25)\right]$$

$$= 1.012$$

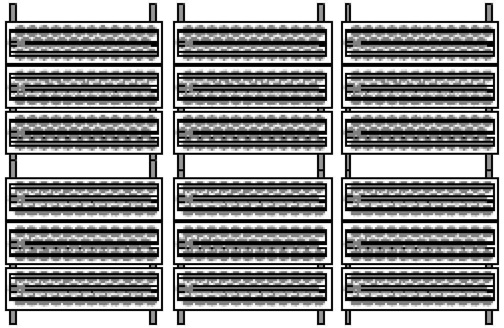
$$I_{sc\_rc} = I_{sc\_STC} \times 1.012 \times 0.9 \times 0.98$$

$$= 9.205\ A$$

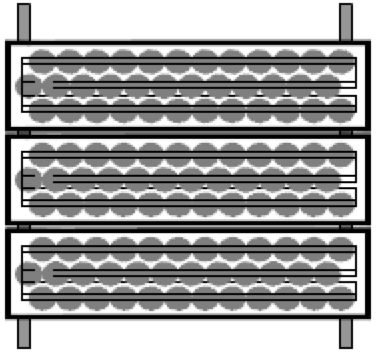
Photovoltaic Modules…cont'd

Array Configuration

- PV modules can be electrically inter-connected to form a string or array:
  - String: consists of several PV modules being electrically connected in series
  - Array: consists of one or more than one PV string(s)



Array



String

Photovoltaic Modules…cont'd

Array Configuration

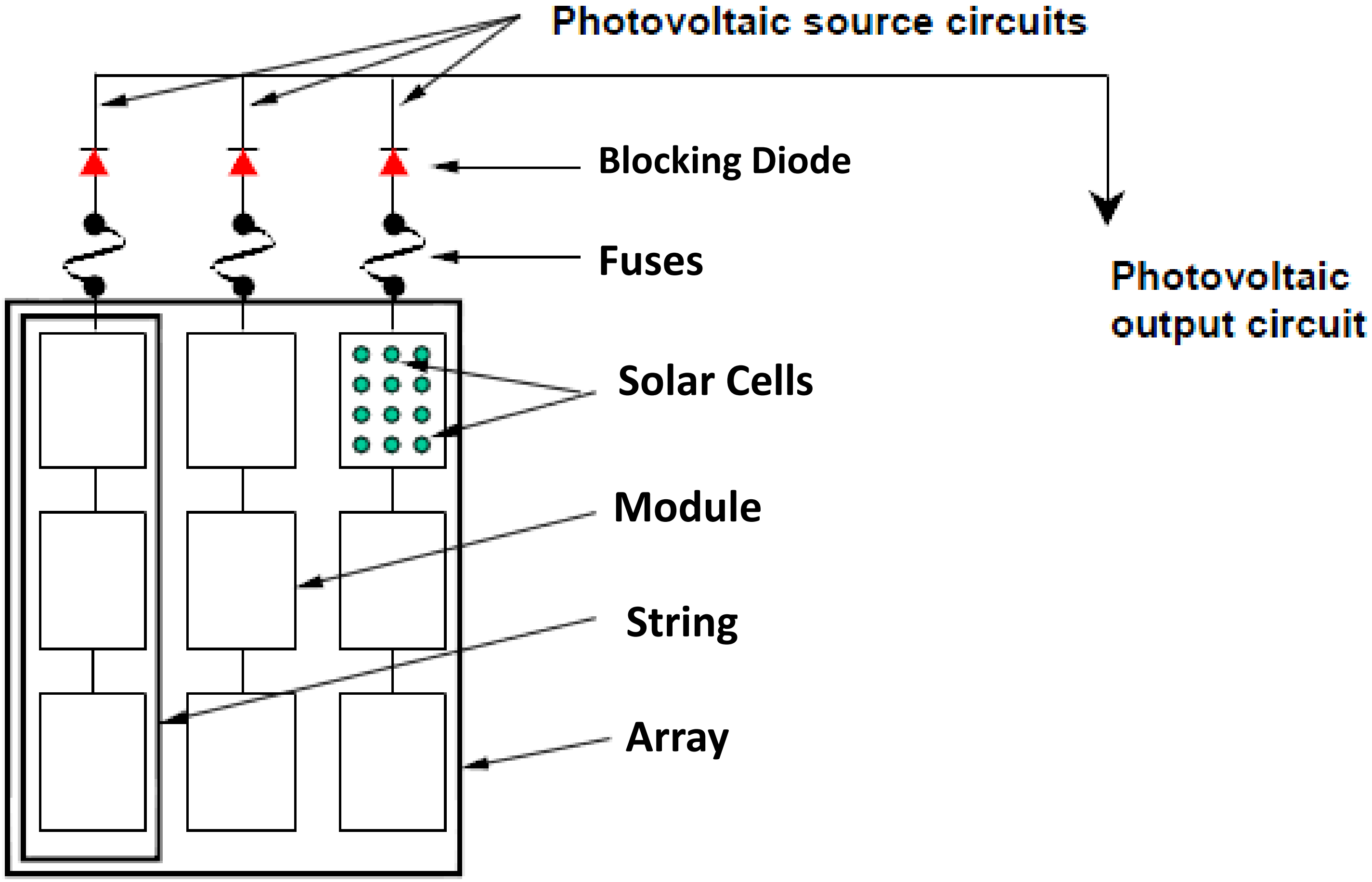


Illustration of string and array

Exercise 3: (20 minutes & 5 minutes discussion)

- Based on the given solar PV module datasheet, works in group:
  - Determine the total output power at STC of 10 modules
  - Determine the total system V_{oc} and I_{sc} of the following configuration;
    a) 5 modules in series per string
    b) 2 modules in series per string
- How many strings for (a) and (b)?

Spesifikasi & Standard MS1837

Installation of grid-connected photovoltaic (PV) system

- This MS sets out the general installation requirements for GCPV arrays with DC open circuit voltage up to 1,500V
  - Includes PV array configuration
    - Single string modules
    - Multi-string PV array
    - PV array divided into several sub-arrays
- Provide guidelines on GCPV system installation, electrical safety & fire protection requirements

Spesifikasi & Standard MS IEC 62093

Balance of system components for photovoltaic system – Design qualification natural environments

- Adoption to IEC 62093
- Describes the requirements for design qualification of BOS components
- Suitable for indoor, conditioned or unconditioned, or outdoor
- Some components such as batteries, inverters, charge controllers, system diode, heat sinks, surge protectors, system junction boxes, MPPT & switch gear
- Includes test procedures of BOS to determine performance characteristics


TAKE SOME REST & SEE U TOMORROW

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

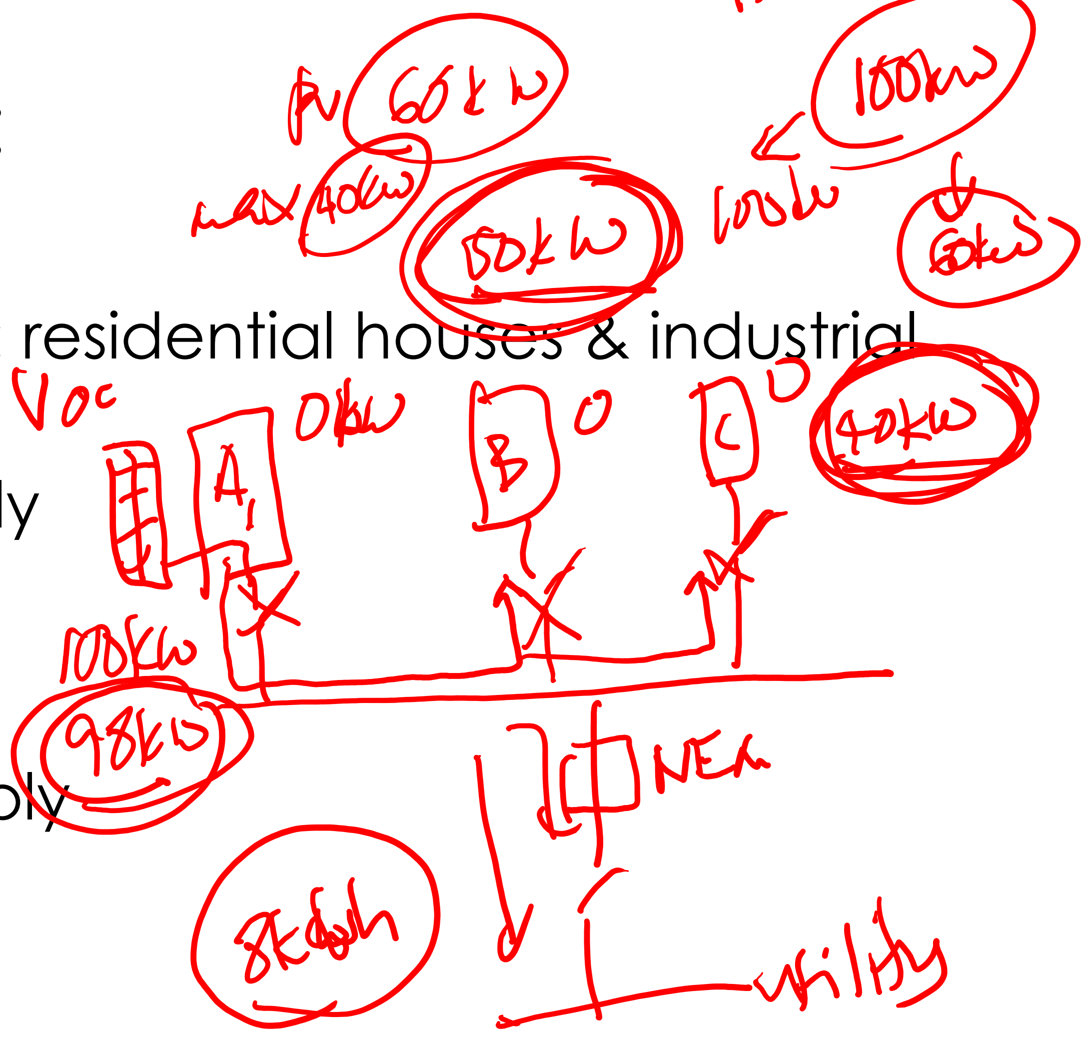
MASA / HARI	8.30 Pg - 9.00 Pg	9.00 Pg - 10.30 Pg	10.30 pg - 11.00 Pg	11.00 Pg - 1.00 tgh	1.00 ptg - 2.30 Ptg	2.30 Ptg - 4.30 Ptg
HARI PERTAMA	PEMBUKAAN & PRE TEST	**SLOT 1** Fundamental of RE Technology Kandungan: - Background - RE Technology - Solar PV system Kaedah : Ceramah Penceramah : (Ir Dr Abdul 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)

Energy Resources

- Determine the solar energy resources of the particular site for each month for a year
  - NASA meteorological data
  - Global Solar Atlas http://globalsolaratlas.info/
  - Local meteorological station

Connection to the Grid

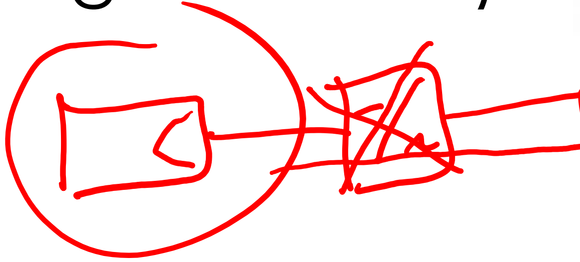
- GCPV can be categorised as:
  - Distributed system
    - Small to medium sized systems, eg: residential houses & industrial premises
    - Connected to LV side of grid supply
  - Centralised system
    - Large scale GCPV, eg: solar farm
    - Connected at MV side of grid supply



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



SUNNY BOY 3.0 / 3.6 / 4.0 / 5.0 / 6.0
with SMA SMART CONNECTED

Compact
- One-person installation due to low weight of 17.5 kg
- Compact design means minimum space requirements

Easy to use
- 100% plug and play installation
- Free online monitoring via Sunny Places
- Automated service thanks to SMA Smart Connected

High yields
- Use of surplus energy through dynamic active power limitation
- Yield increase without installation effort due to integrated shade management SMA ShadeFix

Combinable
- Intelligent energy management and storage solutions can be added anytime
- Can be combined with TS4-R components for module optimization

SUNNY BOY 3.0 / 3.6 / 4.0 / 5.0 / 6.0

Higher yields for private homes – intelligent solar power generation

The new Sunny Boy 3.0–6.0 ensures maximum energy yields for private homes. This inverter combines the integrated Service SMA Smart Connected service and intelligent technology for all ambient requirements. Thanks to its extremely light design, the device can be installed quickly and easily. The Sunny Boy can be commissioned quickly via smartphone or tablet thanks to its integrated web interface. For specific requirements on the roof, such as shading, the TS4-R module optimizers can be added into the system, with all communication and monitoring facilitated through the inverter. Current communication standards make the inverter future-proof, meaning intelligent energy management solutions as well as SMA storage solutions can be flexibly added anytime.

Technical data	Sunny Boy 3.0	Sunny Boy 3.6	Sunny Boy 4.0	Sunny Boy 5.0	Sunny Boy 6.0
Input (DC)					
Max. generator power	5500 Wp	5500 Wp	7500 Wp	7500 Wp	9000 Wp
Max. input voltage	600 V				
MPP voltage range	110 V to 500 V	130 V to 500 V	140 V to 500 V	175 V to 500 V	210 V to 500 V
Rated input voltage	365 V				
Min. input voltage / initial input voltage	100 V / 125 V				
Max. input current input A / input B	15 A / 15 A				
Max. DC short-circuit current input A / input B	20 A / 20 A				
Number of independent MPP inputs / strings per MPP input	2 / A:2; B:2				
Output (AC)					
Rated power (at 230 V, 50 Hz)	3000 W	3680 W	4000 W	5000 W[1]	6000 W
Max. apparent power AC	3000 VA	3680 VA	4000 VA	5000 VA[1]	6000 W
Nominal AC voltage / range	220 V, 230 V, 240 V / 180 V to 280 V				
AC power frequency / range	50 Hz, 60 Hz / −5 Hz to +5 Hz				
Rated power frequency / rated grid voltage	50 Hz / 230 V				
Max. output current	16 A	16 A	22 A[2]	22 A[2]	26.1 A
Power factor at rated power	1				
Adjustable displacement power factor	0.8 overexcited to 0.8 underexcited				
Feed-in phases / connection phases	1 / 1				
Efficiency					
Max. efficiency / European Efficiency	97.0% / 96.4%	97.0% / 96.5%	97.0% / 96.5%	97.0% / 96.5%	97.0 % / 96.6 %
Protective devices					
Input-side disconnection point	●				
Ground fault monitoring / grid monitoring	● / ●				
DC reverse polarity protection / AC short circuit current capability / galvanically isolated	● / ● / –				
All-pole-sensitive residual-current monitoring unit	●				
Protection class (as per IEC 61140) / overvoltage category (according to IEC 60664-1)	I / III				
General data					
Dimensions (W / H / D)	435 mm / 470 mm / 176 mm (17.1 inches / 18.5 inches / 6.9 inches)				
Weight	17.5 kg (38.5 lb)				
Operating temperature range	−25°C to +60°C (−13°F to +140°F)				
Noise emission, typical	25 dB(A)				
Self-consumption (at night)	5.0 W				
Topology	Transformerless				
Cooling method	Convection				
Degree of protection (as per IEC 60529)	IP65				
Climatic category (as per IEC 60721-3-4)	4K4H				
Max. permissible value for relative humidity (non-condensing)	100%				
Equipment					
DC connection / AC connection	SUNCLIX / AC connector				
Display via smartphone, tablet, laptop	●				
Interfaces: WLAN / Ethernet / RS485	● / ● / ●				
Communication protocols	Modbus (SMA, Sunspec), Webconnect, SMA Data, TS4-R				
Shade management: integrated SMA ShadeFix / TS4-R	● / ○				
Warranty: 5 / 10 / 15 years	● / ○ / ○				
Certificates and approvals (more available upon request)	AS 4777.2, C10/11, CE, CEI 0-21, EN 50438, G59/3-4, G83/2-1, DIN EN 62109 / IEC 62109, NEN-EN50438, IE-EN50438, NT_Ley20.571, ÖVE/ÖNORM E 8001-4-712 & TOR D4, PPDS, PPC, RD1699, TR3.2.1, UTE C15-712, VDE-AR-N 4105, VDE0126-1-1, VFR 2014, RfG compliant				
Certificates and approvals (planned)	DEWA, IEC 61727, IEC 62116, MEA, NBR16149, PEA, SI4777, TR3.2.2				
Country availability of SMA Smart Connected	AU, AT, BE, CH, DE, ES, FR, IT, LU, NL, UK				
Type designation	SB3.0-1AV-41	SB3.6-1AV-41	SB4.0-1AV-41	SB5.0-1AV-41	SB6.0-1AV-41

● Standard features ○ Optional features
– Not available
Data at nominal conditions Status: 11/2019

1) 4600 W / 4600 VA according to VDE-AR-N 4105
2) AS 4777: 21.7 A

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

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

Galvanic isolation
- Transformer
- Transformerless

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

Capacity Rating

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

Galvanic isolation

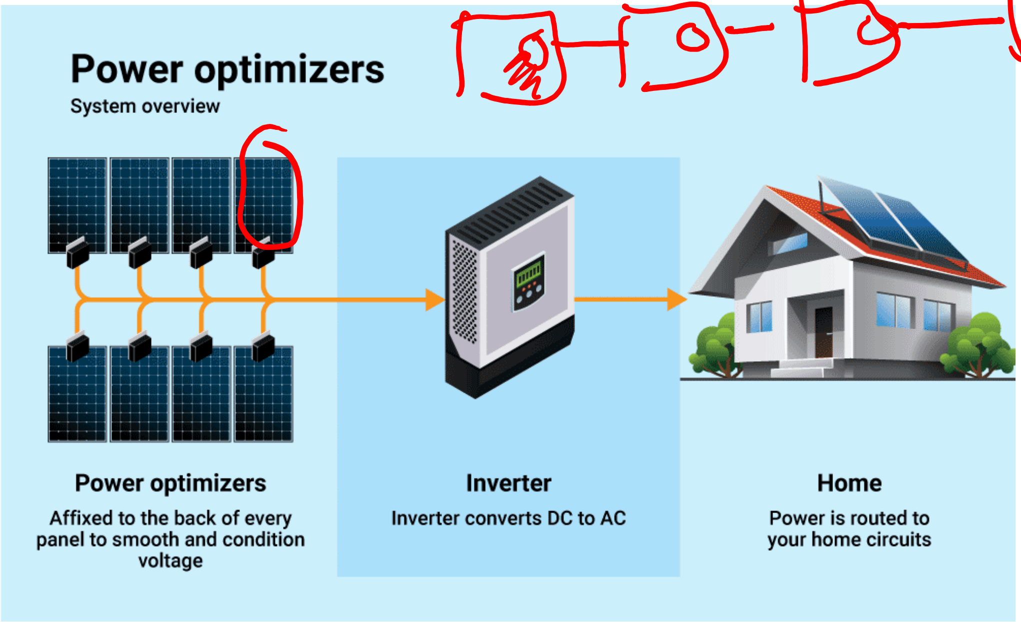
- Transformer
- Transformerless

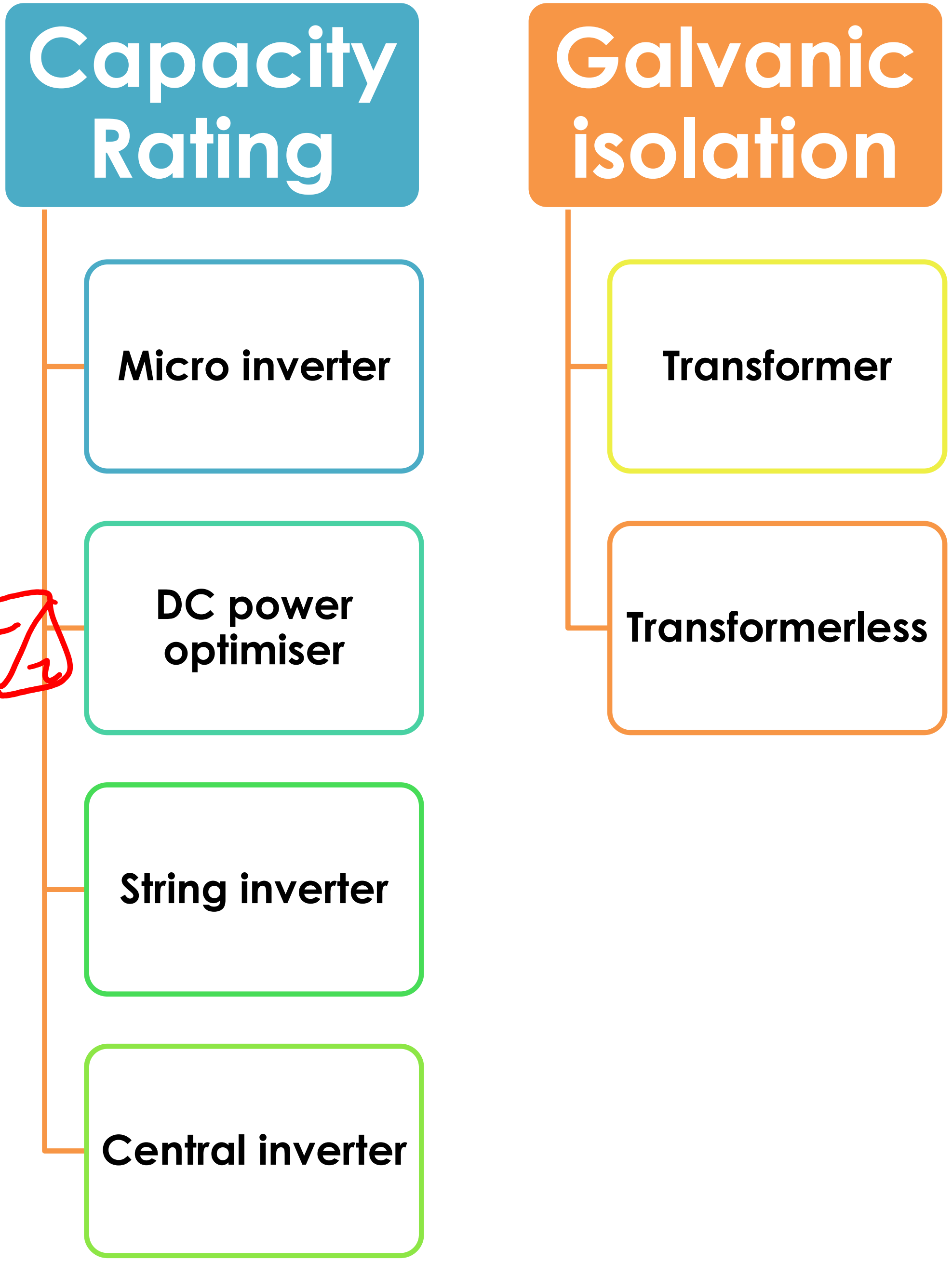
Grid Inverter

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





Derating Power of Inverters

- Input voltage variation
- Ambient temperature

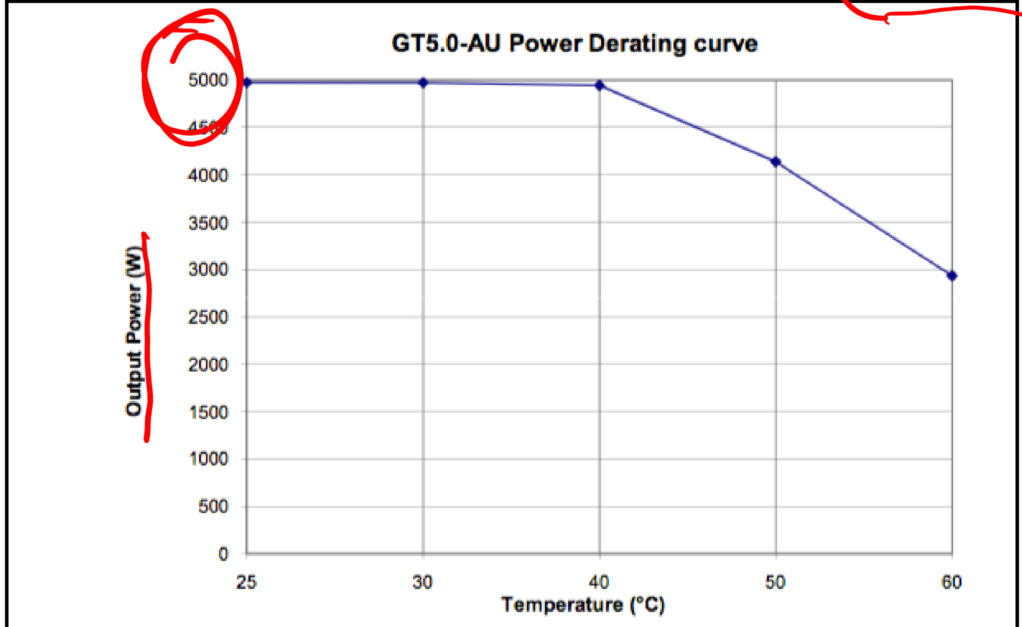
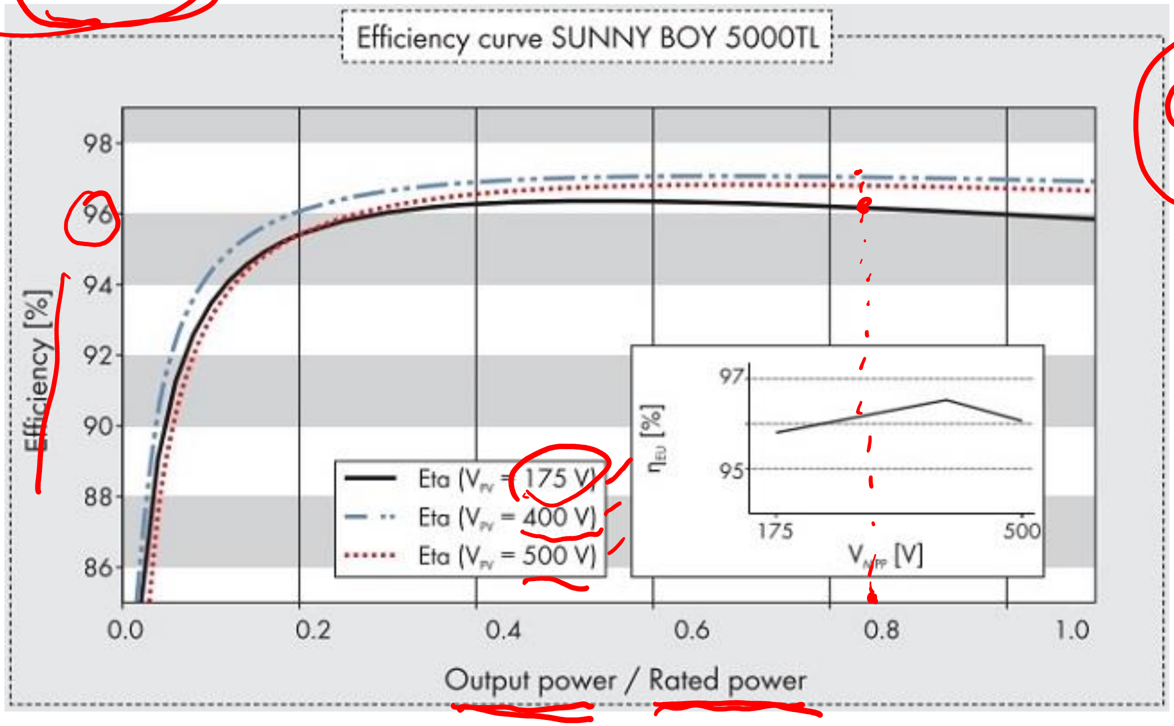


Figure A-2 Output Power vs. Ambient Temperature (GT5.0-AU)



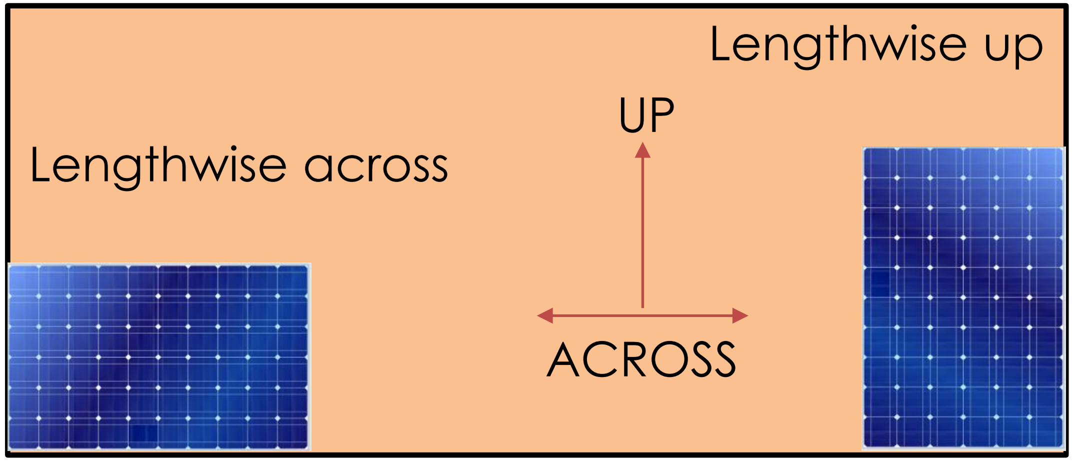
Types of Connection

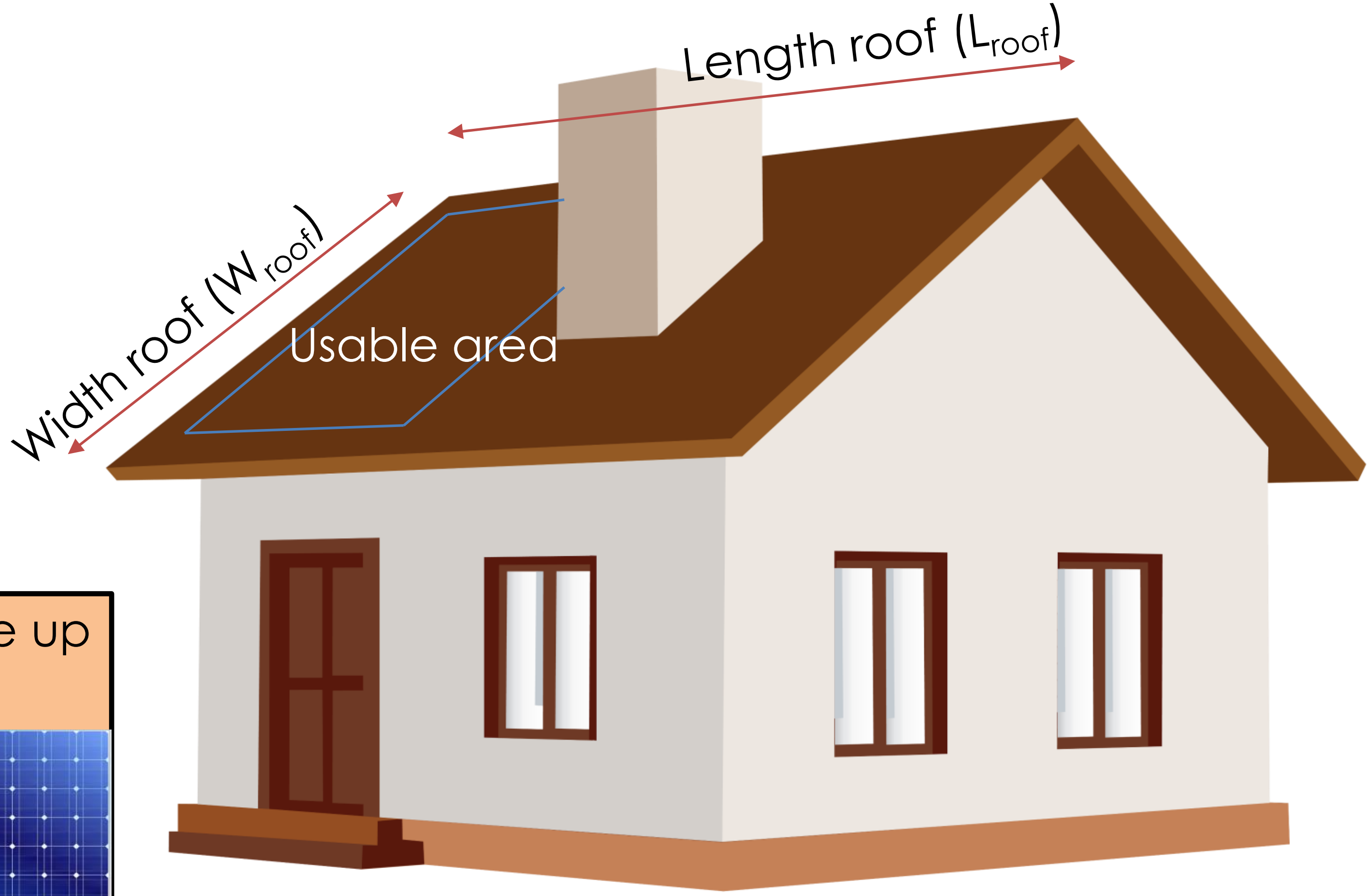
- Direct connection
  - Used for Feed-in-Tarif (FiT)
  - Export all generated power/energy into the grid network
- Indirect connection
  - Used for Net Energy Metering (NEM)
  - Connected to MSB or SSB or DB
  - Energy generated for PV used for building consumption, excess to be exported into the grid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

CHAPTER 4
: GCPV system design

Dimensioning of PV Array

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

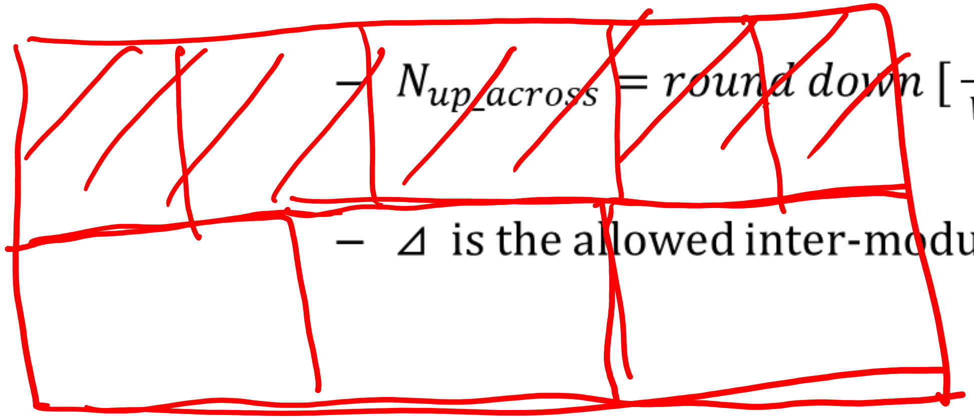




Dimensioning of PV Array

- 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.

W = 1m
L = 2m

LWL :

$N_{a\text{-}up} = r.d \left[\frac{15m}{1m + 0.01} \right] = 14.85 \approx 14$

$N_{a\text{-}a} = r.d \left[\frac{30}{2 + 0.01} \right] = 14.92 = 14$

30m

15m

$N_{max} = 14.85 \times 14.92 = 221.56$ panel

$\approx$ ~~221~~ 196 panel

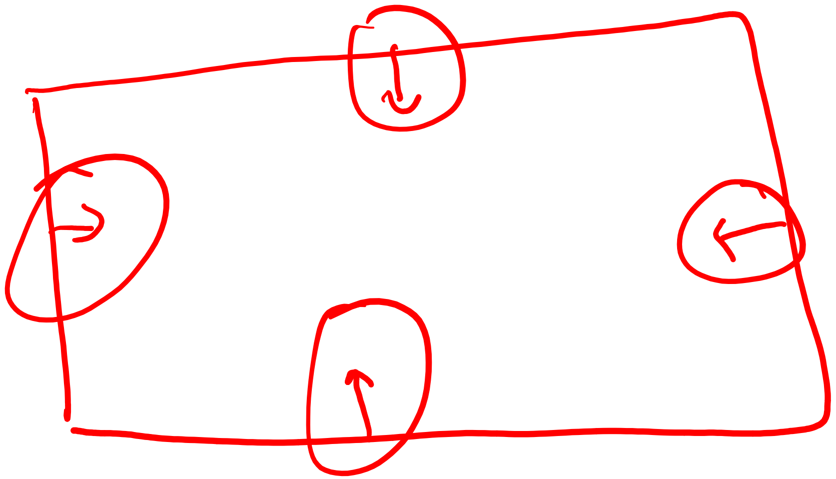
$P_{STC} = 196 \times 420W = 82.32\ kW$

LWU

$$N_{u-u} = r.d\left[\frac{15}{2+0.01}\right] = 7 \text{ module}$$

$$N_{u-a} = r.d\left[\frac{30}{1+0.01}\right] = 29$$

$N_{max} = 203$ $P_{STC} = 85.26$ kW



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

$$T_{cell} = 36 + \left[\left(\frac{43-20}{800}\right) \times 1000\right] = 64.7\ ^\circ C$$

$$f_{temp} = 1 + \left[\frac{-0.35}{100} \times (64.7 - 25)\right] = 0.8655$$

$$f_{derating} = 0.8655 \times 0.96 = 0.8309$$

$$E_{reg} = \frac{70}{100} \times \frac{12}{8} \times (7{,}055) = 7407.5 \text{ kWh/yr}$$

day

$$P_{array} = \frac{7407.75}{5 \times 365 \times 0.8309 \times 0.97 \times 0.97} = 5.19 \text{ kW}$$

$$N = r.u \frac{5.19}{0.42} = 13 \text{ modules}$$

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

$$B = P_{array\_stc} \times k_{index}$$

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

$P_{array} = \frac{37,500}{5,000} = 7.5\text{ kW} = 7,500\text{ W}$

$N_{mod} = \frac{7500}{420} = 17$ module

B = RM25,950

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.

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

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

Exercise

Based on previous exercise, determine the required inverter range.

$$5.19 \times 0.9 \leq P_{nom.inv} \leq 5.19 \times 1.0$$

$$\boxed{4.671 \leq P_{nom.inv} \leq 5.19}$$

SB 5.0 – $P_{nom.inv}$: 5kW / 5kVA

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

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

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

Exercise

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

5000 W $P_{array} = 7500\ W$

$7500 \times 0.9 \leq P_{inv} < 7500$

$6750 \leq P_{inv} \leq 7500$

7000 W

$N_{min} = \frac{7000}{1.0 \times 420} = 17$ mod

$N_{max} = \frac{7000}{0.9 \times 420} = 18$ mod

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

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

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

Sizing of PV array to Inverter

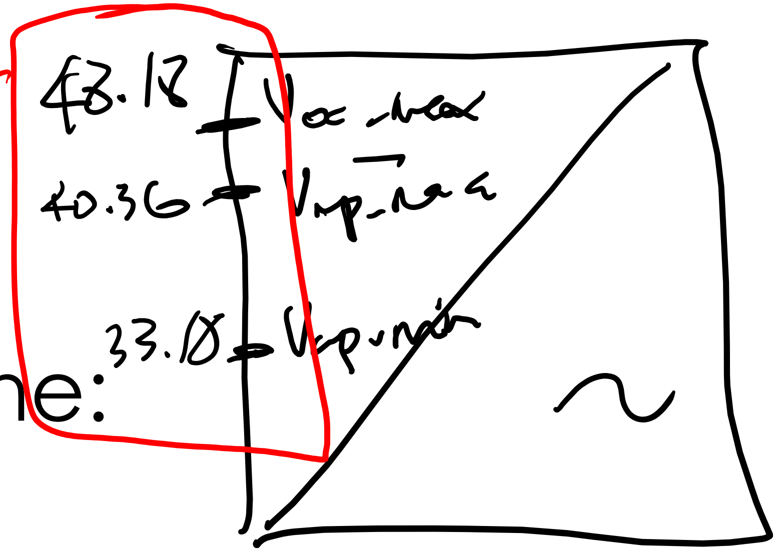
- Limits on voltages of PV module
  - The highest allowable voltage of maximum power PV should generate

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

  - The lowest voltage of maximum power from PV module

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

Exercise



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

|| – 3 module

$$V_{oc,max} = 48.84 \times \left[1 + \left(\frac{-0.27}{100} \times (20-25)\right)\right]$$

$$= 48.18\,V$$

$$V_{mp\_max} = 41.08 \times \left[1 + \left[\frac{-0.35}{100} \times (20-25)\right]\right]$$

$$= 40.36\,V$$

$$V_{mp\_min} = 41.08 \times \left[1 + \frac{-0.35}{100} \times (75-70)\right]$$

$$= 33.89\,V$$

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:

$$N_{s\_max} = round\ down\ [\frac{V_{max\_inv}\ x\ f_4}{V_{mp\_max}}]$$

$$N_{s\_min} = round\ up\ [\frac{V_{min\_inv}\ x\ f_6}{V_{mp\_min}\ x\ f_5}]$$

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

Sizing of PV array to Inverter

|| series = Isc

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

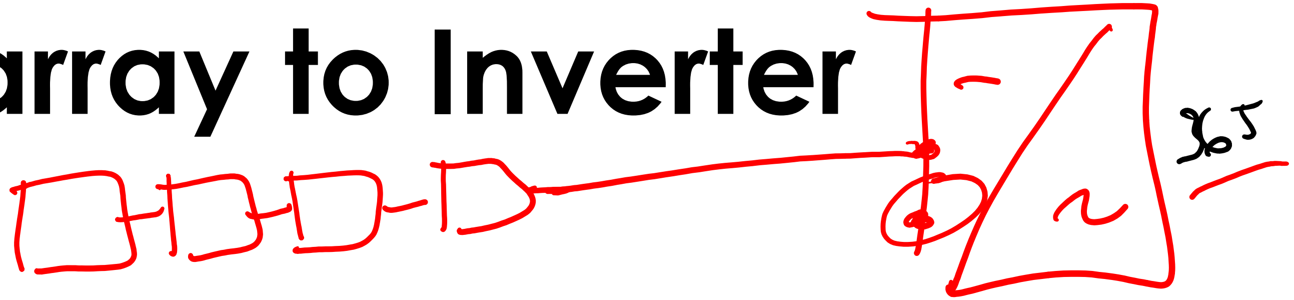
$$N_{p\_max} = round\ down\ [\frac{I_{\max\_inv}}{I_{sc\_string}}]$$

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

V ↑ I =

$N_{p\text{-}max} = r.d \left[\frac{15}{10.74}\right] = 1$

Sizing of PV array to Inverter



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

$$N_t = N_s \; x \; N_p$$

Exercise

Using Q-Cell 420 Wp and SMA Sunnyboy 5,500 W, determine optimum array configuration & total PV modules.

What is the peak PV array?

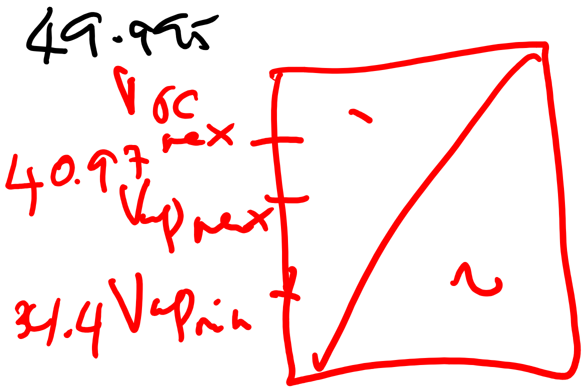
Inv : V_{range} : 130 – 500 V 3600 W 20°C

75°C

I_{max} : 15 A

PV : 430 W : V_{oc} : 49.33 V I_{sc} : 10.83

V_{mp} : 41.70



$$V_{oc\,max} = 49.33\,V\left[1 + \left(\frac{-0.27}{100} \times (20-25)\right)\right]$$

$$= 49.995\,V$$

$$V_{mp\,max} : 41.7 \times \left(1 + \left(\frac{-0.35}{100} \times (20-25)\right)\right]$$

$$: 40.97\,V$$

$$V_{mp\,min} : 41.7\,V\left[1 + \left(-\frac{0.35}{100} \times (75-25)\right)\right] = 34.4\,V$$

$$N_{s\,max} = \frac{500 \times 0.95}{40.97} = 11 \text{ modules}$$

$N_s = 5 \ldots 11$ modules.

$$N_{s\,min} = \frac{130 \times 1.1}{34.4 \times 0.97} = 5 \text{ modul}$$

$N_p = \text{Fl}\left[\frac{15 \times P_{max} \times 0.95}{10.83}\right] = 1$ parallel   36

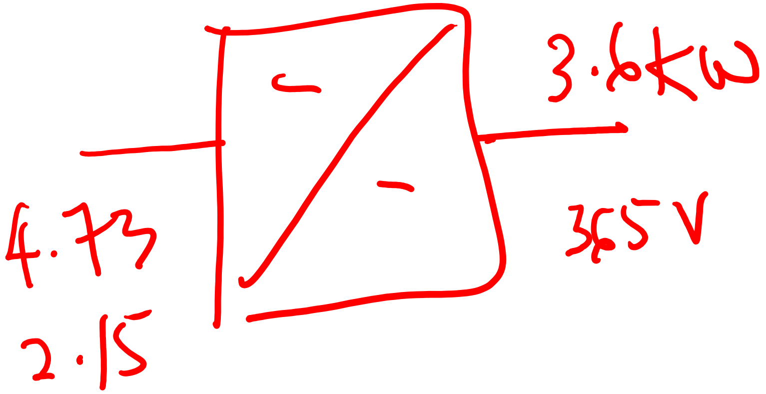
333.6 V

$N_s = $ ~~5×11~~ + 5×1 (8×1)

− 11×1

$V_{mp\text{-}total} = 208.5\,V$ $P_{total} = 2.15\,kW$

$V_{oc\text{-}total} = 458.7\,V$ $P_{total} = 4.730\,kW$



$N_s = 5 \ldots 11$

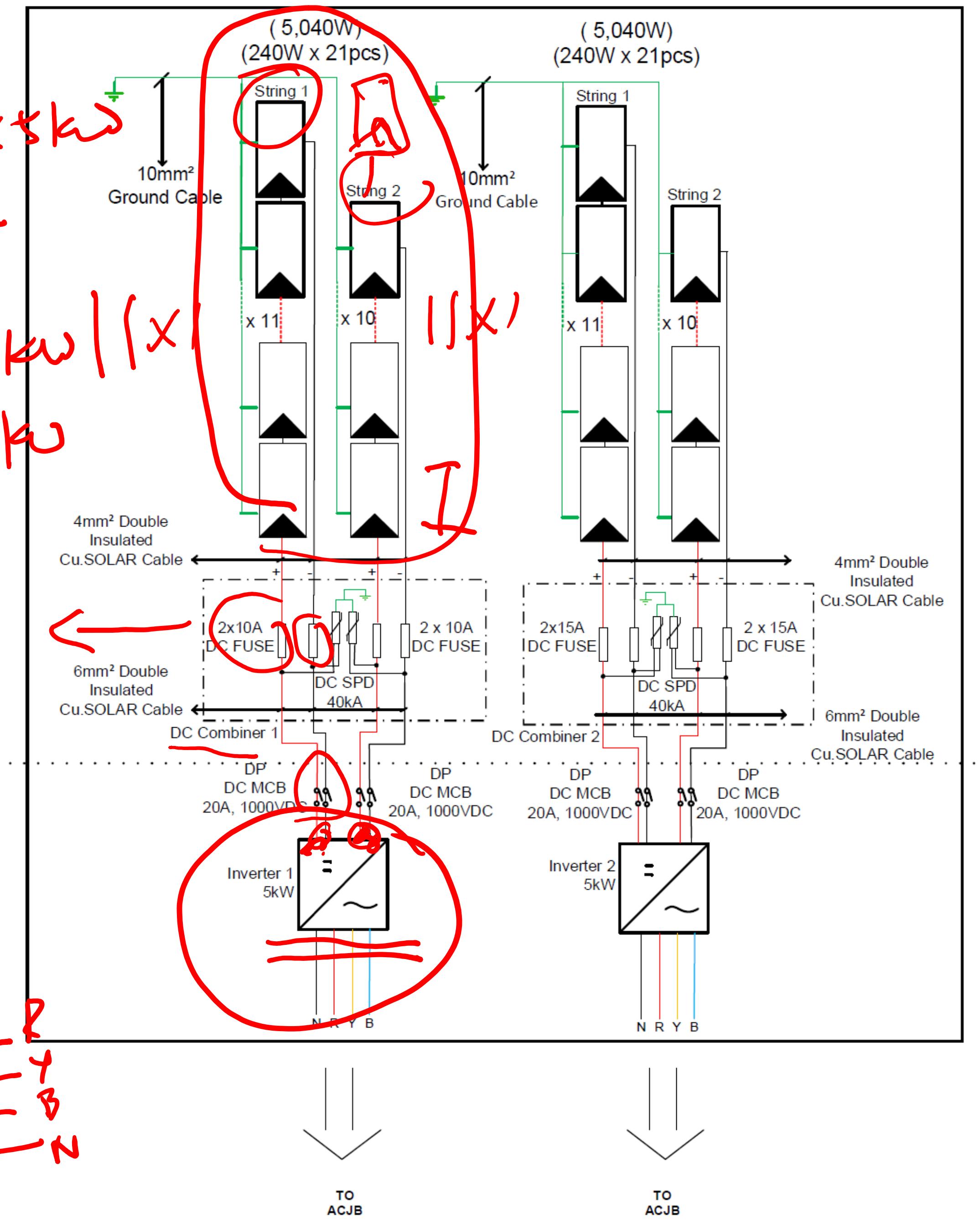
6, 7, 8

Exercise

- Given that a client wants to reduce his house annual energy consumption by 60% and he has budget of RM50,000. Determine the best configuration of PV & Inverter according to energy constraint method.
  - Annual energy consumption is 12,600 kWh
  - What would you suggest to him?

Example of PV Array & Inverter configuration

PV ARRAY SECTOR 1 (10.08kW)



Sizing of other BOS components

- Current carrying capacity – maximum current carrying capability of a conductor
  - Effects by cross sectional area (mm2), type of insulation, & environment

$$I_{\min\_string} \geq 2\ x\ I_{sc\_stc\_string}$$
$$I_{\min\_array} \geq 1.3\ x\ I_{sc\_stc\_string}$$

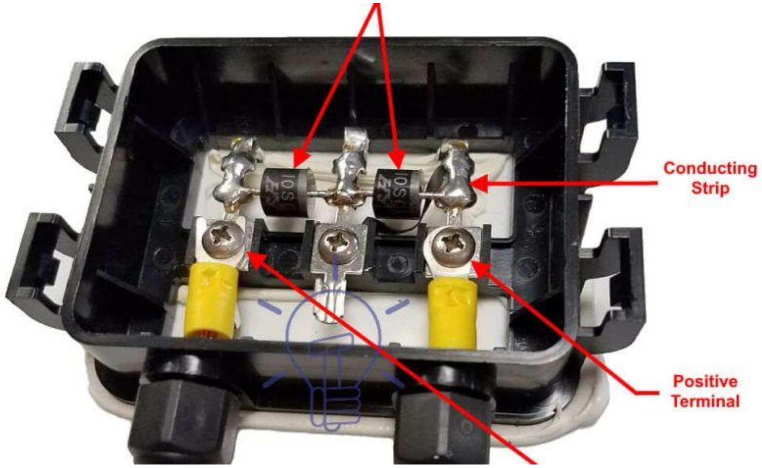
- DC cable
  - Minimum CSA of DC cable can be calculated:

$$A_{\min\_dc\_cable} = \frac{2\ x\ L_{dc}\ x\ I_{dc}\ x\ \rho}{Loss\ x\ V_{\min\_string}}$$

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

Balance of System



By-pass diode

MC4 connector

Single core DC cable for PV

Sizing of other BOS components

- DC cable
  - Voltage insulation rating

$$V_{dc\_cable} \geq 1.2\ x\ V_{oc\_stc\_array}$$

Exercise

A PV array using Q-Cell 420W is configured using 8 x 1 arrangement. Longest length of string cable is 8m & length of array cable is 5m. Minimum MPPT voltage is 34.4V. Maximum dc current is 10.22A. Voltage drop is 3% in string cable, 1% in array cable. Find:

- Minimum CSA of string & array cable
- Actual voltage drop in string & array cable
- Voltage insulation rating in string & array cable

Sizing of other BOS components

- Power & voltage losses

$$P_{dc} = \frac{2\ x\ L_{dc\_cable}\ x\ (I_{dc})^2\ x\ \rho}{A_{dc\_cable}}$$

Or

$$P_{dc} = V_{drop\_dc}\ x\ I_{dc}$$

$$\%V_{drop\_dc} = \frac{V_{drop\_dc}}{V_{min}\ x\ N_s}\ x\ 100\%$$

Sizing of other BOS components

- String fuse
  - MS1837 – string fuse is required on the +ve cable

$$V_{fuse} = 1.2\ x\ V_{oc\_string\_stc}$$

$$1.5\ x\ I_{sc\_string} \ \leq\ I_{trip} \ \leq 2\ x\ I_{sc\_string}$$

V_{fuse} is the voltage rating of string fuse

I_{trip} is tripping current of string fuse

Sizing of other BOS components

- DC main switch

$$V_{dc\_ms} = 1.2\ x\ V_{oc\_array\_stc}$$
$$I_{sc\_string} \geq 1.3\ x\ I_{sc\_array}$$

- Surge Protection Device
  - Protects the electronic components from surges. It is recommended that SPD shall be installed:
    - Between each of array DC cables & earth
    - Between each of inverter output AC cable & earth

System Performance & Evaluation

- Advantages of proper & appropriate system performance monitoring, analysis & reporting:
  - Key indices describes whether the system is operating as designed
  - Data analysis
- Standard for system performance & evaluation
  - MS IEC 61724:2010 – Photovoltaic system performance monitoring: guidelines for measurement, data exchange & analysis
  - IEA PVPS: Task 2 – describe technical information on the system's performance, which highlighted the use of normalized system performance indicators that are energy yields, system efficiency, and performance ratio.

System Performance & Evaluation

- Key Performance Indices
  - Yield is the amount of energy generated by the system. Can be described annually, monthly or daily

$$Y_{exp} = P_{array} \; x \; PSH_{poa} \; x \; f_{deration} \; x \; \eta_{sub\_system}$$

$$Y_{mea} = Actual\ energy\ meter\ reading$$

- Specific Yield
  - Amount of energy generated per unit capacity (kWh/kWp)

$$SY_{exp} = \frac{Y_{exp}}{P_{array\_stc}} \qquad SY_{mea} = \frac{Y_{mea}}{P_{array\_stc}}$$

System Performance & Evaluation

- Performance Ratio
  - Dimensionless quantity of overall quantity of the system, ie; normalised indication of the system

$$PR_{exp} = \frac{Y_{exp}}{Y_{ideal}} \qquad PR_{mea} = \frac{Y_{mea}}{Y_{ideal}}$$

$$Y_{ideal} = P_{array\_stc} \, x \, PSH_{poa}$$

Assignment

- GCPV system is required at N 45.76, E 78.48
- Based on the data sheet, design and configure an optimum configuration of a GCPV system:
  - Total energy consumption per year is 145,800 kWh
  - Energy saving of 75%
  - Area availability is 600 m2
  - No budget constraint
  - Insert all assumption and factors
- Determine the BOS rating & sizing
- Produce the schematic diagram of the complete system
- Determine the performance indices