“Solar Energy” WS 2014/2015

Lecture 16: Photovoltaic Components and Systems

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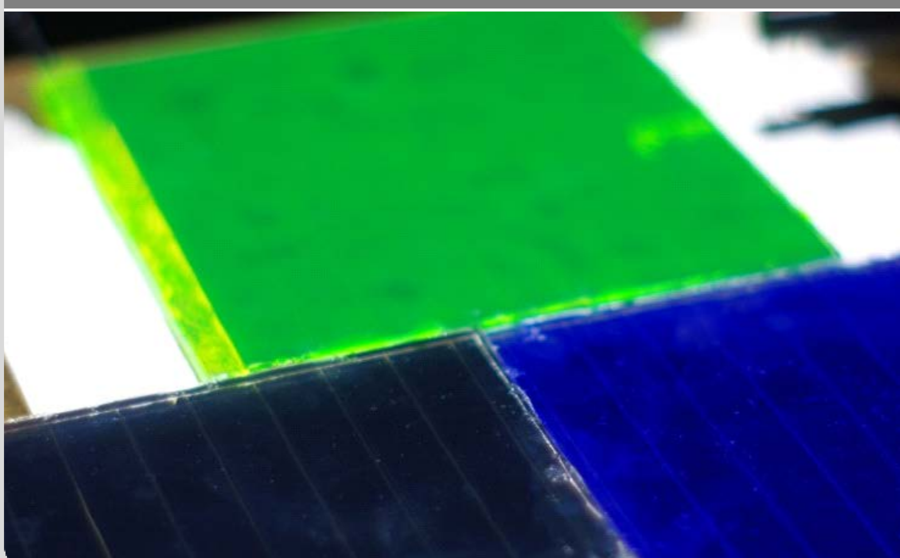
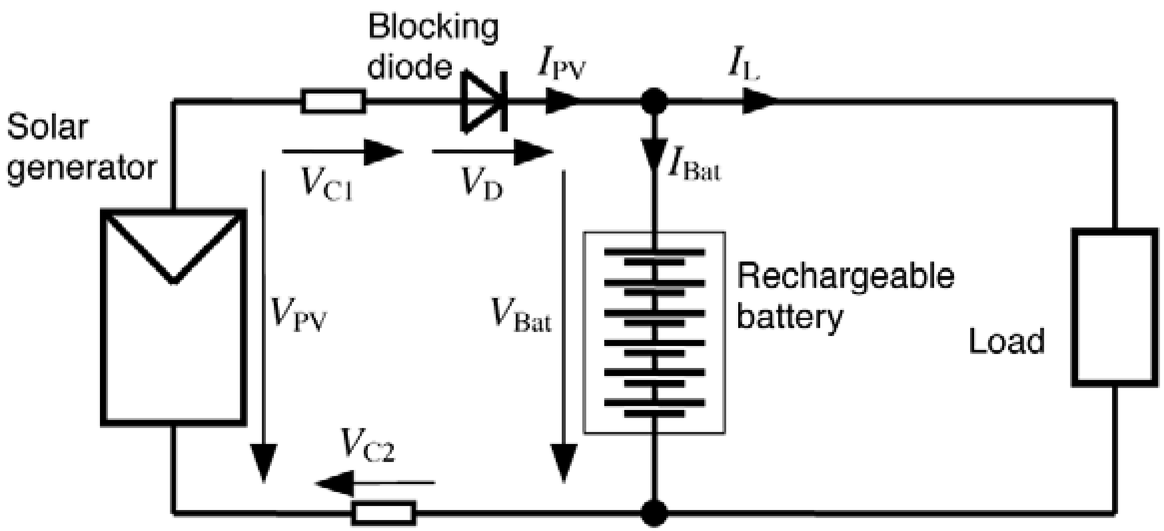


Battery Systems

- Simplest system consists only PV module, a battery, and load.
- Since internal resistance of PV module is very small ⇒ battery discharges through PV module if solar irradiance is low
- Can avoid such reverse currents by placing a “blocking diode” between PV module and battery, but this diode causes permanent a permanent loss

$$P_{\mathrm{L,diode}} = I_{\mathrm{PV}} \cdot V_{\mathrm{D}}$$

- Hence diodes with low forward voltages (e.g. Schottky diode, V_D ~0.55 V) often used



Source: *Quashing, “Understanding Renewable Energy Systems”, Earthscan 2005*

Battery Systems

- Cables cause further losses: a connection cable with cross-section *A*, specific resistance ρ and cable lengths l_1 and l_2 for the cables from PV module generator to battery and back, respectively, causes following losses:

$$P_{\mathrm{L,cable}} = I_{\mathrm{PV}} \cdot (V_{\mathrm{C1}} + V_{\mathrm{C2}}) = I_{\mathrm{PV}}^2 \cdot (R_{\mathrm{C1}} + R_{\mathrm{C2}}) = I_{\mathrm{PV}}^2 \cdot \frac{\rho}{A} \cdot (l_1 + l_2)$$

- Copper cable (ρ_{Cu}=0.0175 Ω.mm^2/m) with cable length $l_1 = l_2$ = 10m, cross-sectionial area = 1.5 mm^2 and a current I_{PV} = 6 A causes cable losses of $P_{L,cable}$ = 8.4 W
- Assuming the PV module can produce 100 W, the cable losses + blocking diode losses of 3.3 W are considerable at 12%!

Battery Systems

- To minimize losses, cables should:
  i. be as short as possible and,
  ii. have large cable cross-sectional area large
- For a 12V battery system, a voltage drop of 3%, or 0.35 V, is acceptable in the cables from the PV module to the battery and 7%, or 0.85 V, from battery to load. Here, the cable cross-section must therefore be 6 mm^2
- For higher power systems , losses can be reduced if batteries are connected in series $\Rightarrow$ increases battery voltage and decreases current flow $\Rightarrow$ thus losses reduced

Battery Systems

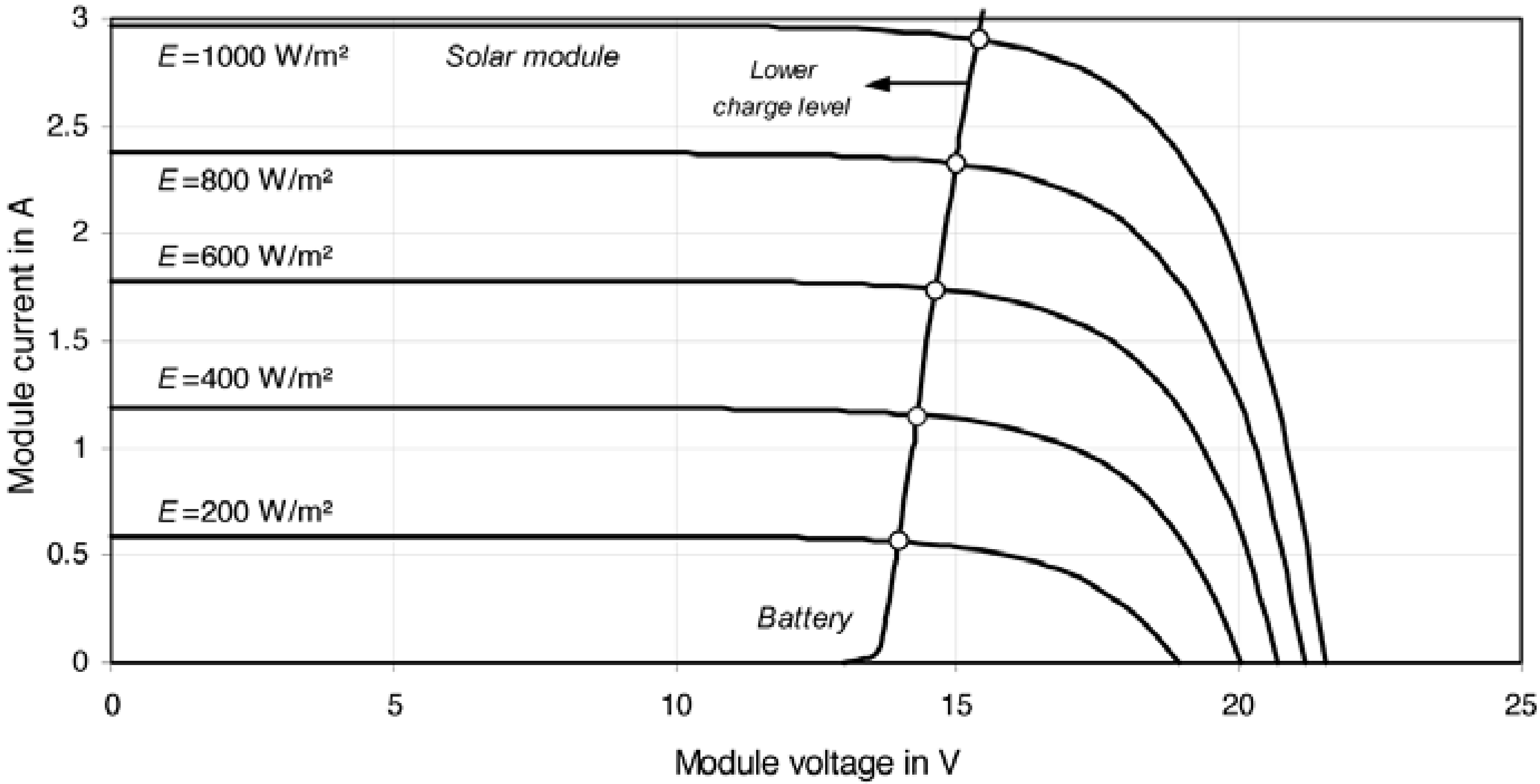
- The PV module has the voltage:

$$V_{PV} = V_{Bat} + V_D + V_{C1} + V_{C2}$$

- The diode voltage V_D being nearly constant, and cable voltage drops V_{C1} and V_{C2} proportional to the photovoltaic current I_{PV}
- The battery voltage V_{Bat} depends on the charge current and state of charge. Hence, the voltage at the PV module increases slightly with rising currents and increasing irradiances, and it varies with the battery SoC
- For a PV system with a directly-connected battery, a fairly good operating point is achieved for a wide irradiance range $\Rightarrow$ DC–DC converters and MPPT'S are rarely used in battery systems
- Sometimes the power consumption of additionally electronics is higher than the possible energy gain!

Source: Quashing, "Understanding Renewable Energy Systems", Earthscan 2005

Battery Systems

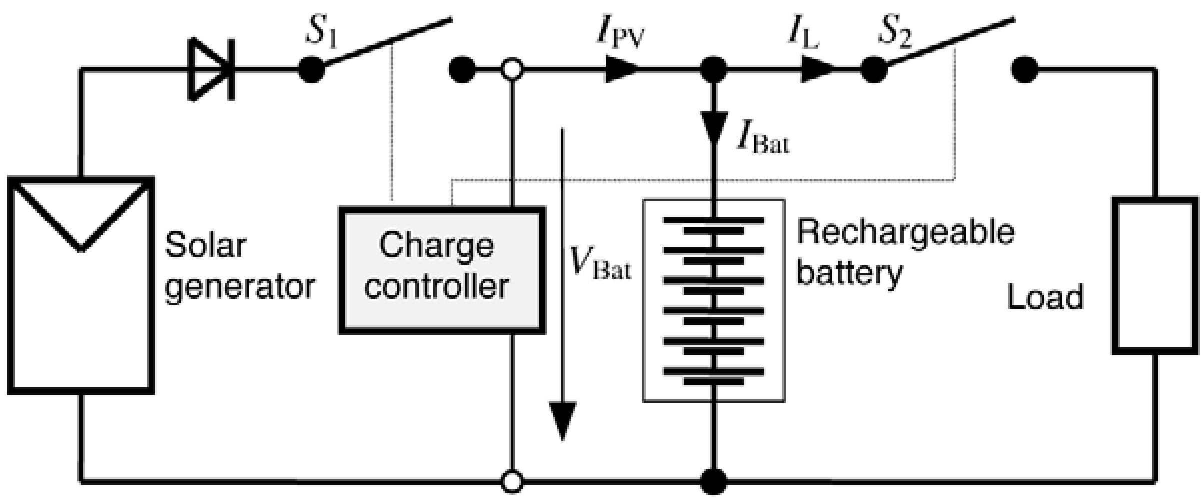


- When would it make sense to include a MPPT?

Source: *Quashing, "Understanding Renewable Energy Systems", Earthscan 2005*

Charge Controllers

- However, charge controllers (or regulators) are still needed in PV-based power systems to protect batteries by limiting discharge levels and preventing overcharging
- Most charge-controllers work on basis of voltage control

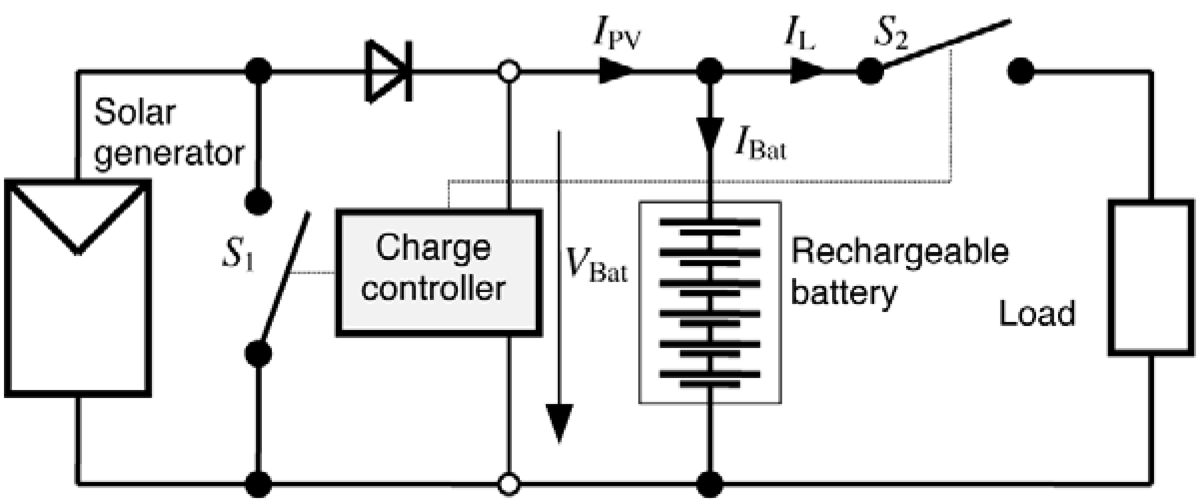


- Charge controller measures the battery voltage V_{Bat}. If it falls below the deep discharge voltage (11.4 V for a 12-V LA battery) ⇒ switch S_2 disconnects load from battery.

Source: *Quashing, "Understanding Renewable Energy Systems", Earthscan 2005*

Charge Controllers

- When battery is charged again (rising above an upper threshold voltage) ⇒ switch reconnects the load.
- If the battery voltage rises above the end of charge voltage (about 14.4 V for a 12-V lead–acid battery), the switch S_1 stops charging.
- The series charge controller (previous slide) and the parallel or shunt charge controller (below) are two main types



Source: *Quashing, "Understanding Renewable Energy Systems", Earthscan 2005*

Charge Controllers

- The parallel (or shunt) charge controller $\Rightarrow$ most commonly used
- If battery is fully charged, the charge controller short-circuits the PV generator across switch S_1. The PV generator voltage falls to the voltage drop across the switch (<1 V). The blocking diode avoids reverse currents from the battery flowing back across the switch
- Note, if PV array is partially shaded and thus not irradiated homogenously, the short circuit conditions can strain the shaded cells very significantly $\Rightarrow$ can cause heating problems in battery enclosures, as dissipation usually occurs when radiation levels and ambient temperatures are high
- One advantage: consume little power when the load or battery is using only PV generated power

Charge Controllers

- Power semiconductors such as power MOSFETs are normally used as switches
- Continuous forward losses at the switch S_1 are a disadvantage of the series charge controller. The forward resistance of good MOSFETS is less than 0.1 Ω, e.g. but still with a current of 6 A, the field-effect transistor BUZ 11 with a forward resistance of 0.04 Ω still causes losses of 1.5 W
- If the PV array voltage is monitored in addition to the battery voltage, the blocking diode can be omitted and the forward losses reduced. In this case, the charge controller must open the switch S_1 if the solar generator voltage falls below the battery voltage

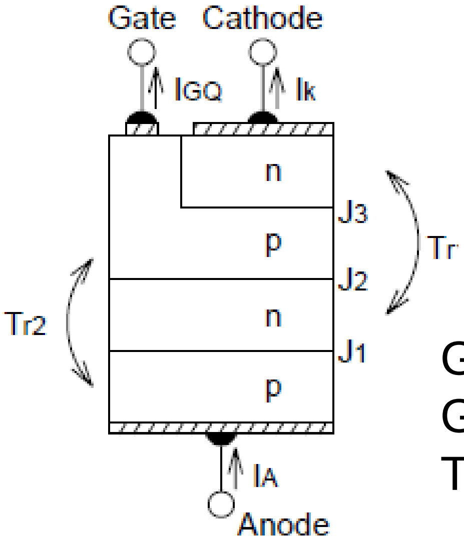
Charge Controllers

- One final question: why does a PV module with V_{mp} of 18 V required to charge a 12 V lead-acid battery?
- Five contributing factors:
  1. ~2.8 V is lost to temperature rises to 60°C.
  2. A drop of ~0.6 V occurs across the blocking diode.
  3. A drop of 1.0 V typically occurs across the regulator.
  4. There can be some voltage loss with reducing light intensity.
  5. The batteries must be charged to 14.0–14.5 V to reach their full state of charge.

Inverters

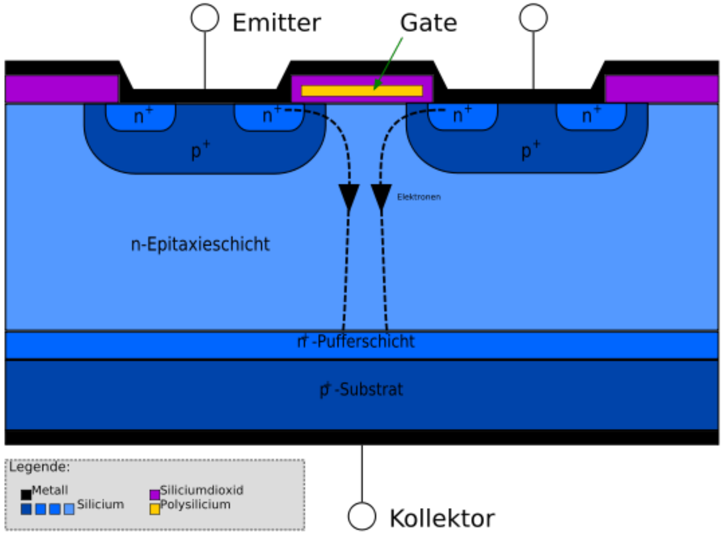
- As we all know, most consumer applications use alternating current (AC) rather than direct current (DC)
- Island grid inverter ⇒ for AC devices in a PV stand-alone system
- Grid-connected inverter ⇒ for system to be connected to national grid. Similar design, but there are some differences in the details.
- Power electronic devices are used today to convert DC to AC. Different types of semiconductor elements that can switch voltages higher than 1000 V or even currents higher than 1000 A are:
  - power MOSFET (power field effect transistors)
  - bipolar power transistors
  - insulated gate bipolar transistors (IGBT)
  - thyristors (controllable diodes)
  - triacs (two-direction thyristors)
  - gate turn-off (GTO) thyristors (switchable thyristors).

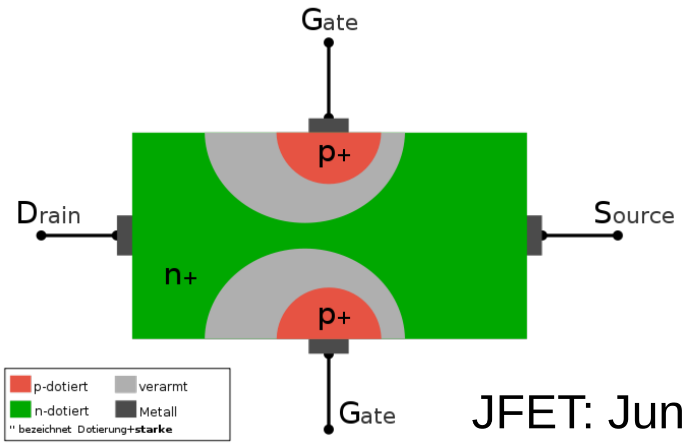
Inverters



GTO:
Gate Turn Off
Thyristor

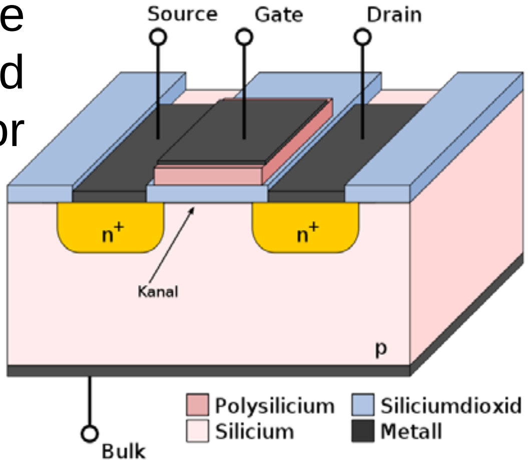
IGBT:
Insulated Gate
Bipolar Transistor



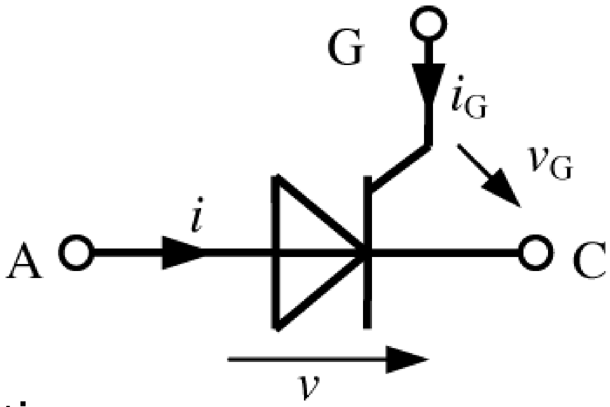


JFET: Junction Gate
Field-Effect Transistor

MOSFET: Metal–Oxide
–Semiconductor Field
-Effect Transistor



Inverters



- Will focus on <u>thyristors</u> as an example of functionality of power electronic switches.
- Symbol shown: three contacts: A (anode), C (cathode) and G (gate).
- If control current $i_G = 0$, the thyristor blocks at negative and positive voltages v. If i_G positive (exceeds voltage v) then thyristor switched into forward mode $\Rightarrow$ current i flows through thyristor
- While the forward current i is above the holding current i_H, the thyristor remains conductive.
- A triac can be operated in both directions and a GTO thyristor can be turned off by a negative control current.

Source: Quashing, "Understanding Renewable Energy Systems", Earthscan 2005

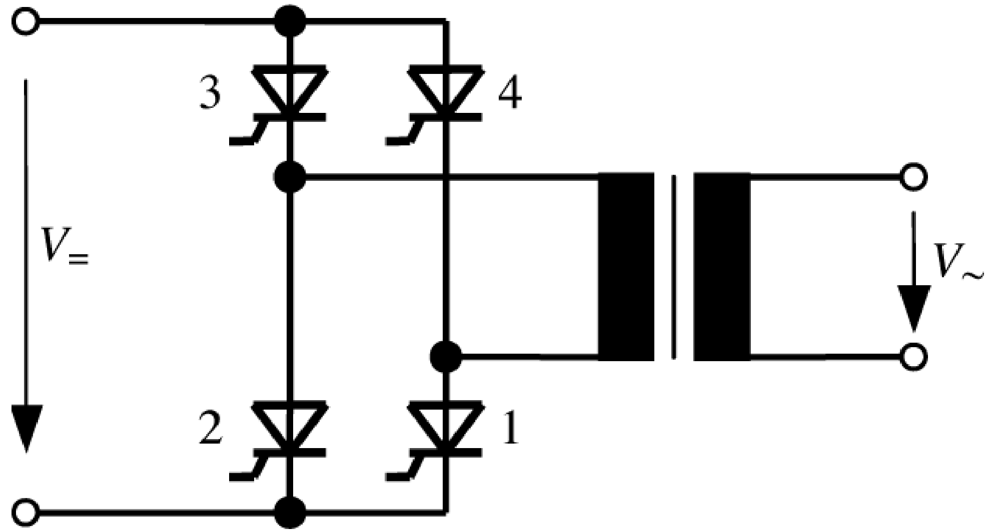
Inverters

- Inverter must periodically direct the current from one branch to another $\Rightarrow$ called commutation $\Rightarrow$ therefore, different thyristors must switch alternately
- If the energy needed to change the state of the thyristor comes from outside (e.g. national grid), the commutation is called external or line commutation. If the circuit can provide this energy itself, it is called self-commutation, but such a circuit needs energy storage.
- Externally commutated inverters are not suitable for stand-alone operation. The grid defines the switching points of externally commutated inverters, whereas a self-commutated inverter must determine them itself.
- Also, the voltage of grid-connected inverters must be synchronized with the grid voltage.

Inverters

- Besides the type of commutation, two most common inverter technologies are:
  - square-wave inverters
  - pulse-width modulated (or sine-wave) inverters.
- Grid-connected inverters have to fulfil stringent criteria to maintain high power quality. Therefore, amplitude, frequency and current shape must follow the rules of the grid operators.
- Also, for grid-protection, the inverter must switch off immediately if the grid fails to prevent “islanding” $\Rightarrow$ where a small arm of the grid remains active due to solar power being exported but the main generators have been disconnected

Inverters

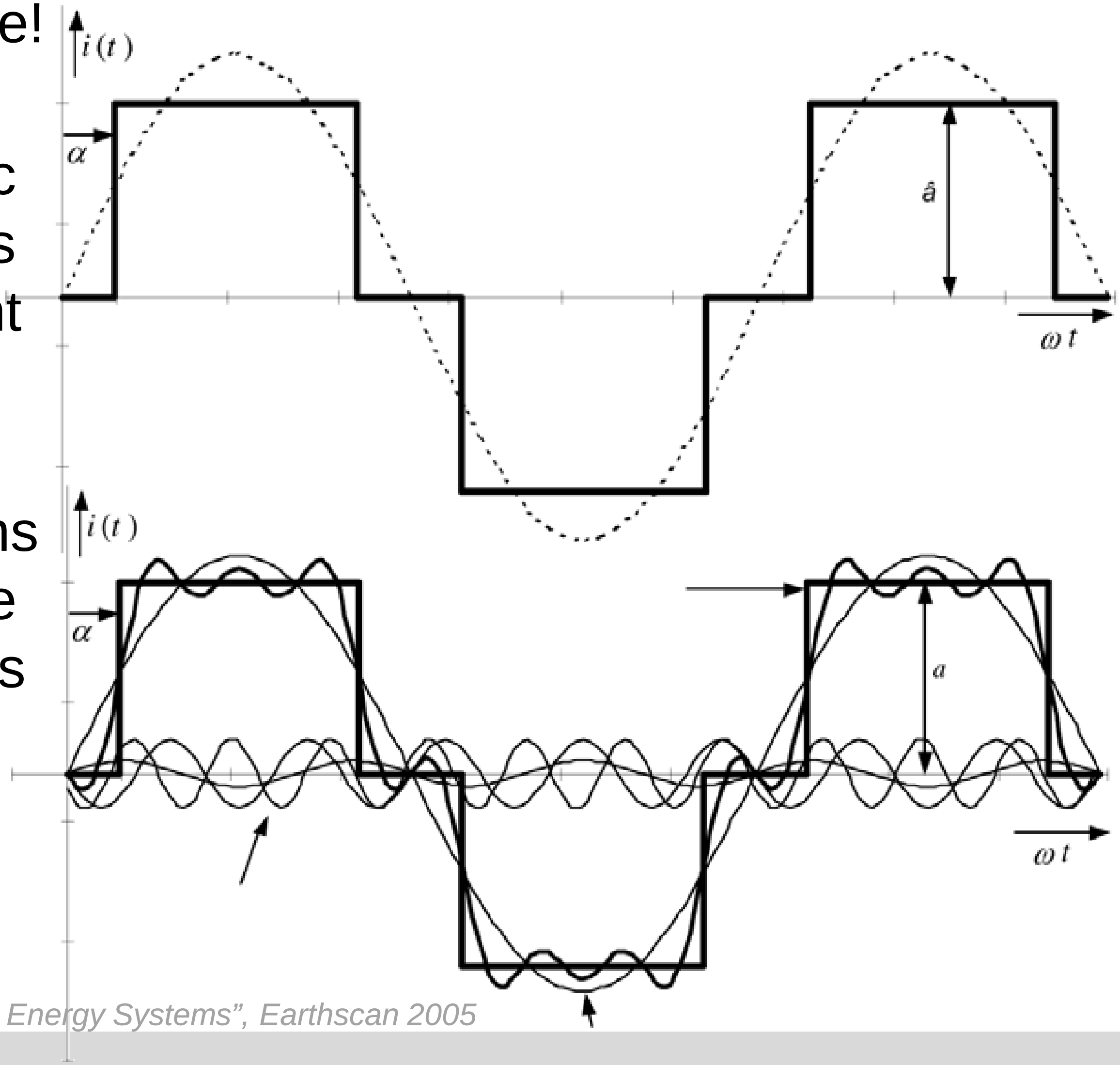


- <u>Square-wave inverter</u>
- Simple circuit of two-pulse bridge connection shown
- Consists of 4 thyristors and a transformer
- Thyristors 1 and 3 work together, as do thyristors 2 and 4. If these two groups switch periodically, they generate a square-wave AC at the transformer
- Thyristors 1 and 2 can be replaced by non-controllable diodes for simplification; in this case, only half of the bridge must be controlled. This connection is then called a half-controlled bridge connection. The switching of the thyristors is delayed by the control angle α compared to the voltage zero crossing. Figure 4.54 shows the current of a B2 connection

Source: Quashing, “Understanding Renewable Energy Systems”, Earthscan 2005

Inverters

- Current output of this circuit ⇒ N.B. shape differs significantly from that of a sinusoidal wave!
- Besides the desired sinusoidal first harmonic (order 1) ⇒ also various oscillations with different periods (order ≥ 2) ⇒ called harmonics
- Most national regulations or grid operators require a minimum of harmonics



Source: *Quashing, "Understanding Renewable Energy Systems", Earthscan 2005*

Inverters

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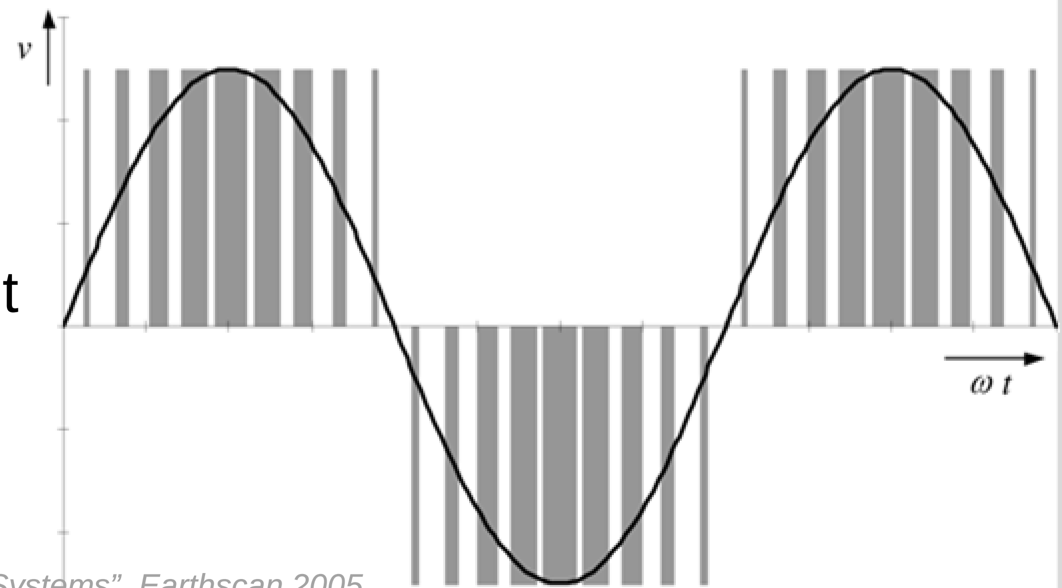
- Pulse-width modulation (PWM)
- An inverter that works on the pulse-width modulation (PWM) principle also uses the bridge circuit described, however, thyristors do not switch just once per half-wave ⇒ instead multiple switching generates pulses of different widths
- Sinusoidal fundamental wave is obtained after filtering
- Quality of sinusoidal oscillation much better than square wave inverters
  ⇒ PWM inverters exhibit much less harmonics content
  ⇒ most common inverter in use today



Source: *Quashing, "Understanding Renewable Energy Systems", Earthscan 2005*

Solar Trackers

- N.B. not be confused with MPPT!
- PV modules typically mounded on fixed arrays. Ideally modules are placed on a support structure, facing within 5° of north in the southern hemisphere or of south in the northern hemisphere
- Tilt angle determined by load requirements, e.g. for most constant output over the year, an angle of latitude plus ~23° is used, which places the array at right angles to the sun's rays in mid-winter
- A minimum tilt angle of 10° is recommended, to allow natural cleaning of the array surface by rain

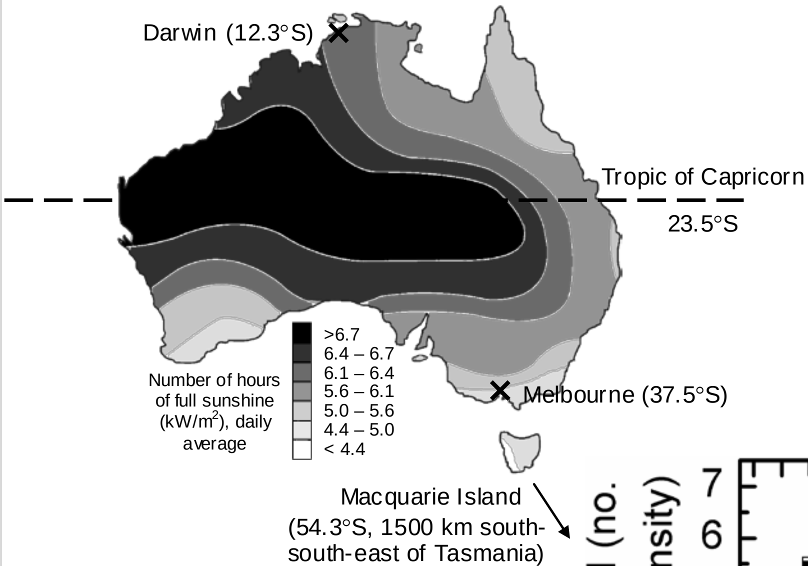
Table 6.1. Approximate optimum array tilt angles for fixed arrays.

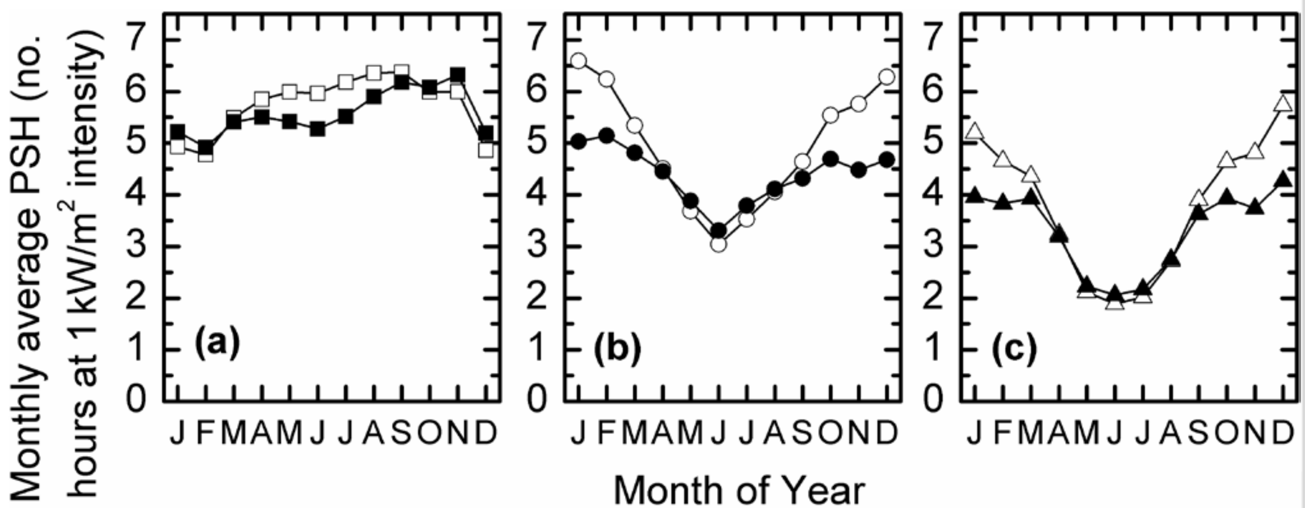
	tilt angle relative to latitude (°)		
latitude (°)	constant seasonal load	winter-peaking load	summer-peaking load
5–25	+5	+5 – +15	–5 – +5
25–45	+5 – +10	+10 – +20	+10

Source: *Wenham et al., "Applied Photovoltaics", 2nd ed, Earthscan 2007*

Solar Trackers

- Varying solar resource as a function of latitude, e.g. Australia
- Why is resource lowest in summer (Dec – Feb) for Darwin?





Monthly average peak sunshine hours (PSH) for three Australian sites at very different latitudes at two different panel tilt angles (θ):

a) Darwin: θ = 12.3° (□) PSH_{yearly} = 5.73 and θ = 0° (■) PSH_{yearly} = 5.58;

b) Melbourne θ = 37.5° (○) PSH_{yearly} = 4.94 and θ = 51.0° (●) PSH_{yearly} = 4.39;

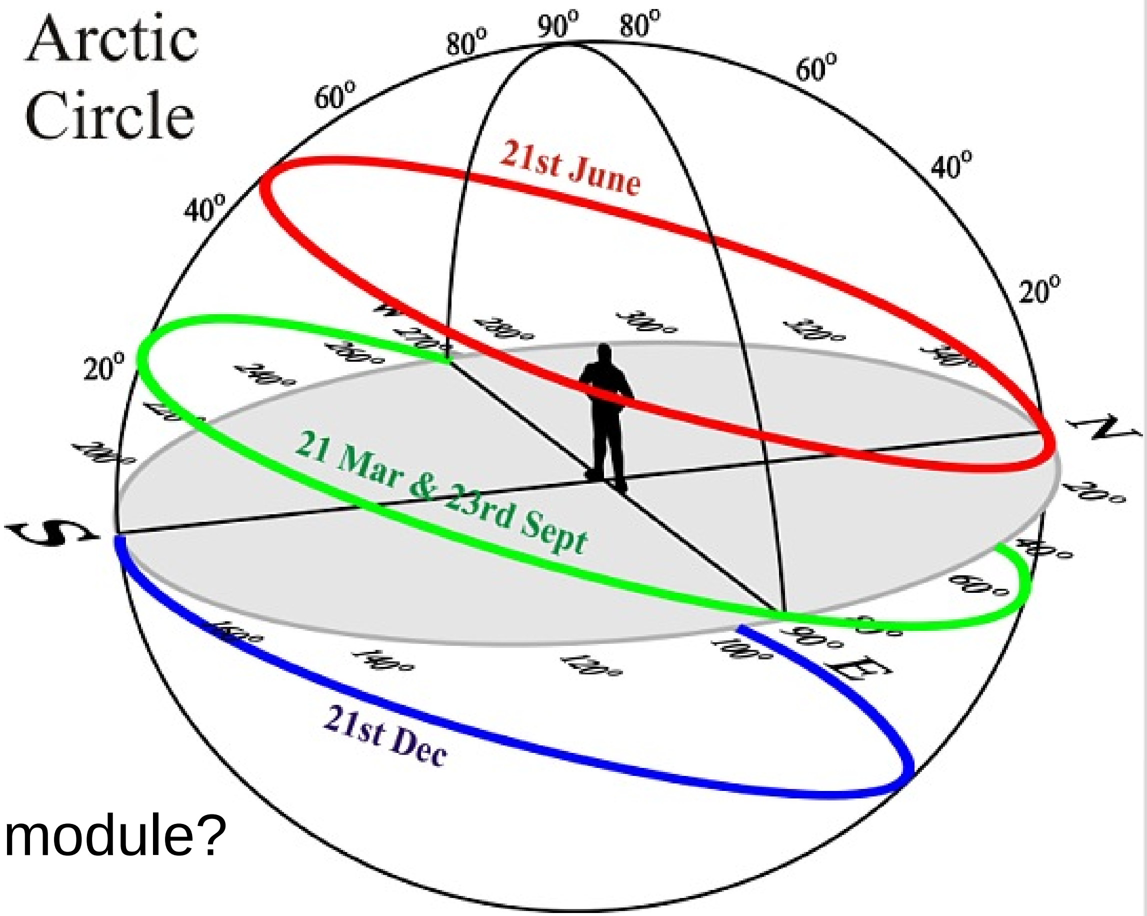
c) Macquarie Island θ = 54.3° (△) PSH_{yearly} = 3.77 and θ = 77.8° (▲) PSH_{yearly} = 3.31.

Source: *Richards and Conibeer , International Journal of Hydrogen Energy 2007: 32(14), 2712--2718*

Solar Trackers

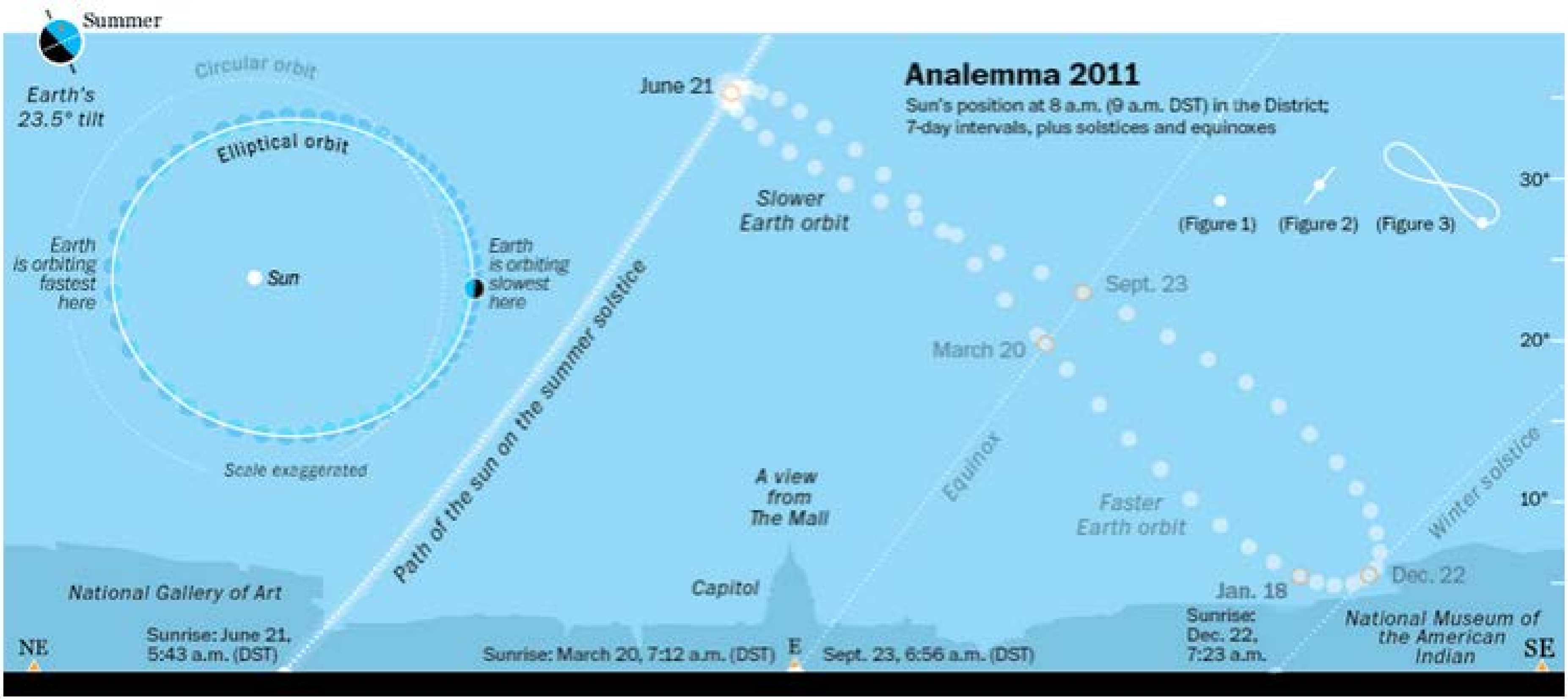
- Back to lecture 2 – thinking about sun's position in the sky at:
  - Noon on summer solstice @ Karlsruhe (49°N)?
  - Sunrise on 21 Mar @ Karlsruhe (49°N)?
  - Noon on summer solstice @ north pole?
  - Midnight on summer solstice @ north pole?

    ↳ what is the best orientation for PV module?



Source: http://www.hsphys.com/dayinb.jpg

Solar Trackers



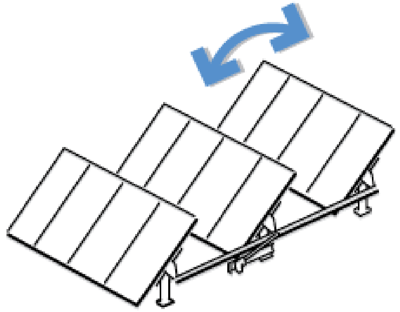
On the summer solstice in Washington, the sun rises at its most northeastern point on the horizon and follows the steepest path in the sky all year.

Source: http://www.washingtonpost.com/blogs/capital-weather-gang/wp/2013/06/20/summer-solstice-2013-northern-hemispheres-longest-day-highest-sun-of-the-year/

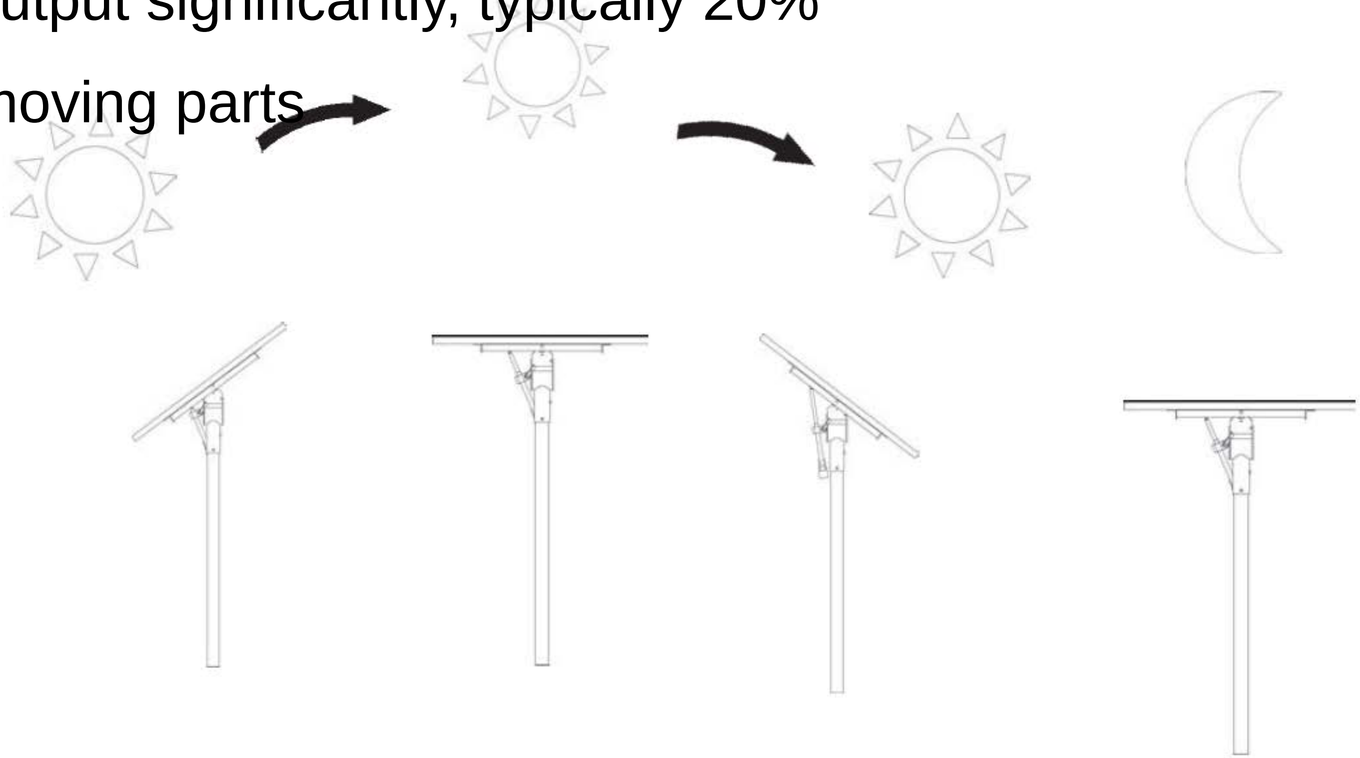
Solar Trackers

- So, what about we adjust the tilt angle of the PV panel?
- With seasonally-adjusted tilting the tilt angle is manually adjusted to allow for the changing solar elevation at noon, e.g. typically seasonally
- Simple way of increasing output that does not add significantly to cost or detract from reliability
- Flexibility in tilt angles for seasonal changes is marginally economical for small systems, e.g. for mid-latitude locations, quarterly adjustment to tilt angle increases annual energy production by less than 5%

Solar Trackers

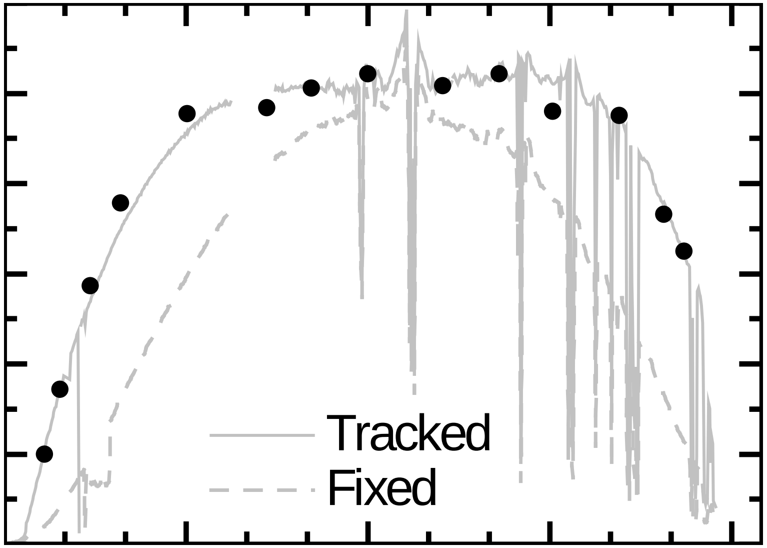


- And what about if we adjust the E-W direction?
- Single-axis tracking tilts the array every 15min – 1 hour along the vertical axis to follow the sun from east to west (GPS controlled)
- This increases output significantly, typically 20%
- N.B. now have moving parts in system
  ⇒ more can go wrong
  ⇒ increased maintenance



Solar Trackers

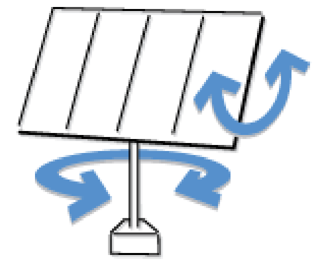
- Single-axis-tracked 300W PV array on solar-powered water treatment system
- Photo taken in Tanzania, data below from outback Australia



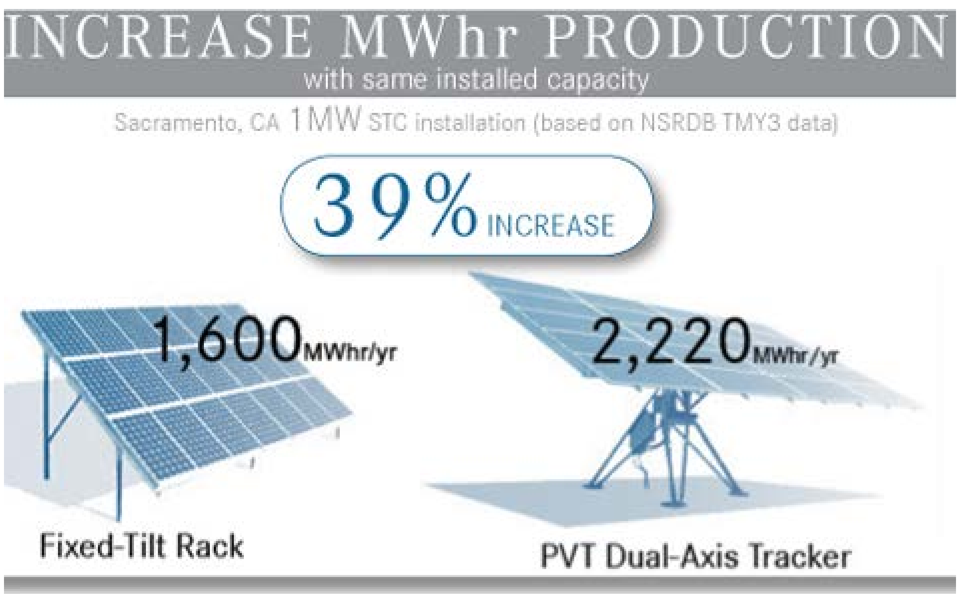
Source: Richards, Capão, Schäfer, Env. Sci. & Tech (2008) 42, 4563–4569

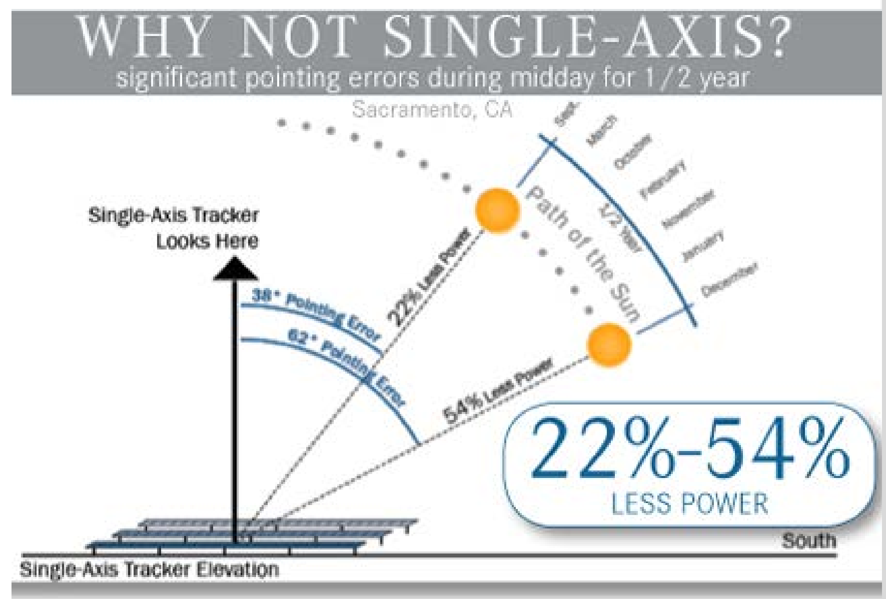
Solar Trackers

- Via <u>two-axis tracking</u> the power output is further increased by tracking the sun along both the north-south and east-west axes



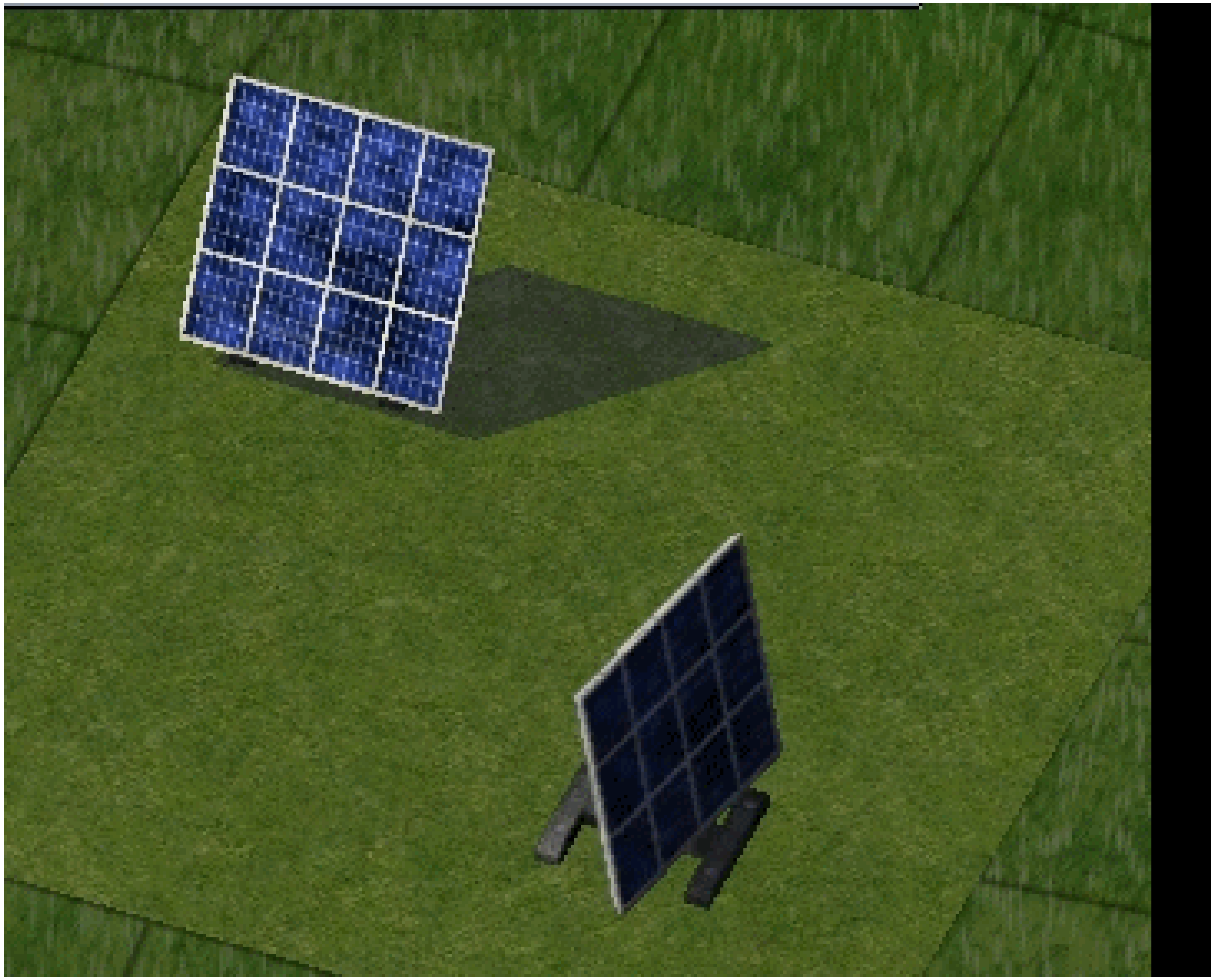
- 30% advantage over a fixed-tilt array have been measured
- Capital and maintenance costs can be high. Also often requires more secure foundations





Source: http://www.pvtrackers.com/DualAxisBenefits.aspx

Solar Trackers



Source: http://imageshack.com/f/21/solarpanel01.gif

Solar Trackers

Source: *http://www.solar-tracking.com/*

Steps to Sizing a PV System

1. **Determine the demands of power consumption (Wh)**

The first step in designing a solar PV system is to find out the total power and energy consumption of all loads that need to be supplied by the solar PV system as follows:

1.1 Calculate total Watt-hours (Wh) per day for each appliance used

Add the Watt-hours needed for all appliances together to get the total Watt-hours per day which must be delivered to the appliances

Also consider time-of-day when used as impacts inverter choice

1.2 Calculate total Watt-hours (Wh) per day needed from the PV modules

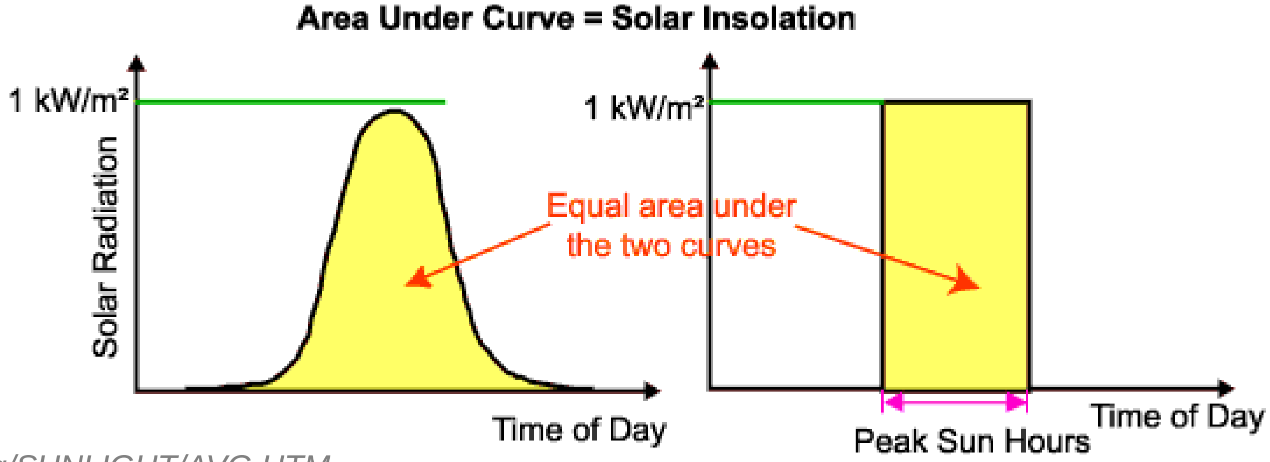
Multiply the total appliances Watt-hours (Wh) per day x 1.3 (the energy lost in the system) to get the total Watt-hours per day which must be provided by the panels

Steps to Sizing a PV System

2. Sizing the PV modules (Wp)

Different size of PV modules will produce different amount of power. To find out the sizing of PV module, the total watt peak (Wp) produced needs. The peak watt (Wp) produced depends on size of the PV module and system location. We have to consider the average “peak sun hours” (PSH), which is different in each site location. For central Europe the PSH is around 3, and corresponds to about 3 hours of sunlight, per day, expected average over the whole year (including in the winter time).

PSH ≡ equivalent no. of hours per day with solar irradiance of 1000 W/m^2



Source: http://pvcdrom.pveducation.org/SUNLIGHT/AVG.HTM

Steps to Sizing a PV System

To determine the sizing of PV modules, calculate as follows:

2.1 Calculate the total Watt-peak rating needed for PV modules

Divide the total Watt-hours per day needed from the PV modules (from item 1.2) by the PSH to get the total Watt-peak rating needed for the PV panels needed to operate the appliances.

N.B: if the PV system is planned to operate only in spring-summer-autumn the average PSH values will be around 4-5 and for systems working only in summer, around 6-7 hours sun per day

2.2 Calculate the number of PV panels for the system

Divide the answer obtained in item 2.1 by the rated output Watt-peak of the PV modules available to you. Increase any fractional part of result to the next highest full number and that will be the number of PV modules required.

Steps to Sizing a PV System

Result of the calculation is the minimum number of PV panels. If more PV modules are installed, the system will perform better and battery life will be improved. If fewer PV modules are used, the system may not work at all during cloudy periods and battery life will be shortened.

3. Sizing pure sine wave PV inverter

An inverter is used in the system where 230V/50Hz AC power output is needed. The input rating of the inverter should never be lower than the total power consumption of appliances.

The inverter must have the same nominal voltage as your battery (12/24/48V). For stand-alone systems, the inverter must be large enough to handle the total amount of watts you will be using at one time. The inverter size should be 25-30% bigger than total watts (W) of appliances.

Steps to Sizing a PV System

In case of appliance type is motor or compressor (these have large startup currents) then inverter size should be minimum 3 times the capacity of those appliances and must be added to the inverter capacity to handle surge current during starting (first 3-6 seconds)

4. Sizing the battery (Ah)

The battery type recommended for using in solar PV system is deep-cycle lead acid battery - designed for to be discharged to low energy level and rapid recharged or cycle charged and discharged day after day for years. The battery should be large enough to store sufficient energy to operate the appliances at night, cloudy days and if needed in winter. To find out the size of battery, calculate as follows:

Steps to Sizing a PV System

4.1 Calculate total Watt-hours per day used by appliances.

4.2 Divide the total Watt-hours per day used by 0.85 for battery loss.

4.3 Divide the answer obtained in item 4.2 by 0.5 for DoD

4.4 Divide the answer obtained in item 4.3 by the nominal battery voltage.

4.5 Multiply the answer obtained in item 4.4 with days of autonomy (the number of days that you need the system to operate when there is no power produced by PV panels, e.g. 5 days if there is no backup generator) to get the required Ampere-hour capacity of deep-cycle battery.

$$\text{Battery Capacity (Ah)} = \frac{\text{Total Watt-hours per day used by appliances x Days of autonomy}}{\text{(0.85 x 0.5 x nominal battery voltage)}}$$

Steps to Sizing a PV System

5. Sizing the charge controller (A)

Charge controller is typically rated against Amperage (A) and Voltage (V) capacities. Select the solar charge controller to match the voltage of PV system and batteries and then identify which type of solar charge controller is right for your application. Make sure that solar charge controller has enough capacity to handle the current from PV system.

For the PWM charge controller type, the sizing of controller depends on the total PV input current which is delivered to the controller and also depends on PV panel configuration (series or parallel configuration).

According to standard practice, the sizing of solar charge controller is to take the short circuit current (I_{sc}) of the PV module, and multiply it by x 1.3

Steps to Sizing a PV System

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PSH data	Horizontal		Latititude (deg S)	At latitude angle		Worst month		Worst month tilt	
Darwin	5.58	hours/day	12.3	5.73	hours/day	4.92	hours/day	4.78	hours/day
Melbourne	4.12	hours/day	37.5	4.94	hours/day	1.61	hours/day	3.31	hours/day
Macq Is	2.51	hours/day	54.3	3.77	hours/day	0.44	hours/day	2.06	hours/day

Load 10696 Wh/d

Assume all AC load, so take into account inverter efficiency (90%)

=> 11884 Wh/d

3904 kWh/yr (taken from Markcart and Castaner)

For >3kWh recommended to use 48 volt system

System V: 48 V DC

Ah rating of system 247.6 Ah/d

Battery capacity = (demand * days of autonomy) / (max DOD)

									Recommended days of autonomy	
Demand:	247.6	Ah/d	Demand:	247.6	Ah/d	Demand:	247.6	Ah/d	Latitude	Days
Autonomy:	5	d	Autonomy:	10	d	Autonomy:	15	d	0-30deg	5 to 6
Max DOD	0.7		Max DOD	0.7		Max DOD	0.7		30-50deg	10 to 12
Battery capacity	1769	Ah	Battery capacity	3537	Ah	Battery capa	5306	Ah	50-60deg	15
	0.14			0.07			0.05			

Correct for battery operating temperature

e.g. if lowest 24hr average temperature is 10degC then correct by 0.96

Average daily DOD = (daily load) / (battery capcity) = 0.14

Rule: average daily DOD should be less than 14% with the maximum allowable in any one day of 20%.

PV array size

Battery efficiency 85%

PV array output 291.3 Ah/d

NOCT operating point of BP4170 (50degC, 28V) 5.39 A

Module Size (m^3) 1.203 — 5.12 A allowing for -5% power tolerance

Average daily module output:	Darwin	29.34	Ah
	Melbourne	25.30	Ah
	Macq Is	19.30	Ah

Number of modules in series = 2

Numer of series connected strings:	Darwin	9.93	=>	10	in series =>	20	x 170W +	1769	Ah battery	, Area	24.1	m2
(in plane array)	Melbourne	11.52	=>	12	in series =>	24	x 170W +	3537	Ah battery	, Area	28.9	m2
	Macq Is	15.09	=>	16	in series =>	32	x 170W +	5306	Ah battery	, Area	38.5	m2

Examples of PV Systems

- 5.3kW grid connected PV system (Boston, USA)

Source: *http://en.wikipedia.org/wiki/Photovoltaic_system*

Examples of PV Systems

- Building integrated photovoltaic (BIPV) balcony (Helsinki, Finland)

Source: http://en.wikipedia.org/wiki/Photovoltaic_system

Examples of PV Systems

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- Community owned solar farm (Westmill, England)

Source: http://en.wikipedia.org/wiki/Photovoltaic_system

Examples of PV Systems

- Photovoltaic power station at Mt. Komekura (Japan)

Source: http://en.wikipedia.org/wiki/Photovoltaic_system

Examples of PV Systems

- Solar array at National Solar Energy Center (Negev Desert, Israel)

Source: http://en.wikipedia.org/wiki/Photovoltaic_system

Examples of PV Systems

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- 23-year old, ground mounted PV system on a North Frisian Island (Germany)

Source: http://en.wikipedia.org/wiki/Photovoltaic_system

Examples of PV Systems

- An isolated mountain hut in Catalonia (Spain)

Source: *http://en.wikipedia.org/wiki/Photovoltaic_system*

Examples of PV Systems

- The Japanese winner of 2009 World Solar Challenge (Australia)

Source: http://en.wikipedia.org/wiki/Photovoltaic_system

Examples of PV Systems

- Photovoltaic powered water pumping system for stock watering (India)

Source: http://regentsolar.com/swp.html

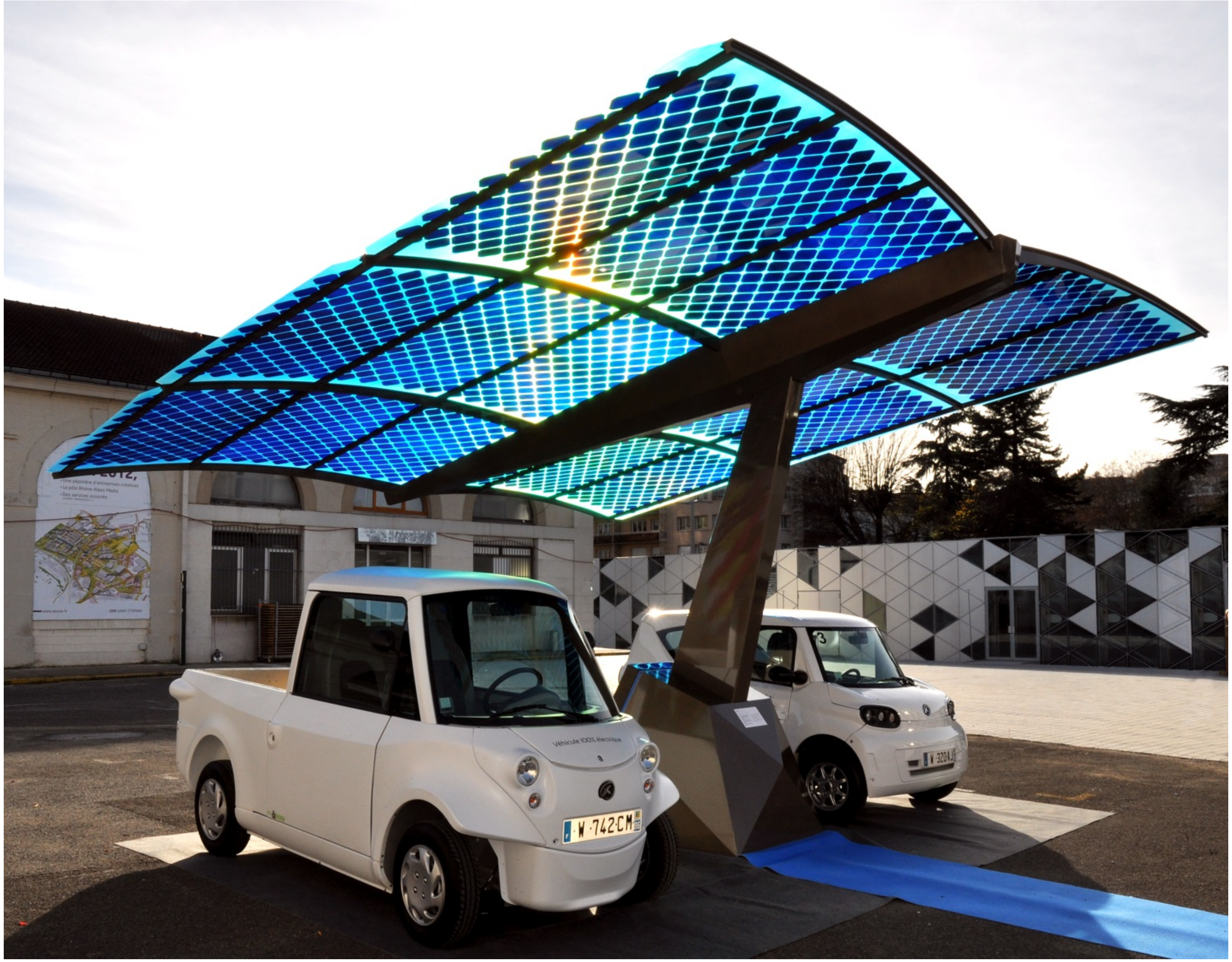
Examples of PV Systems

- Small hybrid wind-PV system on a yacht

Source: *http://www.micamalecharter.com/barca_en.html*

Examples of PV Systems

- An electric vehicles charging station (France)



Source: *http://en.wikipedia.org/wiki/Photovoltaic_system*

Examples of PV Systems

- A solar-powered community satellite phone in Western Australia

Source: blog.activ8me.net.au

Examples of PV Systems

- PV-power for Philae comet lander… well, sometimes…. with Rosetta in background (artist's impression)

Source: http://www.natureworldnews.com/articles/6466/20140328/rosetta-missions-comet-lander-wakes-up-from-deep-space-sleep.htm

Examples of PV Systems

- A navigation marker in Otago Harbour (New Zealand)

Source: http://en.wikipedia.org/wiki/Photovoltaic_system

Examples of PV Systems

- Solar powered electric fence in Northumberland (U.K.)

Source: http://en.wikipedia.org/wiki/Photovoltaic_system

Examples of PV Systems

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- Solar sailor ferry in Darling Harbour (Sydney, Australia)

Source: *http://en.wikipedia.org/wiki/Photovoltaic_system*

Examples of PV Systems

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- Solar power for a yurt (Mongolia)

Source: *http://en.wikipedia.org/wiki/Photovoltaic_system*

Examples of PV Systems

- 46MW tracked solar farm in Amareleja (Portugal)

ACCIONA nimmt größtes Photovoltaik-Kraftwerk der Welt in Portugal in Betrieb

Solarpark Amareleja (46 MWp).

Das Unternehmen ACCIONA Energy hat ein Solar-Kraftwerk mit einer Photovoltaik-Spitzenleistung von 46 Megawatt (MW) in Amareleja (Moura, Portugal) in Betrieb genommen. ACCIONA habe in die Solarstromanlage - die größte ihrer Art weltweit - rund 261 Millionen Euro investiert, berichtet das Unternehmen in einer Pressemitteilung. Nach Angaben von ACCIONA kann der Solarpark jährlich rund 93 Millionen Kilowattstunden Solarstrom produzieren, was rechnerisch den Elektrizit

Haushalten d

89.383 Tonne

Kohle freiges

erzeugen. Der Solarpark sei in der Re

ACCIONA.

262.080 Solarmodule auf 250 Hektar

Der Solarpark erstreckt sich auf einer Ges
Region Alentejo, nahe der spanischen Gr
Typ "Buskil" montiert, die ACCIONA selb
Quadratmetern. Die Buskil-Tracker sind 1
polykristalline Silizium-Module (170 bzw.
Sonne einachsig nachgeführt werden.

Source: http://www.solarserver.de/solarmagazin/new

Examples of PV Systems

- 35MW 2-axis tracked solar farm in Alamosa (Colorado, USA)

Source: http://en.wikipedia.org/wiki/Photovoltaic_system

Examples of PV Systems

- Solar-powered unmanned aerial vehicle (NASA/AeroVironment)

Source: http://en.wikipedia.org/wiki/Electric_aircraft

Examples of PV Systems

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- The future of flight? Solar-powered plane – planned circumnavigation of Earth in 2015 (Solar Impulse)…

Source: *http://www.powerclouds.com/index.php/photovoltaics-that-make-you-fly-the-solar-impulse-venture/*

Examples of PV Systems

- … 2 passengers and wingspan similar to that of an Airbus A340!

Source: http://www.aerospace-technology.com/projects/solar-impluse/solar-impluse2.html

Competing with coal and nuclear?

- Topaz Solar Farm is a 550MW PV power station in California (USA)
- Construction began Nov 2011, ended in Nov 2014
- Currently world's largest solar farm
- U$2.5 billion project
- 25 km^2 area
- 9 million CdTe PV modules from First Solar
- 400 construction jobs created
- Annual generation is expected to be 1,096 GWh
- A utility (Pacific Gas and Electric) have 25 year contract to buy the electricity

Location of Topaz Solar Farm

Country	United States
Location	Carrizo Plain, San Luis Obispo County, California
Coordinates	35°23′N 120°4′W
Status	Operational
Construction began	2011
Commission date	2014
Owner(s)	MidAmerican Renewables
Solar farm	
Type	Flat-panel PV
Site area	9.5 sq mi (25 km^2)
Power generation	
Nameplate capacity	550 MW_p
Annual generation	1,096 GWh (125 MW avg)
Website	topazsolar.com

Source: *http://en.wikipedia.org/wiki/Topaz_Solar_Farm*

Competing with coal and nuclear?

Source: *http://papichco.com/construction/project/topaz-solar-farm/*

PV Systems >50MW Worldwide

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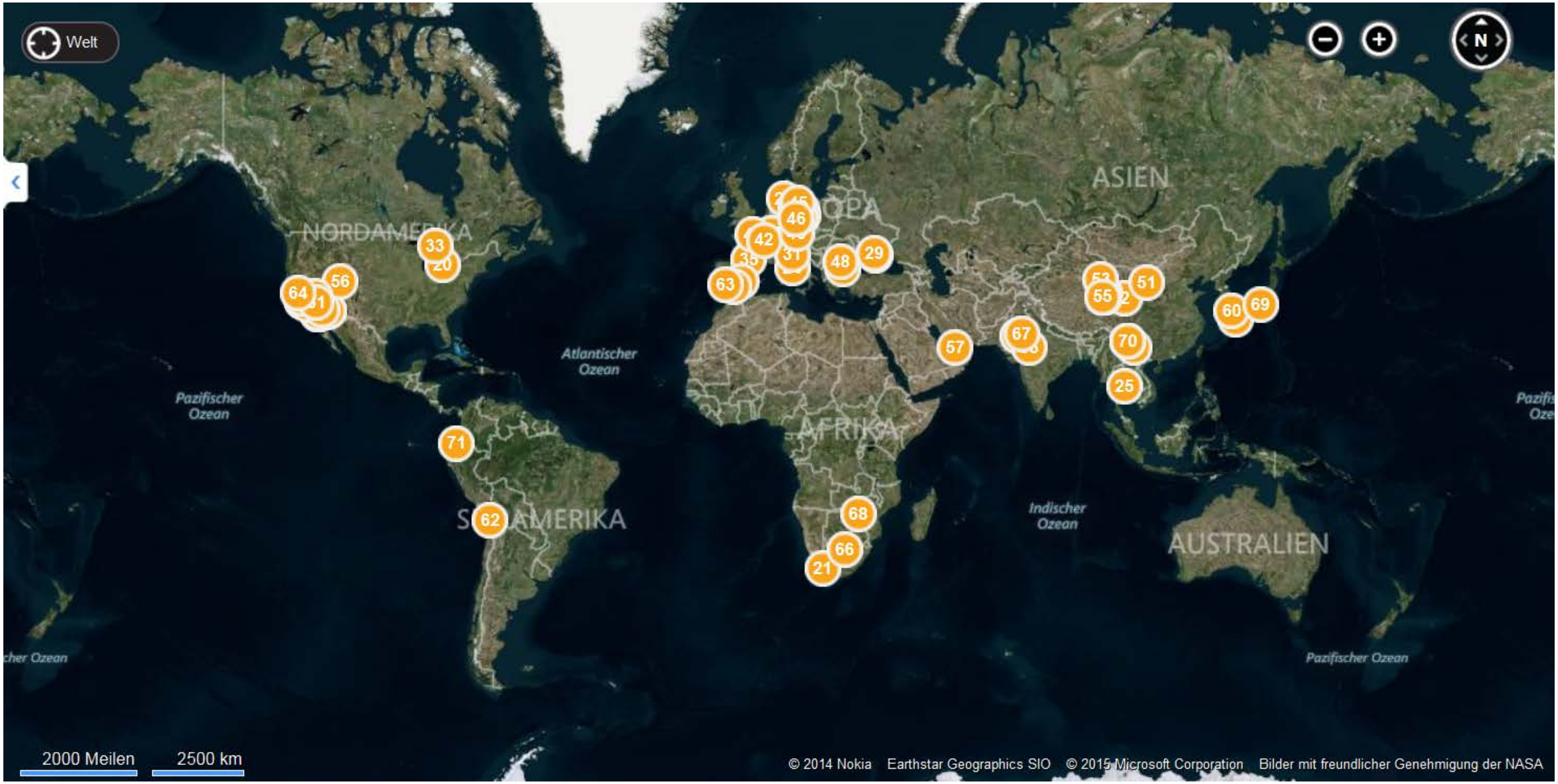

Source: http://www.bing.com/maps/?mapurl=http%3A%2F%2Ftools.wmflabs.org%2Fkmlexport%2F%3Farticle%3DList_of_photovoltaic_power_stations%26usecache%3D1