PV Excel – Designer & Installer

2 Day solar PV Excel Course for Designers and Installers of PV systems

Created by Carel Ballack – www.pqrs.co.za

The Copper Development Association Africa
Promoting the use of copper in Africa

Content Disclaimer & Feedback

- Electricity is dangerous.
- The purpose of this training course is to promote the use of solar, for both electrical & plumbing solar technologies.
- The instructors cannot be held liable for information presented; or the way in which information has been interpreted through this; or any other training, marketing or media platform. Please read product instructions and comply to manufacturer recommendations
- Your feedback is important
- Please complete the feedback form.
- We trust that you will enjoy the course

Additional information & courses

- See the 2nd page of the notes.

1. Leonardo Energy offers free online training for electricians and engineers on energy efficiency, transformers, motors, harmonics and electrical networks (advanced)
http://www.leonardo-energy.org

2. For a free tool to assess and determine available solar irradiation at a specific venue, visit the following link;
http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?map=africa

3. For a free tool to calculate solar systems viability
http://www.retscreen.net

4. For free training on energy efficiency: Moderate to Easy…..to difficult.
Google - "schneider energy university"
http://www2.schneider-electric.com/sites/corporate/en/products-services/training/energy-university/energy-university.page

5. String sizing tools - see solarweb.com (Fronius configurator) or www.stringsizer.abb.com

6. For a free tool to calculate solar systems yield via mobile
http://scanthesun.com/scanthesun.php

7. Free Book - Unlimited Energy
http://www.victronenergy.com/upload/documents/Book-Energy-Unlimited-EN.pdf

Largest systems in SA

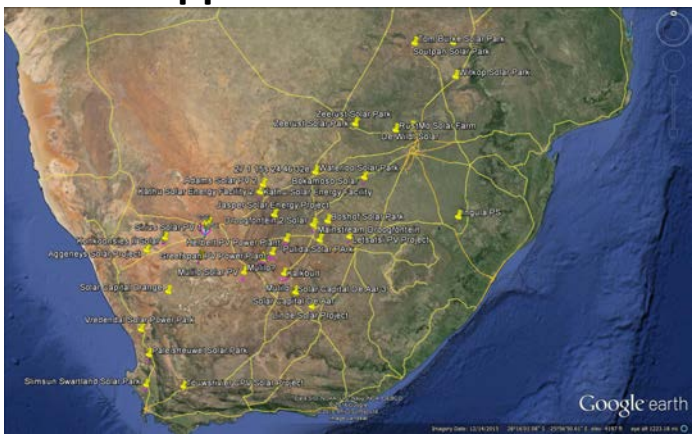
SA's Largest Utility PV Plant
Jasper 95MW (Kimberley)

SA's Largest Rooftop
Mall of Africa 5MW

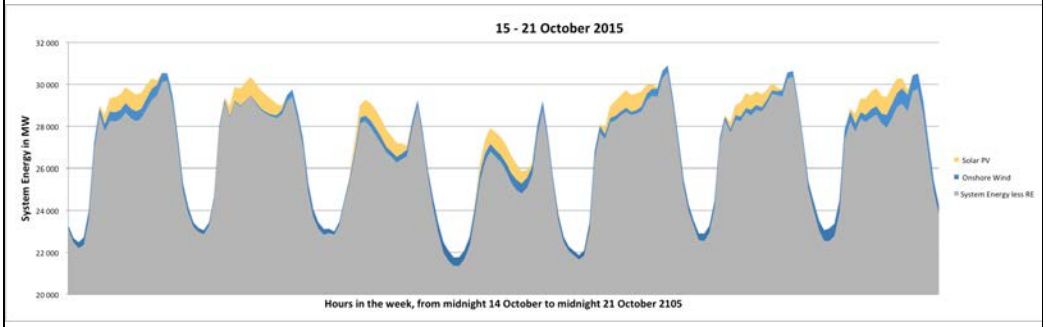
PQRS Intro - REIPPPP PV - 2016

2,2 GW REIPPP + approx. 200MW installed

- Well documented
- level of installation - Good
- Engineered design
- Monitored performance & ongoing maintenance



PQRS Intro - Symphony of power

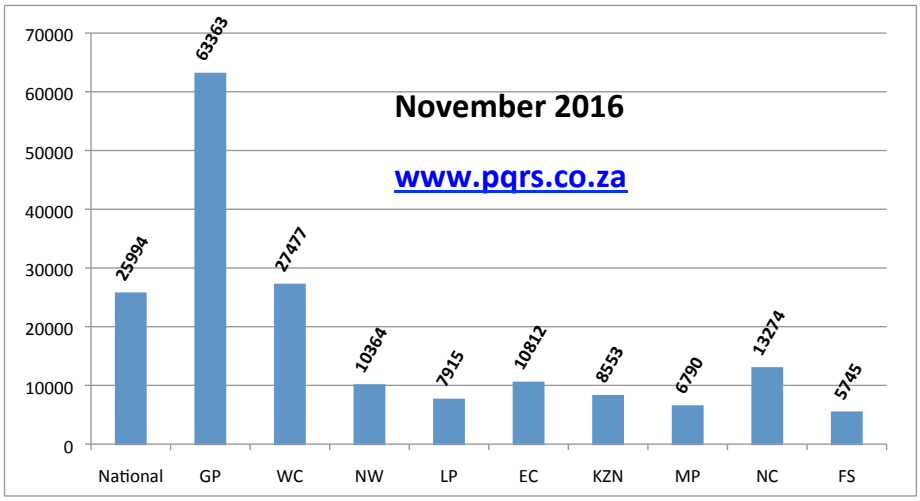


PQRS Intro

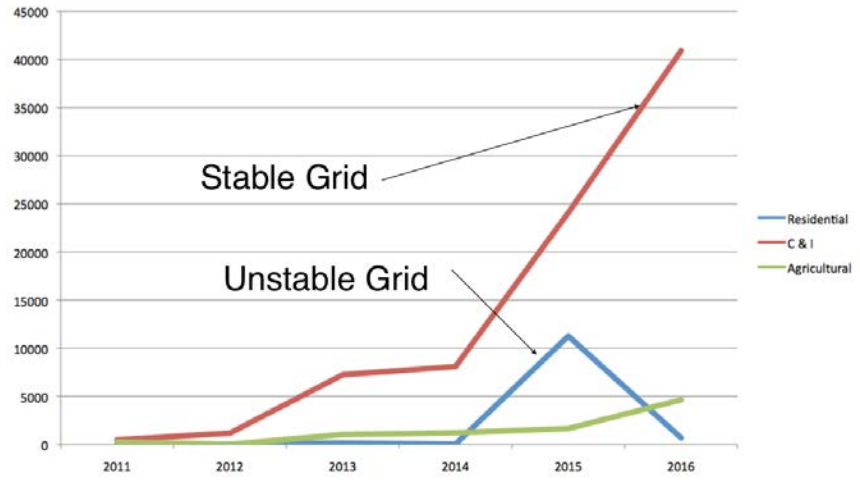
- Data collection since Nov. 2014
- PQRS to forward data to D.o.E. REDIS
- Be part of a national initiative.
- Western Cape Government 135MW program

- Data expanded into Africa

PQRS - Data according to Province



PQRS – Grid conditions



Source: www.pqrs.co.za

PQRS - Top 20 Nov 2016

Nr.	Co. Name	Largest of the three	Designer	Installer	Installer 2	Project Manager
1	Unknown	58574	58573,8	58573,8	1264,6	58324,0
2	Solareff (PTY) Ltd	16650	16649,9	15409,9	400,0	16239,9
3	Sunworx (Pty) Ltd	8494	8494,0	6519,0	0,0	8359,0
4	Sustainable Power Solutions	8286	8286,0	8286,0	0,0	8286,0
5	Rhino Energy	7957	7956,8	7956,8	0,0	7956,8
6	Romano	7318	7318,0	3078,0	0,0	7318,0
7	Sola Future Energy	5663	5663,0	3515,0	0,0	3644,0
8	Energy Partners Solar	4722	4721,6	4721,6	0,0	4721,6
9	BrightBlack Energy	4426	4426,0	4326,0	0,0	0,0
10	Dorman Projects	4240	0,0	4240,0	0,0	0,0
11	New Southern Energy	3111	2975,8	3110,8	0,0	3110,8
12	Emergent Energy (PTY) LTD	2798	2798,0	2798,0	0,0	2798,0
13	Juwi Renewable Energy	2758	2758,0	2758,0	0,0	2758,0
14	SPP Projects	2500	2500,0	2500,0	0,0	2500,0
15	Terra Firma Solutions	2361	2361,2	2361,2	0,0	2361,2
16	Valsa Trading	2335	0,0	0,0	2334,7	0,0
17	Solsquare	2334	2333,7	2331,0	0,0	2331,0
18	African sun energy	2193	2193,0	1195,0	0,0	1195,0
19	African Technical Innovations	2144	2144,0	0,0	0,0	2144,0
20	Besamandla WC	2128	0,0	2128,0	0,0	0,0

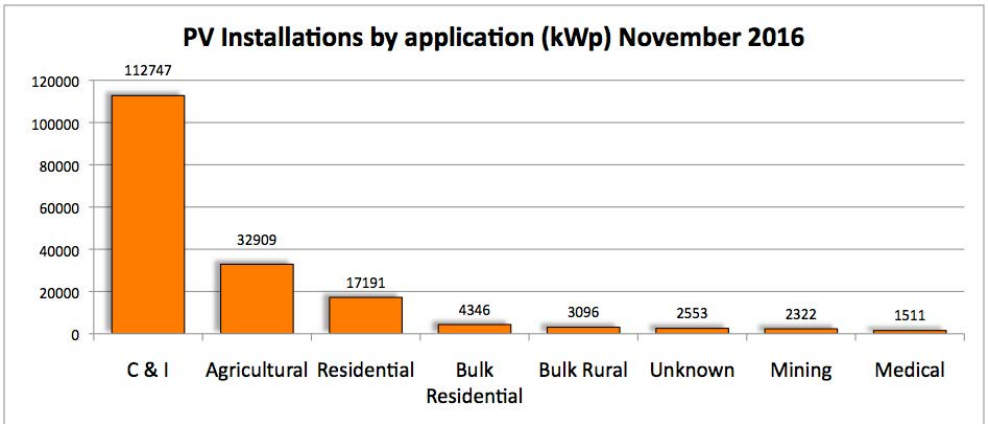
Source: www.pqrs.co.za

PQRS - Inverters in SA

84 Locally Available Inverter Brands - November 2016							
1	ABB	22	Embassy Off-Grid	43	KLNE(Beijing Kinglong New Energy)	64	Selectronic
2	AE Renewables	23	Enersolis	44	Kyoto	65	SF Sonic
3	AEG	24	Enphase	45	Luminous	66	Siemens
4	AEI Power GmbH	25	Exeron	46	Magnum	67	SMA
5	Anhui (EHE New Energy)	26	Extender	47	Meanwell	68	Socomec
6	APS	27	Firefly	48	Mecer	69	Solaredge
7	Axpert	28	Friem	49	Microcare	70	Solarfox
8	Bosch	29	Fronius	50	MLT (Karoo-PowerStar-Oasis)	71	Solar Frontier
9	Bright Black Inverter	30	Goodwe	51	MrPower Off-Grid	72	Solax
10	CB Solar (Axpert)	31	GridMax	52	New Earth Energy (Akspert)	73	Soltra
11	Chint	32	Growatt	53	NEXA Off-Grid	74	Steca
12	Consol	33	Hawkins Off-Grid	54	Omnik New Energy	75	Studer Off-Grid
13	Cotek Off-grid	34	Icon	55	Omnipower Off-Grid	76	Sunniva
14	Danfoss	35	IEnergy Micro inv.	56	Omron	77	Sunsys by Socomec
15	Darfon - Micro inv.	36	Imeon	57	Outback	78	Tenesol Energrid
16	Delta	37	Infini	58	Platinum	79	TES Off-Grid
17	Devel Off-Grid	38	Ingeteam	59	ProLink	80	Tescom SS(Axpert)
18	Diehl AKO	39	INVT	60	RefuSol	81	Tigo - Optimizer
19	Eco-Hybrid	40	JFY	61	Renesola	82	Victron
20	Ecco Off-Grid	41	Jiangu	62	Samil Power	83	X-Hybrid
21	Efacec Central inv	42	KACO	63	Schneider	84	ZeverSolar

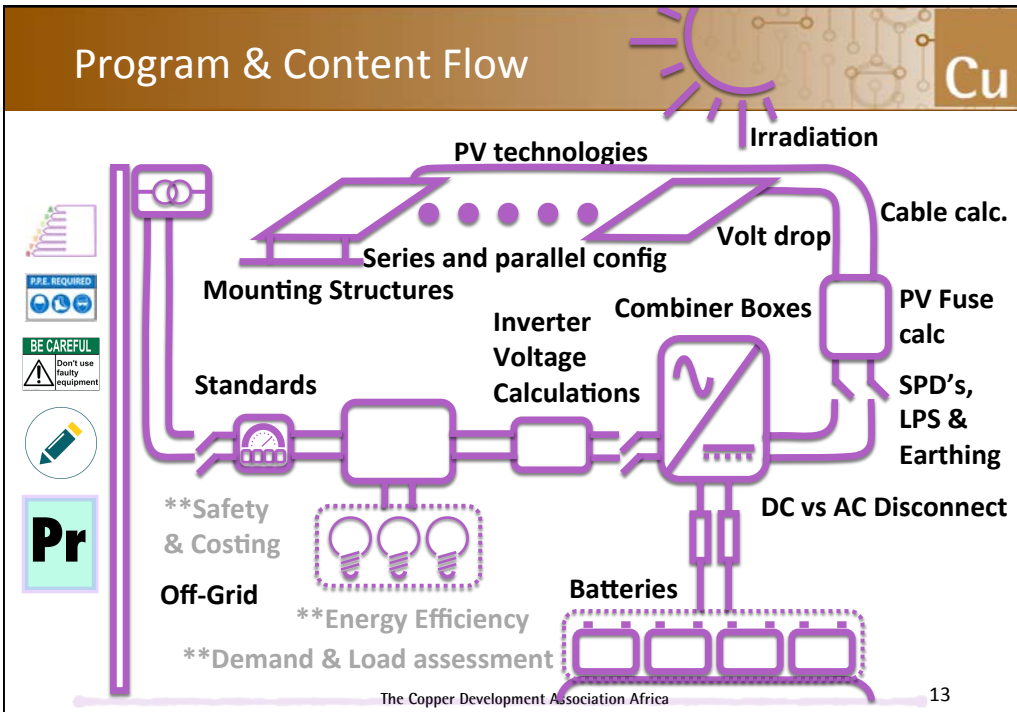
Source: www.pqrs.co.za

PQRS – Data according to application



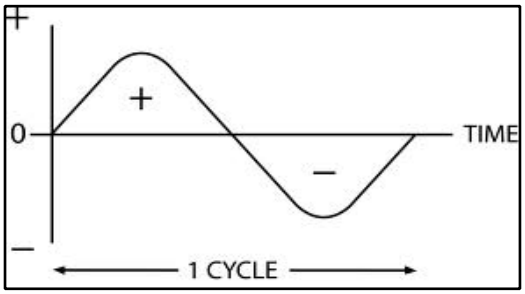
Source: www.pqrs.co.za

Program & Content Flow



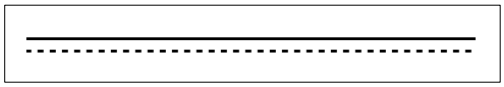
AC & DC

- AC IS NOT COMPATIBLE WITH DC
- The frequency of AC in SA is around 50Hz
- The fundamental, is defined as the lowest frequency of a periodic waveform



AC & DC

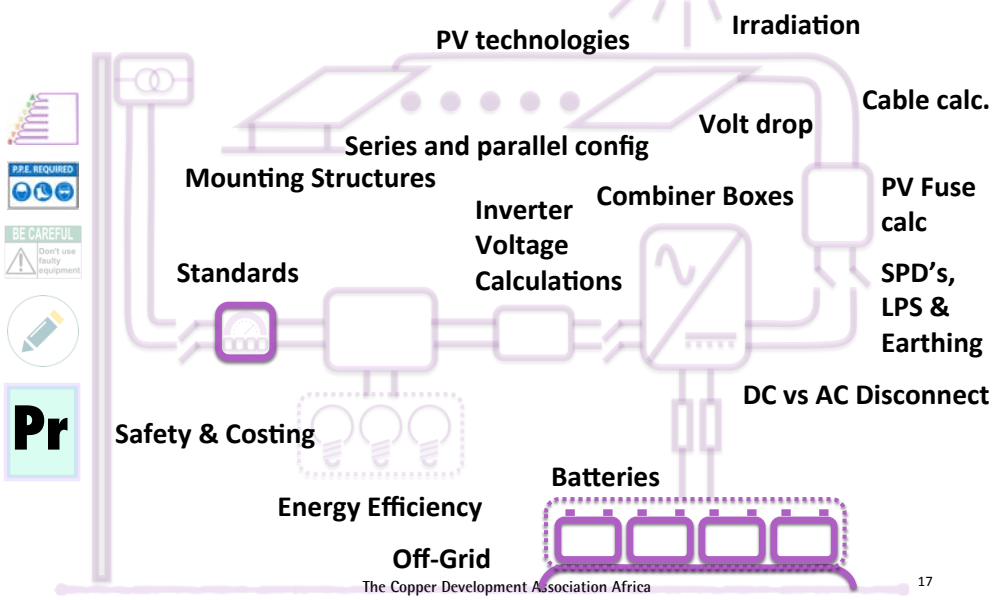
- Convert
  - AC to DC - Rectifier
  - DC to AC - Inverter
- Both inverters and rectifiers are sources of Harmonics



AC & DC

- Multiple sources of AC need to be synchronised (2 generators on the same network, same voltage + same frequency)
- With DC no synchronisation is required.
- With DC; charging and discharging takes place from the same Bus-bar / manifold or battery terminals
- With both AC & DC Voltages need to be the same

Batteries



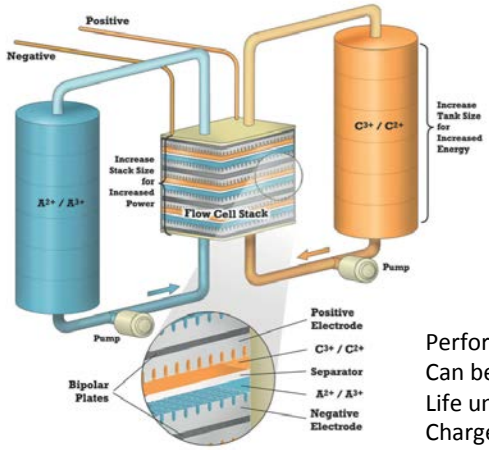
Cost of energy equation - Life cycle cost

$$\text{Cost of Energy} = \frac{\text{Battery Price}}{(\text{Energy}_{(Ah*V)} \times \text{DoD} \times \#\text{Cycles} \times \text{Round trip efficiency})}$$

$$\text{Cost of Energy (SMF)} = \frac{\text{R1200}}{(1{,}2\text{kWh} \times 50\% \times 120 \times 90\%)}$$

Cost of Energy (SMF) = R18,52/kWh

Redox Vanadium Flow



Performance not affected by temperature
Can be drained 100% over full service life
Life unlimited or 10 years
Charge Voltage 54VDC
System weight 1800kg - 3000kg
5 year standard warranty
WxDxH 2.20 x 1.22 x 2.15 m 2,7m^2

http://www.cesa.org/webinars/showevent/flow-battery-basics-part-1-what-they-are-how-they-work-where-they-re-used?d=2014-06-19

Li-Fe Suppliers for Solar sector

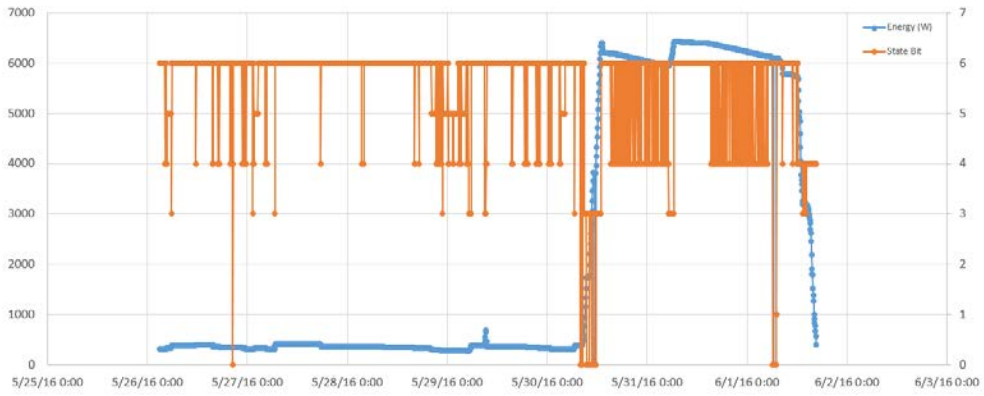
- Local landscape (Brands Available)
  - Akasol Neocube
  - Blue Nova
  - Freedomwon
  - LG Chem
  - BattCo.
  - Icon
  - Tesla
  - BMZ
  - Zettajoule
  - MyPower24
  - Extra2000 (SolaX)

Li-Fe Battery technology

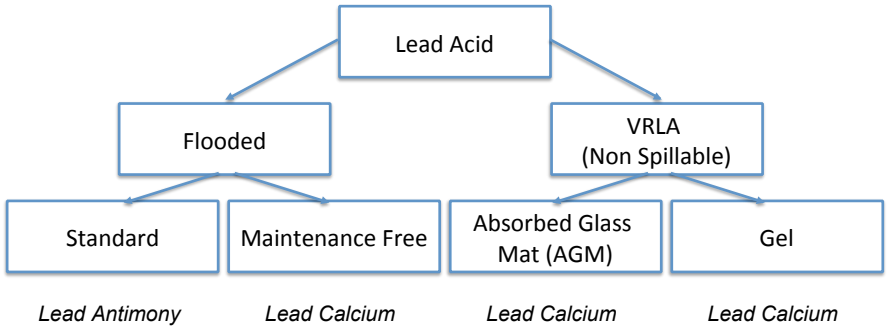
- Lithium Iron Phosphate
- No significant heating during charging and discharging process.
- Larger battery architecture.

- Tesla - Lithium Iron (Nickel Manganese Cobalt (NMC)Cathode)
- Water cooled system
- approx. 880 small batteries to create 48V packs stepped up to 400V(DC-DC Converter)
- 6,4kWh per day at a max of 3,3kW peak.(18MWh)
- Full closed loop recycling by 2020

Online Battery Monitoring



Lead Acid Family



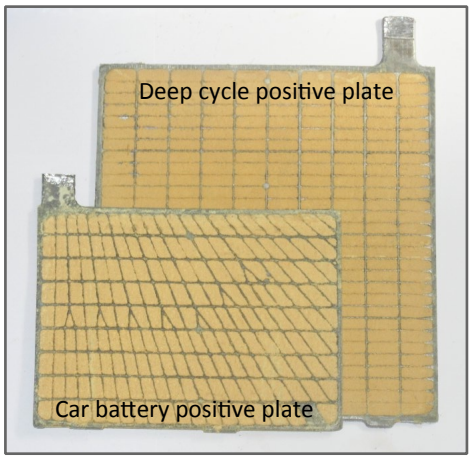
Higher level of gassing & self discharge
Requires higher charge voltage

Calcium = Lower level of gassing

**Tip -Compare weight

Lead Acid Construction

- Batteries have positive and negative plates separated from one another to prevent short circuit conditions.
  - Standard lead acid (car battery)
    - 2,2mm positive &
    - 1,4mm negative plate
  - Deep Cycle (brand dependent)
    - 3,3mm positive &
    - 2,3mm negative plate



Lead Acid Construction

- 12 Volt batteries
  - 6 Cells
    - Which always produce approx. 2,1 - 2,3 Volts/ Cell regardless of size of cell.

Batteries

Car
Leisure
Deep Cycle

- Batteries with a high power density and low energy density
  - Good for delivering large volumes of power over a short period of time
    - Good for vehicles
- Semi-Traction Batteries (a happy medium)
  - Good for delivering smaller volumes of energy over a longer period of time in light duty applications
    - Also referred to as “Leisure” Batteries
- Batteries with a low power density and high energy density
  - Good for delivering smaller volumes of energy over a longer period of time
    - Good for solar

Battery Capacity

- Capacity of the battery provides the storage capacity of a battery, e.g. 100Ah
- Batteries are usually marked as C_{10}, C_5, C_2, C_1 or $C_{0.5}$. The subscripts 10, 5, 2, 1 or 0.5 gives the charge/discharge rate
- If we have a battery denoted by C_{10}, having a capacity of 40 Ahr, then (40/10) = 4 Amps of current can be drawn from such a battery for 10 hours.

Batteries - Cycle life & Design Life

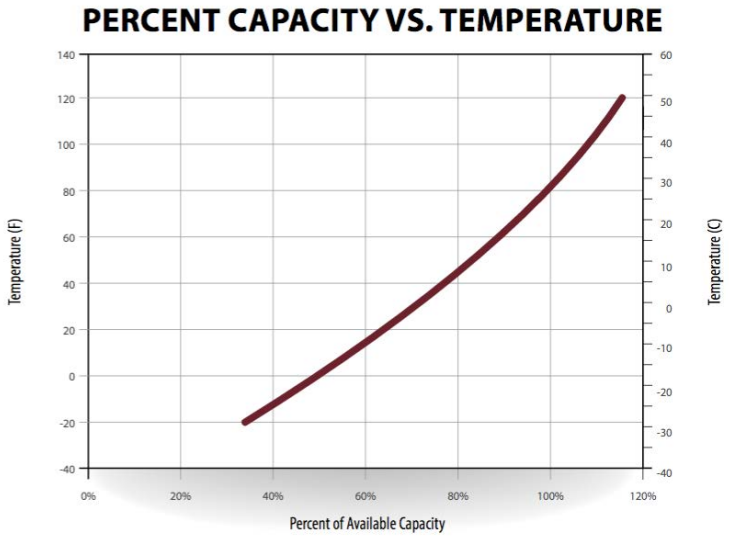
- Batteries remaining in a floating state may or may not last longer than batteries that are cycled
- A fully charged battery that can only deliver 60-80% of its rated capacity may be considered to be at the end of its cycle life
- Batteries are not an exact science
  - The energy storage and draw-off is as a result of a chemical reaction subjected to external factors

Design life under float conditions

Average Temperature	AGM Deep Cycle years	Gel Deep Cycle years	Gel Long Life years
20 ℃ / 68 ℉	7 - 10	12	20
30 ℃ / 86 ℉	4	6	10
40 ℃ / 104 ℉	2	3	5

Table 2: Design service life of Victron batteries under float service

Live fast die young



OCV vs Voc

Open Circuit Voltage (OCV):

Measurement made after voltage stabilizes (no load)

SOC	Specific Gravity	OCV (12V Battery)
100%	1.280	12.8
75%	1.227	12.4
50%	1.172	12.2
25%	1.111	11.8
Discharged	1.098	11.6

Battery Testers measure liquid density; similar to the red/white/ green indicator on certain batteries

Technology and brand dependent

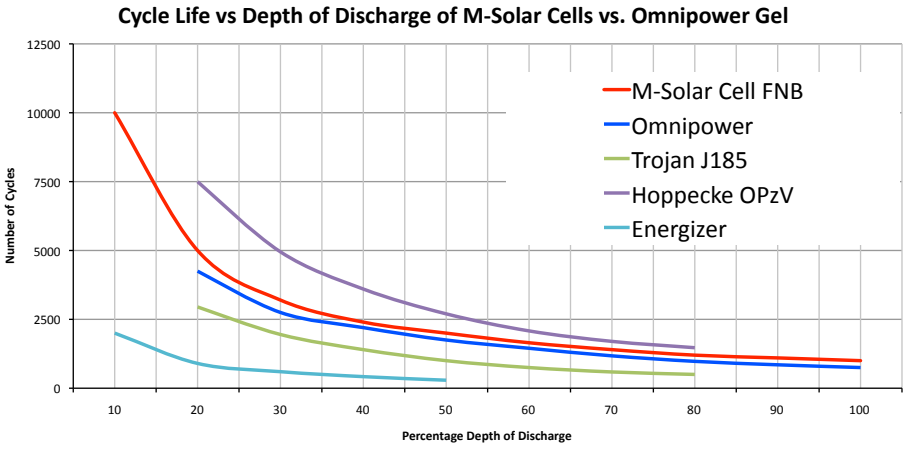
Battery charging principles

- Recommended Charging current 10 - 20%
- (Sonnenschein) The charge current must not exceed 35A / 100 Ah nominal capacity. The cell / bloc temperature must never exceed 45°C. If it does, stop charging or switch down to float charge to allow the temperature to decrease
- *Higher currents will not lead to relevant gain of recharging time.* Lower currents will prolong the recharging time significantly.
- When not in service all batteries self-discharge at a rate of about 1-15% per month depending on the type of battery.
- The rate of self-discharge increases as the temperature increases.

Batteries - DOD

- Battery life is directly related to how deep the battery is cycled each time. Depth of Discharge (DOD)
- If a battery is discharged to 50% every day, it will last about twice as long as if it is cycled to 80% DOD.
- If cycled only to 10% DOD, it will last about 5 times as long as one cycled to 50%.

Depth of Discharge as % of capacity



Source: www.pqrs.co.za

Battery sizing - Peukert's Law

$$t = \mathrm{H}\left(\frac{C}{IH}\right)^{k}$$

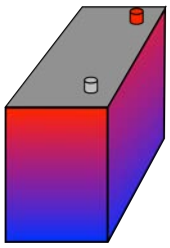
- H is the rated discharge time in hrs
- C is the rated capacity in that discharge time in Amp-hours
- I is the actual discharge current (amps)
- K is the Peukert constant (that is not constant)
- T is the actual time to discharge the battery

- Lead–acid between 1.1 to 1.3
- AGM batteries between 1.05 to 1.15
- Gel between 1.1 to 1.25
- Flooded batteries between 1.2 to 1.6
- The Peukert constant:
  - Varies according to the age of the battery, generally increasing with age.
  - Does not make provision for temperature fluctuations

Batteries - Storage

- Myth:Storing batteries on concrete floors will cause them to discharge.
  - About 100 years ago, battery cases were made up of wood and asphalt. The acid would leak from them, and form a slow-discharging circuit through the now acid-soaked and conductive floor.
  - Wood is not used in modern battery cases

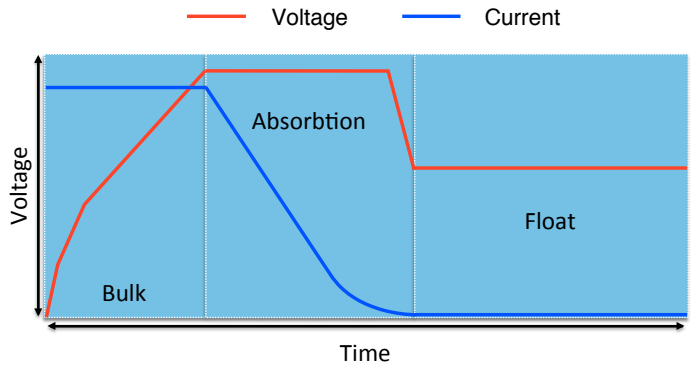
- To prevent large voltage differences between the upper and lower regions of batteries
- Should not be placed directly on concrete



Measuring battery voltage

- A realistic reading cant be achieved during a state of charge as the panels or regulator might be delivering a charge as high as 14.5V
- As a result of a chemical reaction batteries could normalise after a period of charge or discharge, which means that they might have to be left for a period before being measured

Lead Acid Charging cycle - 3 stages



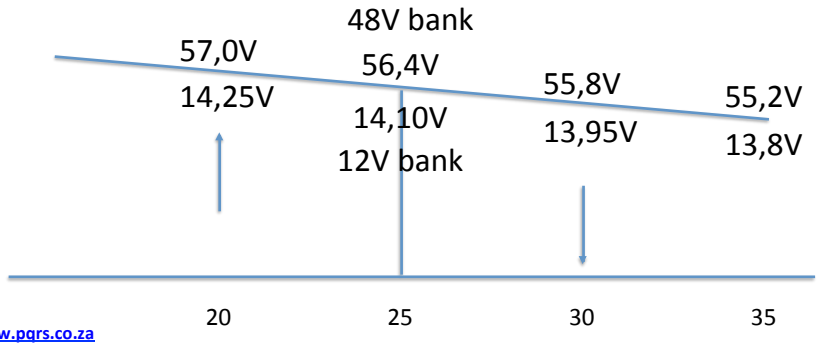
Bulk charge (aka constant current charge) Current stays constant and voltage increases

Absorbtion Charge (aka Topping charge) Voltage remains constant and current drops consistently until battery is fully charged

Float stage
Charge voltage is reduced to between 13 & 13,8V and held constant while the current is reduced to less than 1% of battery capacity.

With or without temp compensation

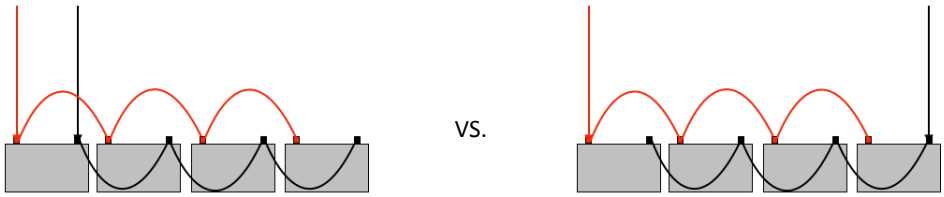
- 0,005 Volt per cell temp compensation
  - = 0,03V/12V Battery per degree Celsius change
  - = 0,12V/48V Battery per degree Celsius change



Source: www.pgrs.co.za

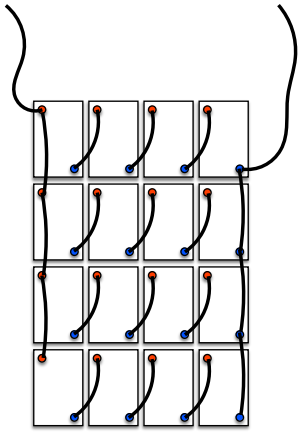
Charging and draw off

- Draw off takes place through the positive terminal
- Charging takes place through the negative terminal



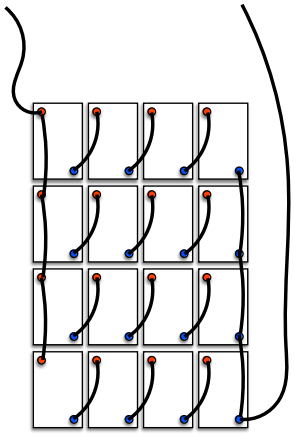
Why are these configurations incorrect?

Charging into the first row only

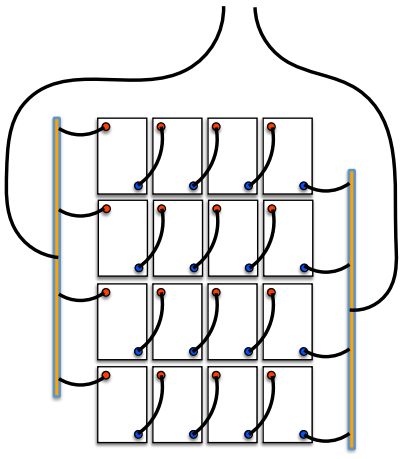


Equalization

Charging cable lengths



Correct Installation



Charging & discharging across bank

Equal cable lengths

Equalization taken care of with busbars

Bus bar calculation - Rule of thumb

Please double check busbar thickness for safety & application

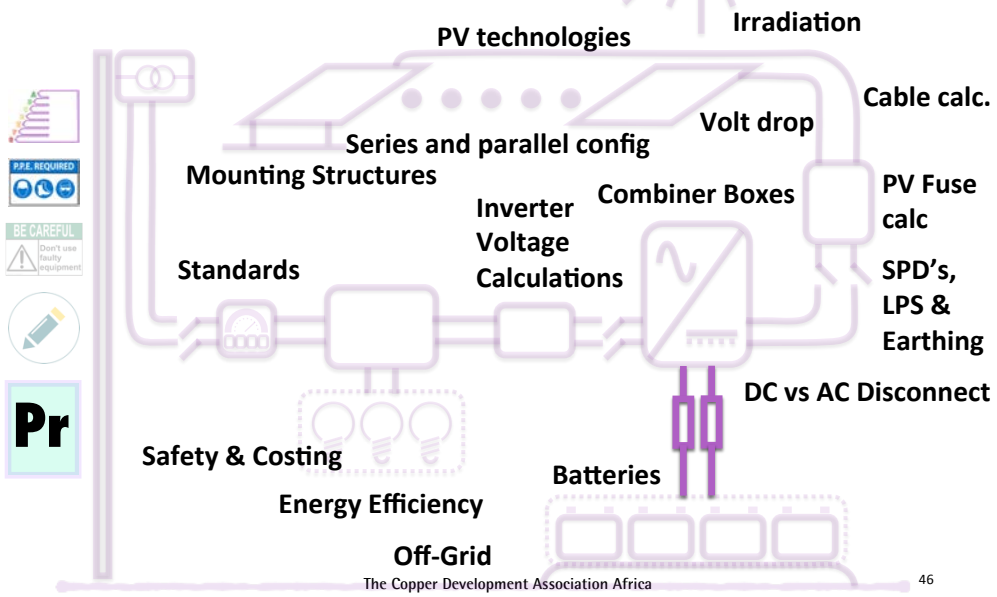
- Bus bar calculation as a rule of thumb
- width x height x 2 should = battery capacity
- 5mm x 20mm x 2 should be sufficient for a 200Ah battery bank.
- (SANS10142-1 6.6.2) for current >1600A = 1,6A per mm^2
  - current <1600A = 2Amps per mm^2

Busbar & Disconnector Layout

Battery Sizing: General

- Minimize voltage drop
- Use oversized cables
- Locate battery and load close to PV panel
- Choose a large enough battery to store all available PV current
- Ventilate or keep battery cool, respectively, to minimize storage losses and to minimize loss of life
- Is a genset/grid available for boost charge ?

Battery Fuse calc's



Battery SCC

- The short circuit of a battery (considered to be a finite power source) depends on:
  - the resistance of the path, and
  - the state of charge and
  - internal resistance of the battery which depends on variables, such as:
    - the material and dimensions of the grids and terminal posts,
      - the surface area and composition of active material,
      - the specific gravity, and
      - the thickness of the separators
- REf : Stationary Battery and DC Power System Electrical Protection Design Considerations; K. Uhlir

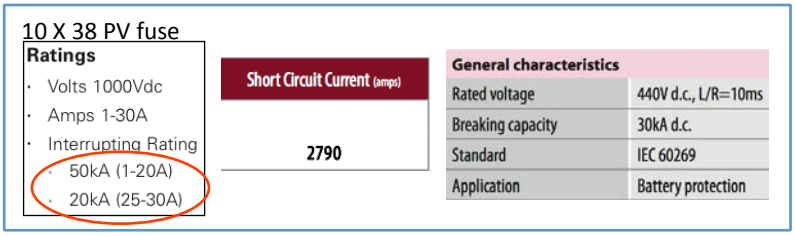
Battery PSSC SANS 10142-1:2012

$$PSSC_b = \left(\frac{E_b}{R_{bbr}}\right)$$

- The prospective short-circuit current of batteries can be calculated using the following values in a formula: (I=V/R)
- EB is the open-circuit voltage of the batteries; if this information is not known, then use
- EB = 1,05 x UNB V (where UNB = 2,0 V/cell);
- RBBr is the total resistance of the upstream network, in ohms, including the internal resistance of the battery and the resistance of the conductors;
- RBBr = 0,9 x RB + RBL + Ry Ω (see figure 8.1);
- RB is the internal resistance of the battery;
- RBL is the resistance of the battery connections;
- Ry is the resistance of the conductors.
- NOTE The internal resistance of the battery can be obtained from the manufacturer's data.

Battery PSCC

- A conservative approach in determining the short-circuit current that the battery will deliver at 25°C is to assume that the maximum available short-circuit current is 10 times the 1 minute ampere rating (to 1.75 V per cell at 25°C and specific gravity of 1.215) of the battery
- **Ref:https:www0.bnl.gov/isd/documents/88634.pdf**
- **Page 10 Section Batteries**

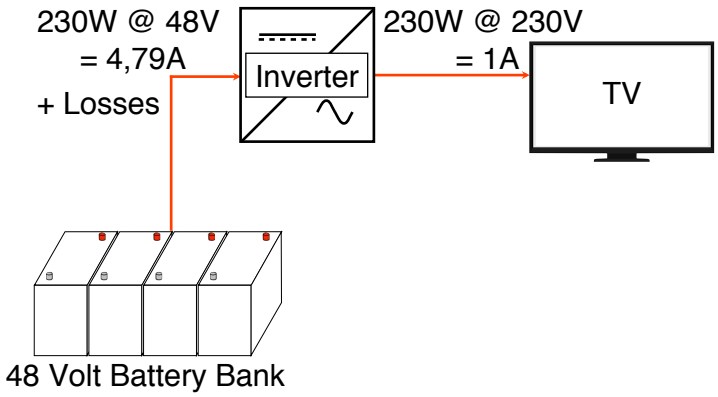


Battery Fuses

- Varied Philosophies on fuse sizing
  - Could be based on:
    - Recommendation by Manufacturer, or;
    - Calculated based on current consumption, and on potential short circuit current, or;
    - Various rules of thumb.

Basic battery discharge principles

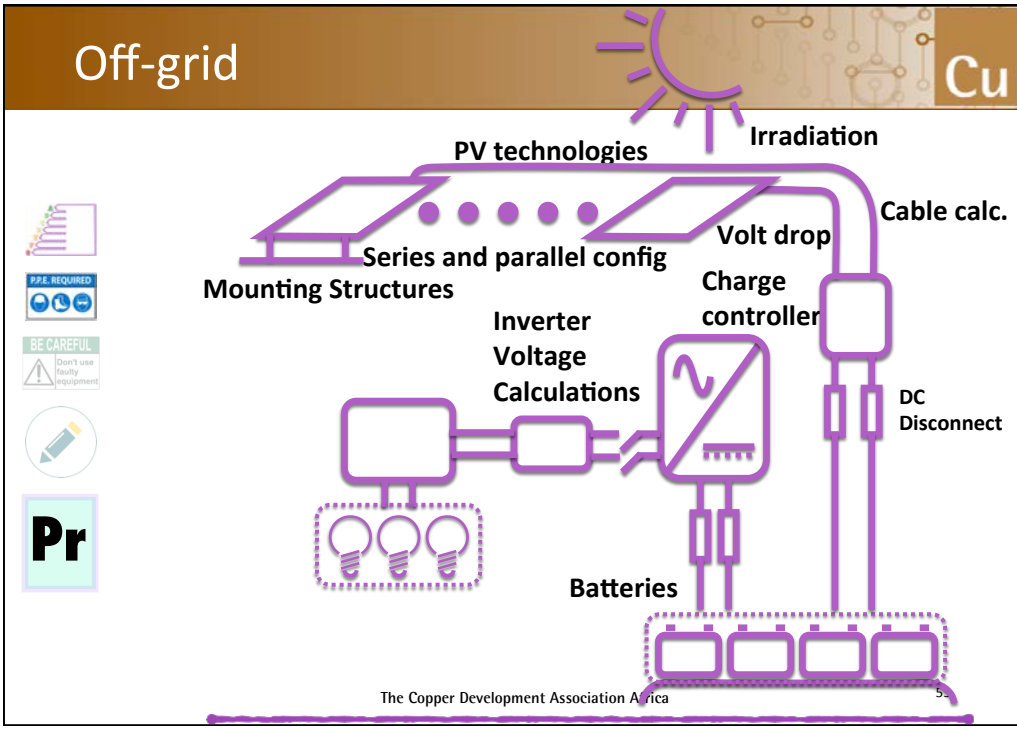
$$I = \frac{P}{V}$$



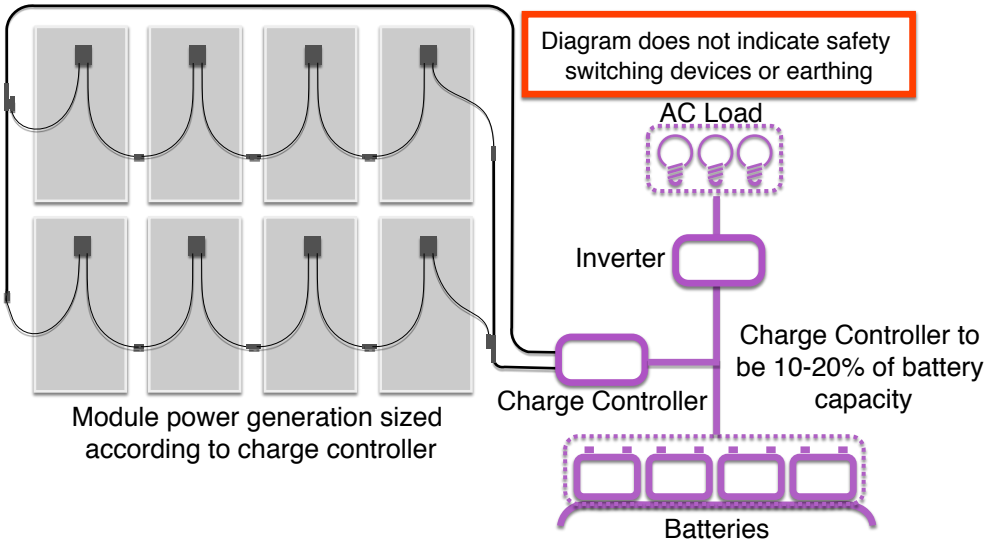
Cable sizing for batteries - 0.259V drop max.

cable section	L(+) + L(-) tot 5 meters	L(+) + L(-) tot 10 meters	L(+) + L(-) tot 15 meters	L(+) + L(-) tot 20 meters
mm²	I max A	I max A	I max A	I max A
0.75	2.3	1.1	0.8	0.6
1.5	4.5	2.3	1.5	1.1
2.5	7.5	3.8	2.5	1.9
4	12	6	4	3
6	18	9	6	5
10	30	15	10	8
16	48	24	16	12
25	75	38	25	19
35	105	53	35	26
50	150	75	50	38
70	210	105	70	53
95	285	143	95	71
120	360	180	120	90

Off-grid



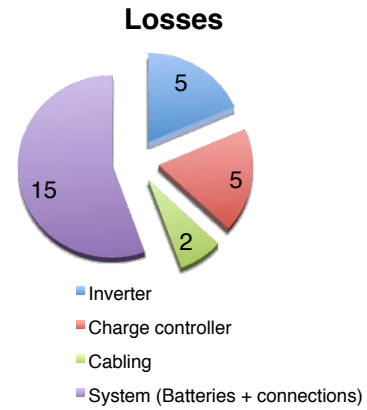
Off-Grid System



Sizing - Calculating consumption

#	Description	Load	Duration	Wh
1	Bedroom 1	18	4	72
2	Bedroom 2	18	4	72
3	Bedroom 3	18	4	72
4	Passage	18	4	72
5	Kitchen	56	6	336
6	Lounge	18	4	72
7	Dining Room	18	4	72
8	TV Room	18	6	108
9	Bathroom 1	18	2	36
10	Bathroom 2	18	2	36
11	TV 1	150	6	900
12	TV 2	150	4	600
13	TV 3	100	4	400
14	Microwave	1500	0,5	750
15	Outside lights(6*18W)	108	12	1296
16	Fridge	350	6	2100
17	W.Mach	1000	1	1000
18	Total	3576		7994

Battery Sizing



- Daily Consumption
- + Losses
- = Daily Storage

- http://www.batterysizingcalculator.com

Inverters

Off-grid system sizing

2. Daily storage divided by DC voltage = Average daily Ah needed
3. Average daily Ah needed adjusted to depth of discharge = Sub Total storage required.
4. Sub Total Storage required x autonomy = Total storage required.
5. Charge controller needs to be 10-20% of battery capacity
6. Modules must be sized according to charge controller being used.

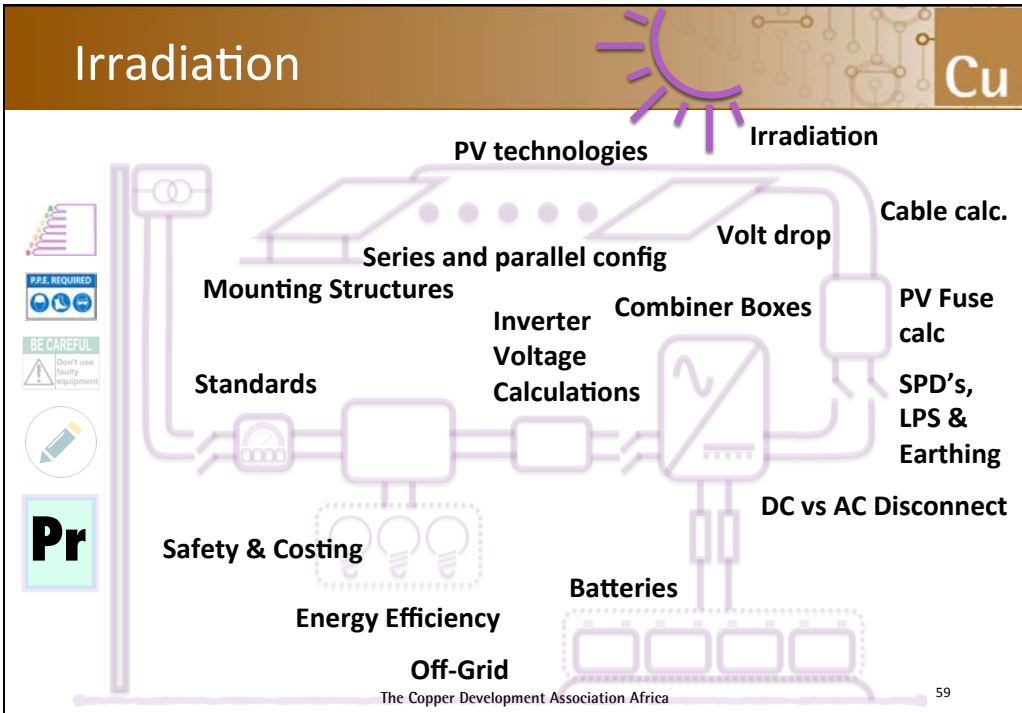
Array sizes for charge controllers

Recommended Photovoltaic Array Sizes in Watts				
Battery Set	20 Amp MPPT	40 Amp MPPT	60 Amp MPPT	100 Amp MPPT
12V	250W	500W	750W	1300W
24V	500W	1000W	1500W	2500W
36V	750W	1500W	2200W	3600W
48V	1000W	2000W	3000W	5000W

BlueSolar charge controller	MPPT 150/45	MPPT 150/60	MPPT 150/70
Battery voltage	12 / 24 /48 V Auto Select (software tool needed to select 36 V)		
Rated charge current	45 A	60 A	70 A
Maximum PV power, 12V 1a,b)	650 W	860 W	1000 W
Maximum PV power, 24V 1a,b)	1300 W	1720 W	2000 W
Maximum PV power, 48V 1a,b)	2600 W	3440 W	4000 W

- Microcare vs Victron recommended chart
- Please check other manufacturer specifications

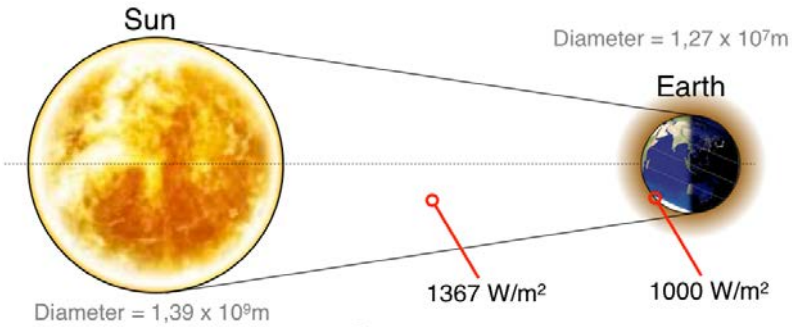
Irradiation



PV Power generation

- PV Power varies based on available insolation.
- This variation could be effected by changes in the atmosphere, weather patterns and seasonal changes.
- Insolation is defined as the amount of radiation striking the earth
- Note the difference in the terms
  - Irradiance : Intensity of Solar energy kW/m2
  - Insolation : Quantity of Solar energy kWh/m2

The solar constant



$$G_{sc} = \left\{ \frac{1367\ W/m^2}{4{,}92\ Mj/m^2/hr} \right.$$

G represents irradiance & SC = Solar Constant

Reflection, Deflection & Absorption

Reference: Duffie Beckman 1991

Irradiation

Irradiation

1000w/m²

Solar Thermal

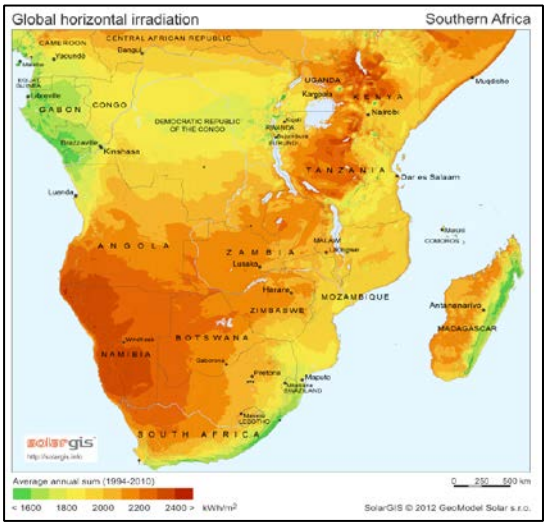
400 - 700w/m²

Solar PV

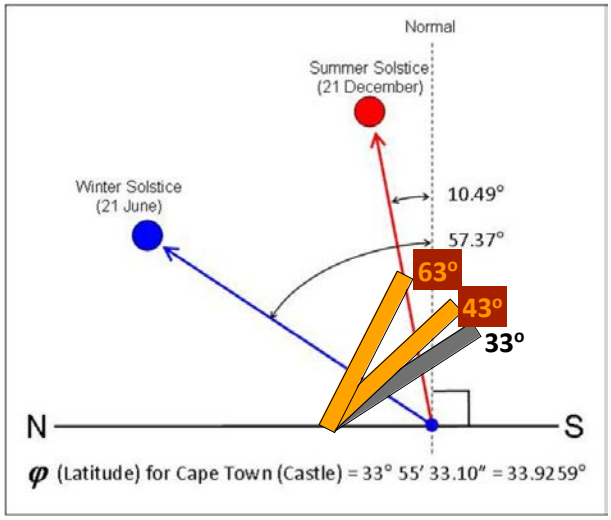
130 - 180w/m²

Sun hours calculation

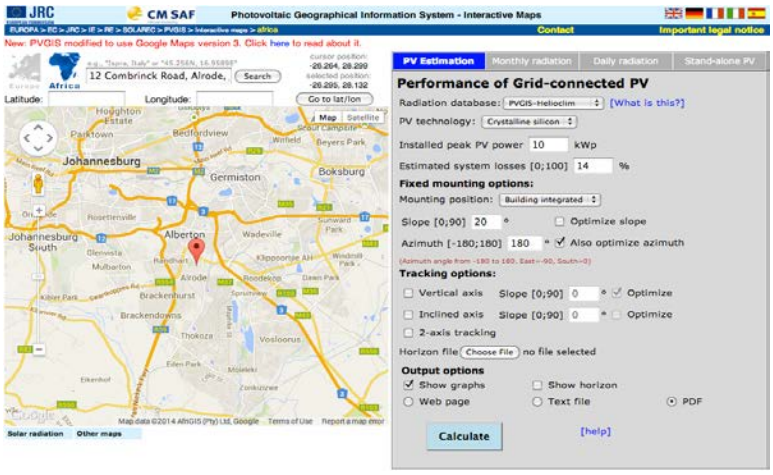
- Peak Sun Hours are used to calculate power generation of PV modules
- Peak Sun Hours can be calculated by dividing annual sun hours by the number of days per year.
- e.g. 2000kWhrs/m^2 divided by 365 = 5,47kWh/m^2



Summer and winter solstice



Tools for calculation & confirmation

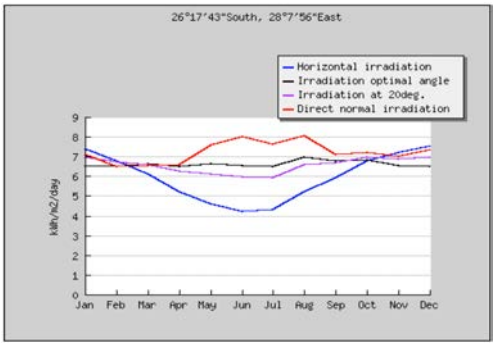


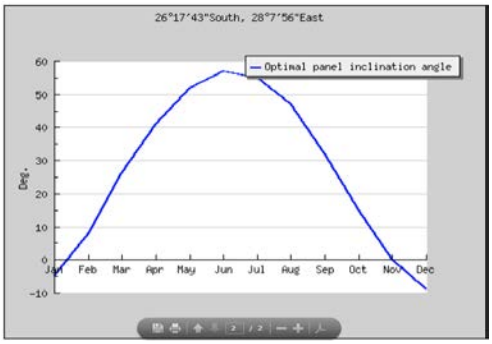
Link to GRS Solar Tool

- http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?map=africa
- GHI - Global horizontal irradiation is used for PV applications
- DNI - Direct Normal irradiation figures are used for solar Thermal applications

Global Horizontal Irradiance (GHI) is the total amount of shortwave **radiation** received from above by a surface **horizontal** to the ground. This value is of particular interest to photovoltaic installations and includes both Direct Normal Irradiance (DNI) and Diffuse **Horizontal** Irradiance (DIF).

Incline





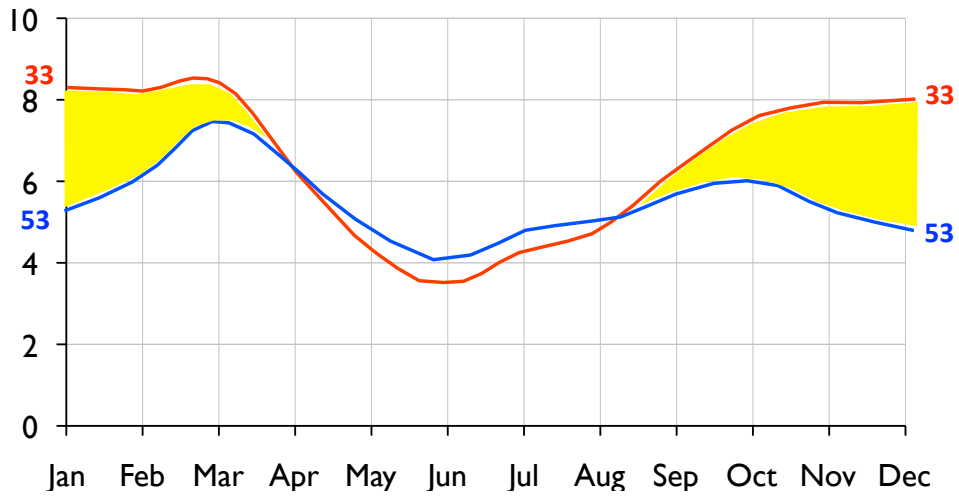
Trackers

- Single axis trackers
  - Implemented in SA
  - Shows approx. 30% improvement on yield
  - Maintenance should be considered in feasibility criteria


Centurion Solar


Sishen 75MW

Impact of incline on yield



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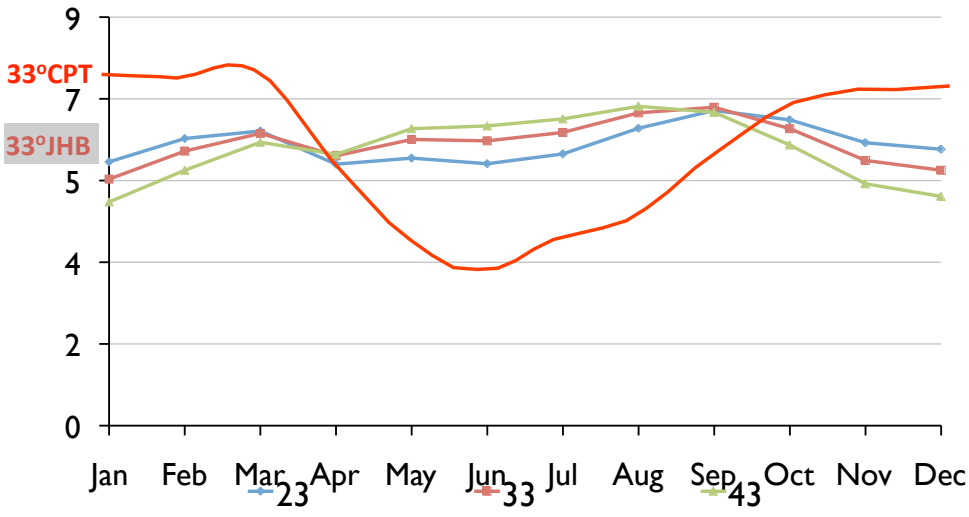
Impact of incline on yield - JHB



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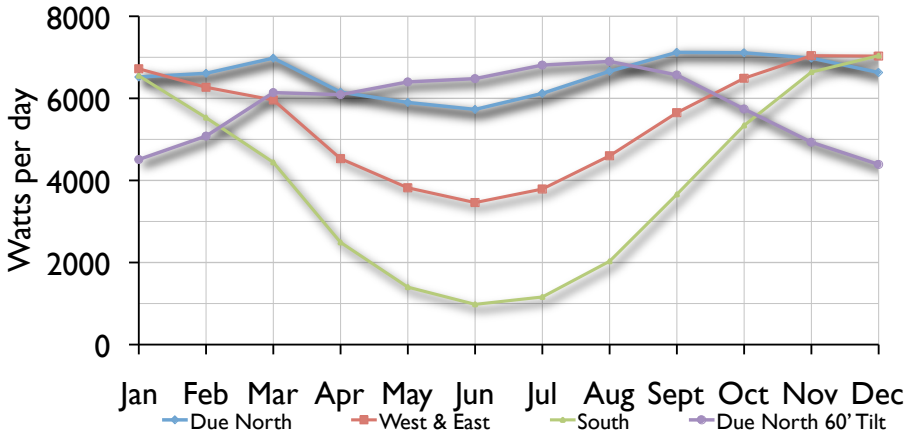
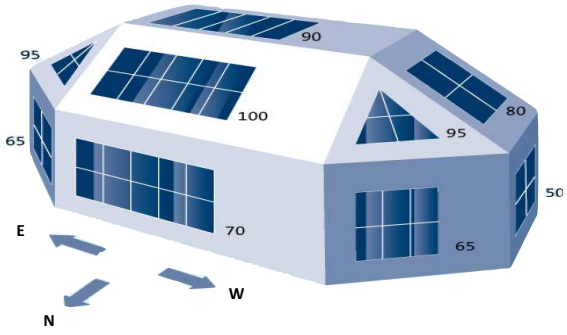
Insolation energy (Bfn 30°)

http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?map=africa



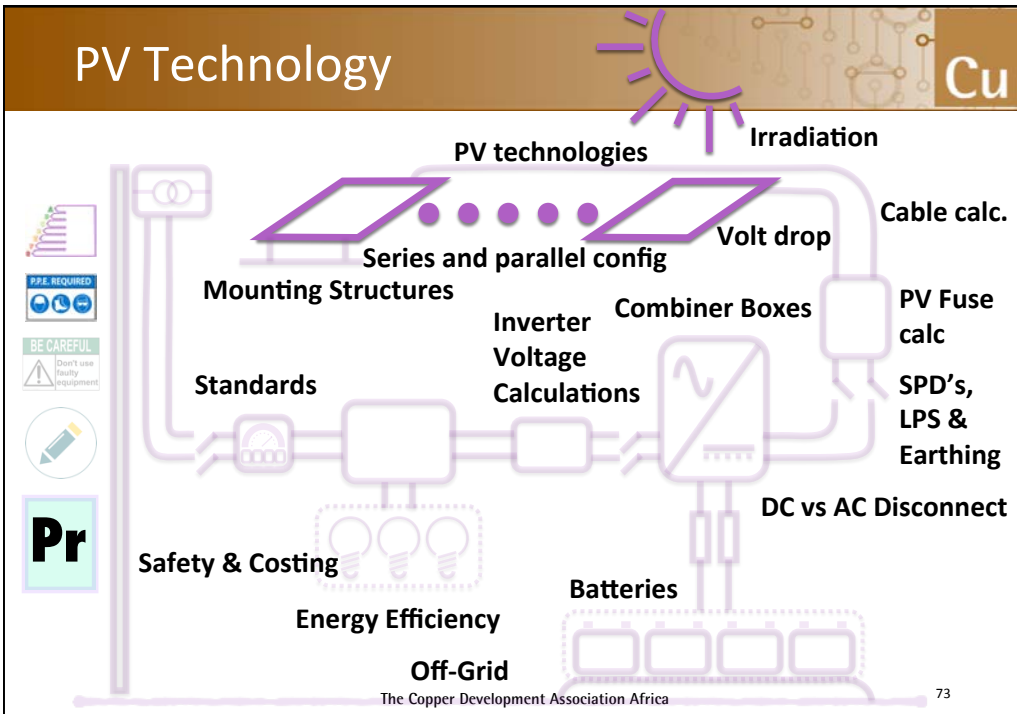
Summary - Impact of orientation

- 1000W/m2 is used as the reference value and global average.
- Solar Irradiation varies according to region and season.



© www.solarpraxis.de

PV Technology



PV History

1839 - Edmund Becquerel discovers the photovoltaic effect

1883 - Charles Fritz creates first solar cell (gold coated selenium)

1953 - Bell labs create Solar Cells that are 6% efficient

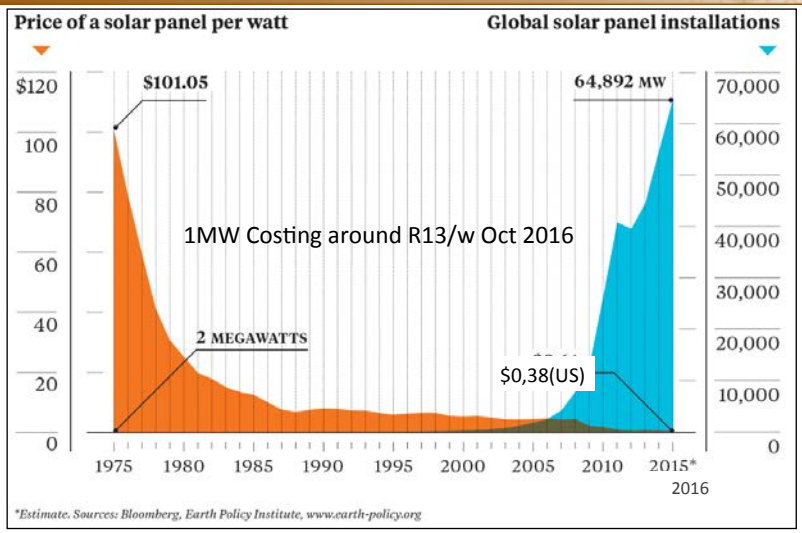
1958 - Solar energy is used in space

1982 - First 1MW plant is built in California

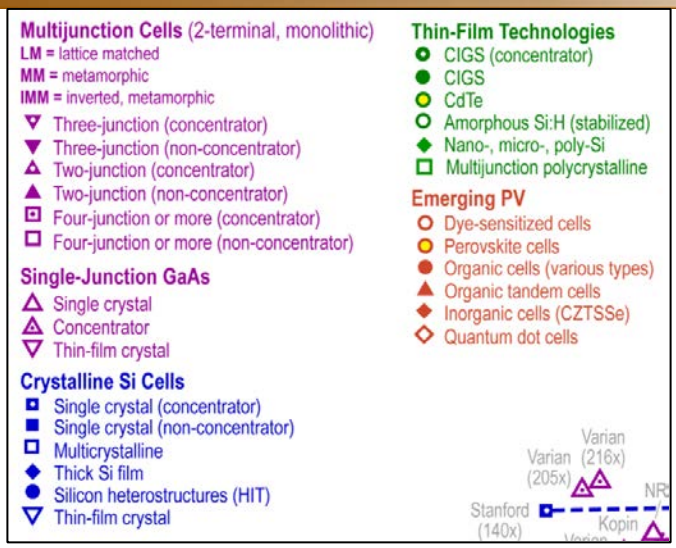
1994 - NREL creates 30% efficient Gallium Indium phosphate

2015 - 5% eff. Flexible Solar cells are printed using a printer

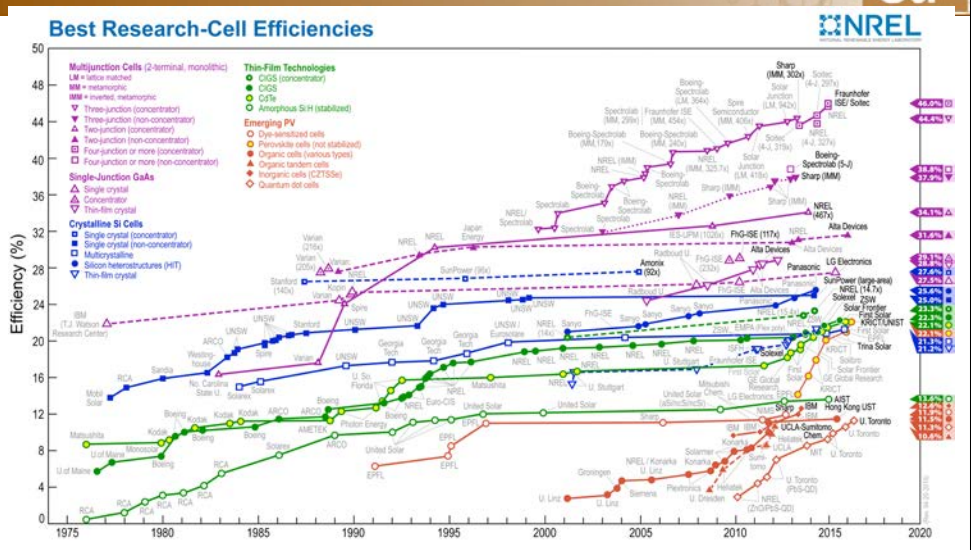
Costs of PV over time



Different PV technologies



NREL PV Performance over time

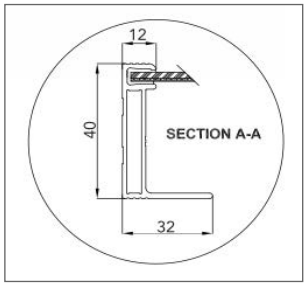


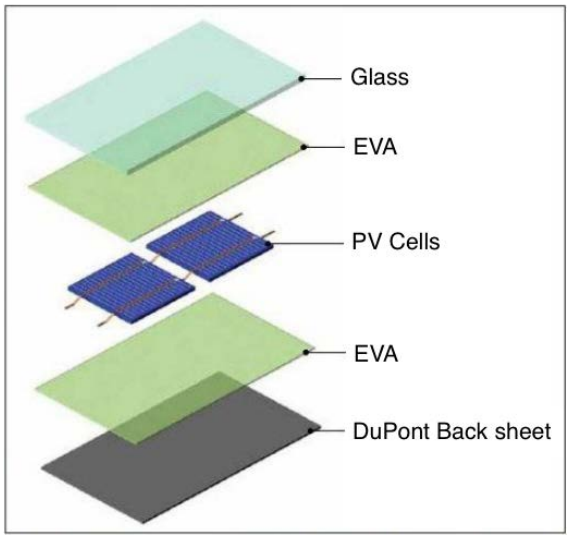
General PV Module Efficiency

Cell Material	Lab	Actual
Concentrated pv (Sharp May 2014)	*47%*	-
Mono-crystalline silicon (Panasonic Feb 2014)	*24.7%*	*18%*
Poly-crystalline silicon	*20.4%*	*17%*
CdTe (Cadmium-Tellurid as at July 2015)	*21.5%*	*16%*
CIGS (Copper Indium Gallium di Selenide July 2014)	*18.3%*	*13%*
Amorphous Silicon (a-Si August 2014)	*12%*	*10%*

Solar Cells configuration

- 36 Cells - Traditionally called 12 Volt modules
- 54 Cells
- 60 Cells
- 72 Cells - Traditionally called 24 Volt Modules





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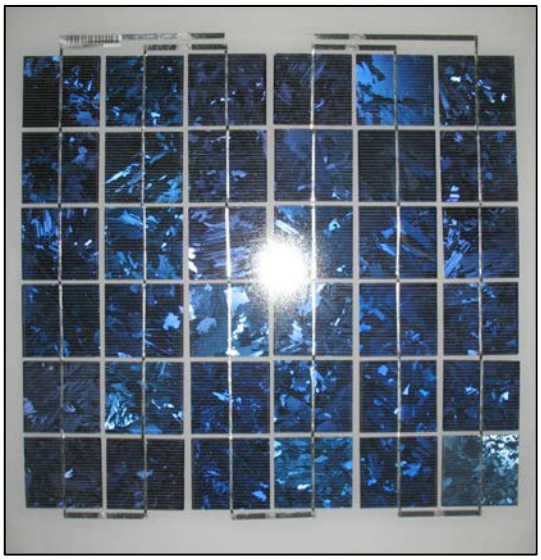
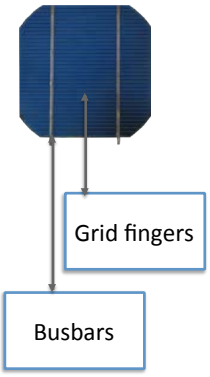
16W Module - Cell configuration





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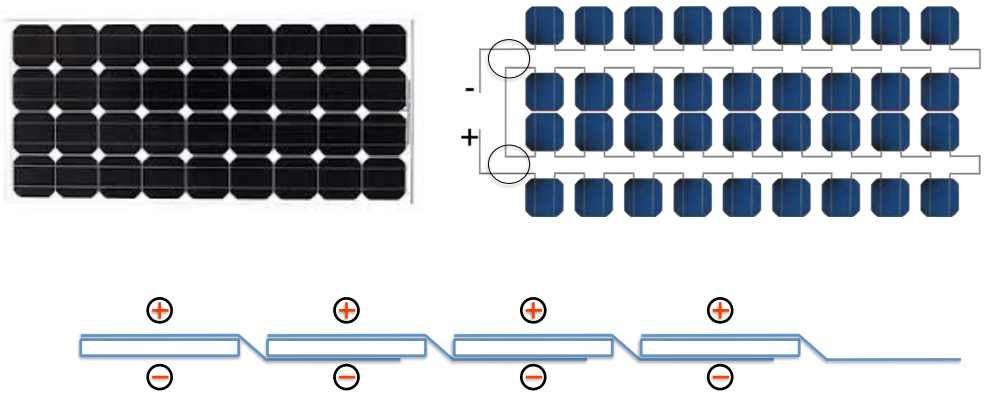
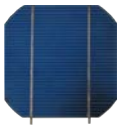
Typical connection



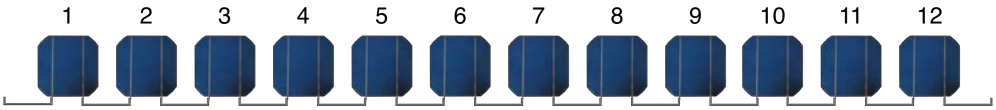
PV Cell Electrical parameters



- Current changes along with cell size
- 100 x 100 cell = approximately 3Amp
- 150 x 150 cell = approximately 6.75Amp

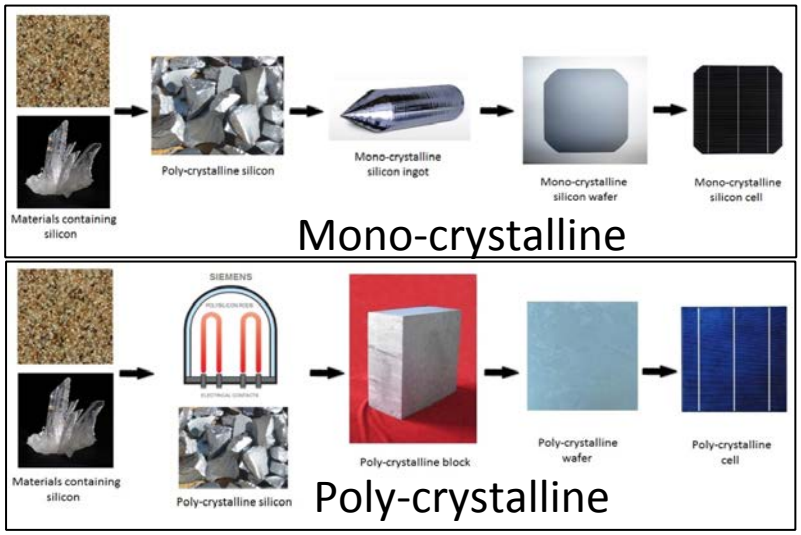
- Voltage of cells remain more or less the same at
  - $0.5V_{oc(\text{open circuit})}$ to $0.7V_{oc(\text{open circuit})}$
- Under varying temperature conditions

PV Cell Electrical parameters



- Calculate the voltage of the string of cells above?
- If the cells where 100 x 100, what would the Current be that can be produced?

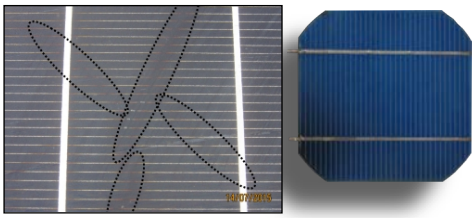
Crystalline Silicon Cells



Main PV technologies (commercially available)

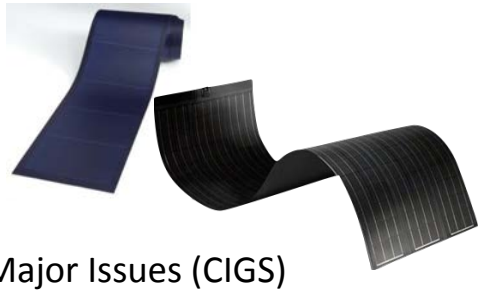
Cu

Silicon wafers



Major Issues (Mono & Poly)
Micro Cracks (snail trails)
Delamination

Thin-Film



Major Issues (CIGS)
Delamination

Module Construction

Cu

- Some modules consist of 5 layers
  - 60 cell Luxen 3,2mm tempered low-iron glass
  - 72 cell Yingli 4,0mm textured low-iron tempered glass with anti-reflective silicon dioxide coating
  - 72 cell Canadian 3,2mm glass
  - Hydrofobic & Hydrophilic coating
    - Anti-reflective coatings
    - Difference is how the modules appear during periods of rain.

Thin-film - CIGS & CdTe

- Additional Information
  - Temperature comparison between thin film and poly/ mono crystalline
  - Solar Frontier 3,2mm top glass + 1,8mm bottom glass. (CIGS)
- Material and workmanship warranty for ten (10) years and a power output warranty of 90% of the nominal output power rating (PMPP+/- 5%) during the first ten (10) years and 80% during twenty-five (25) years subject to the warranty terms and conditions.

STC vs NOCT

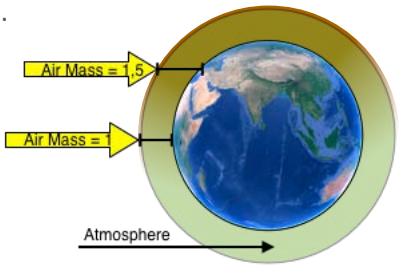
- STC corresponds to:
- 1000W/m2
- At 25°C cell temperature,
- with an Air Mass 1.5 (AM1.5),
- as defined in IEC 60904-3

NOCT is the temperature reached by open circuit cells in a module under the conditions as listed below:

- Open back mounted module
- At a 45° tilt angle from the horizontal
- Total irradiance of 800 W/m2 and
- 20°C ambient temperature where a
- 1 m/s wind speed is available
- on a panel in an open circuit condition

Air Mass

- One and a half times the spectral absorbance of the Earth's atmosphere. It refers to the amount of light that has to pass through Earth's atmosphere before it can hit Earth's surface, and has to do mostly with the angle of the sun relative to a reference point on the earth.



- Modules used in space are tested against AM=0 as the atmosphere is not a factor in space.

Definitions – Open Circuit Voltage

- Open-circuit voltage is the difference of electrical potential between two terminals of a device when disconnected from any circuit.
- There is no external load connected.
- No external electric current flows between the terminals.
- It is sometimes given the symbol Voc

Definitions – Sorting Limits

- Also referred to as “power output tolerances”
- Cells vary in performance. Sorting limits relate to possible variances in panel performance
  - Hail testing done with 25mm hail at approx. 80km/h

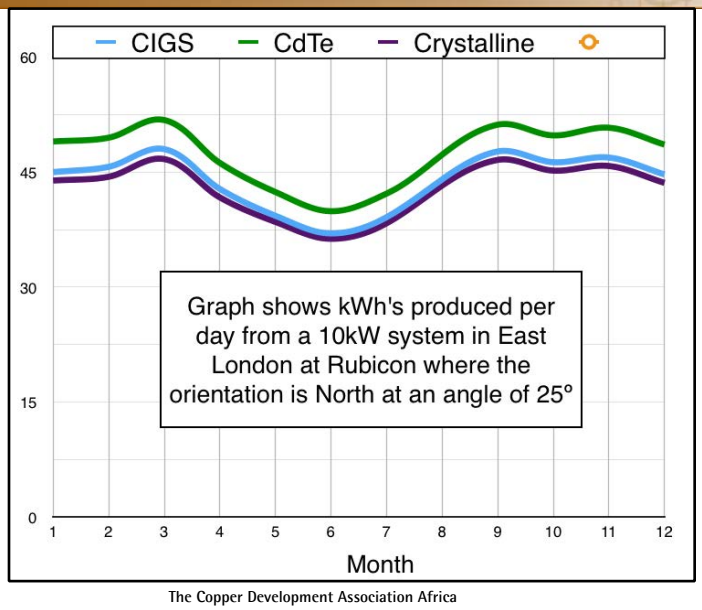
Definitions – Short circuit current

- The short-circuit current is the maximum current through the solar cell (i.e., when the solar cell is short circuited). Usually written as I_{SC}
- All values in specifications are at STC
- STC = standard test conditions

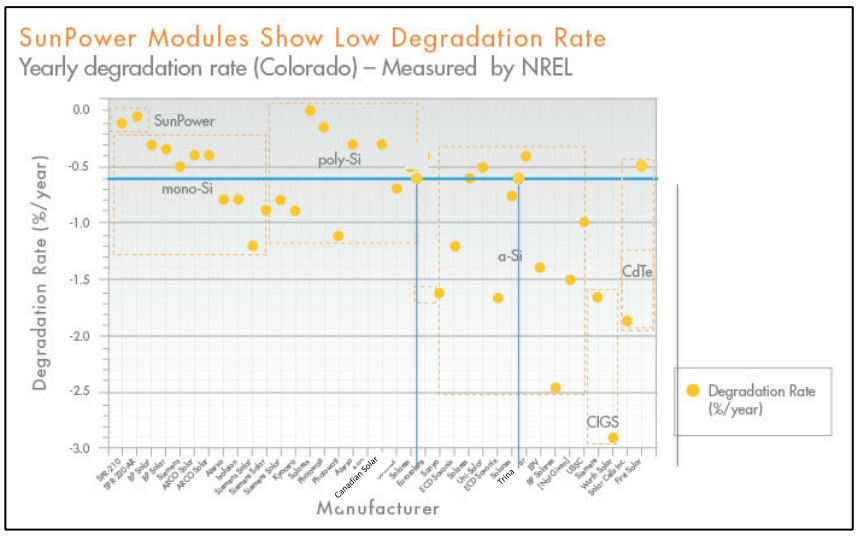
Technology performance under temp.

Description (STC)	CdTe (First Solar)	CIGS	mC
Temp Co-efficient of P_{mpp}	*-0.25%/°C*	*-0.34%/°C*	*-0.47%/°C*
Temp Co-efficient of V_{oc} – High temp	*-0.27%/°C*	*-0.28%/°C*	*-0.32%/°C*
Temp Co-efficient of I_{sc}	*+0.04%/°C*	*+0.003%/°C*	*+0.05%/°C*

Technology Performance Eastern Cape

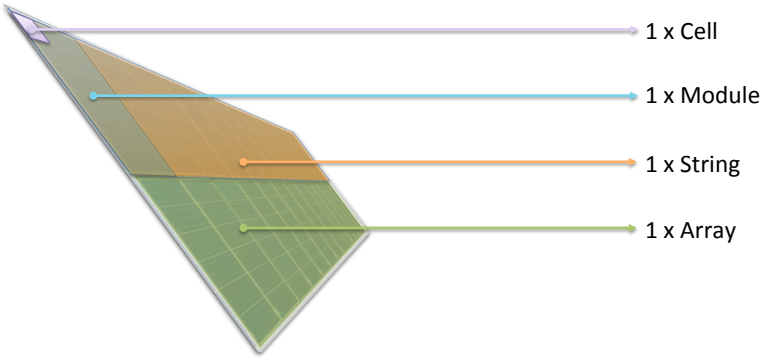


PV Panel Degradation

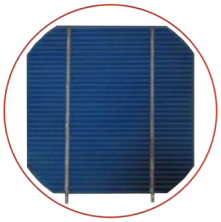


Cell, Module, String, Array

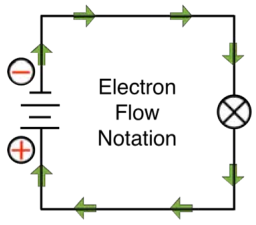
- Cell, module, string, array

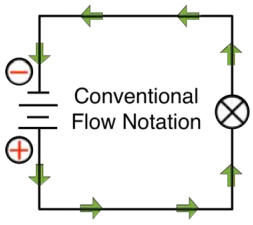


Cell –> Module –> Generator



Electron Flow



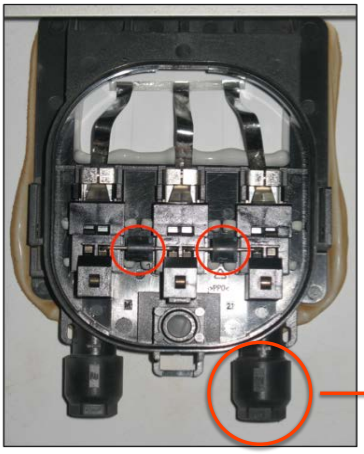


- Benjamin Franklin
  - Glass & Silk Experiment
  - Kite experiment
- Electrons
  - Charged 'negative'
  - Move from areas of abundance to areas of depletion
- The same principles can be seen in solar modules

Electron flow in a cell - video

By-Pass diodes in panels

Factory Fitted Diodes

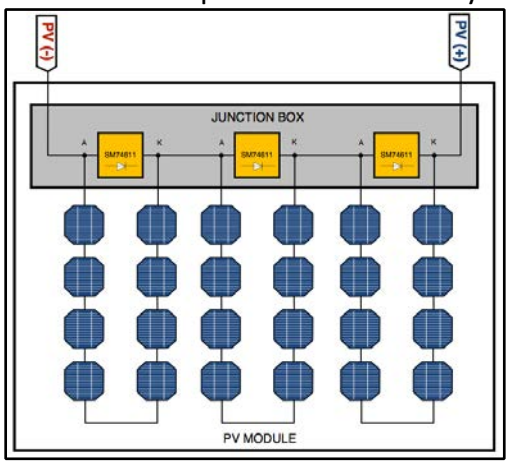


No Visible Diodes

Polarity: Positive is always on the right and negative always on the left in crystalline modules

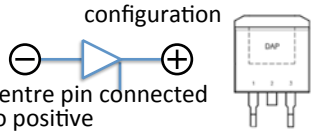
How to overcome the effect of shading

- Most good quality panels are factory fitted with Diodes.
- A diode can be explained as a one way valve for current.



- These diodes are referred to as bypass diodes
- Bypass diodes do not have an impact in reverse current

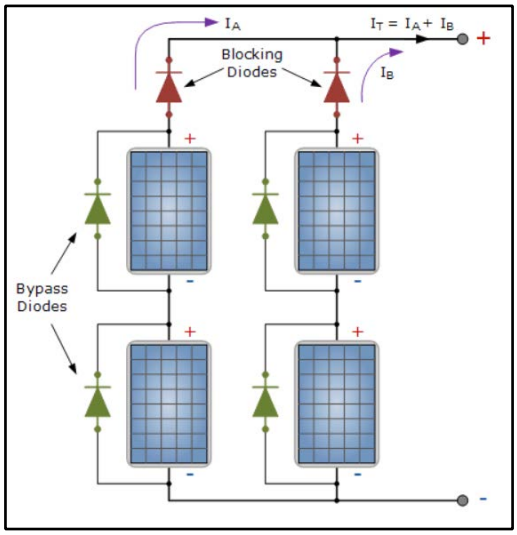
Typical bypass diode wiring configuration



Centre pin connected to positive

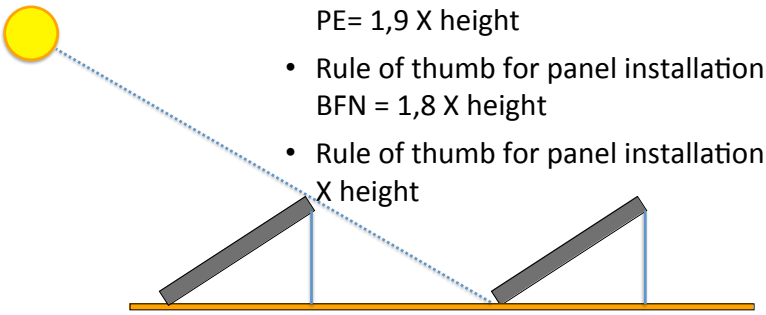
Long pins connected to negative

By-Pass vs Blocking Diodes



- By-Pass diodes are connected in parallel
- Blocking diodes are connected in series and used in some instances to prevent reverse current

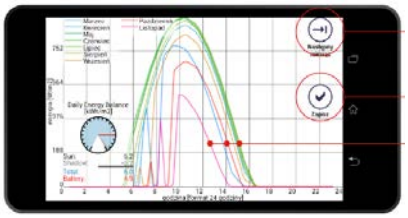
Spacing of rows - rule of thumb



- Rule of thumb for panel installation in CT, EL & PE= 1,9 X height
- Rule of thumb for panel installation in DBN & BFN = 1,8 X height
- Rule of thumb for panel installation in JHB = 1,6 X height

Free mobile app - Scan the sun app

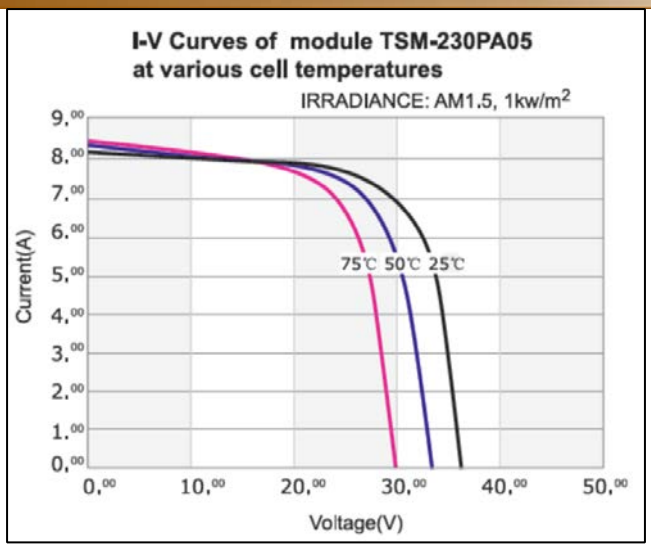
- Find your location
- Map the horison
- Synchronise orientation
- Synchronise tilt



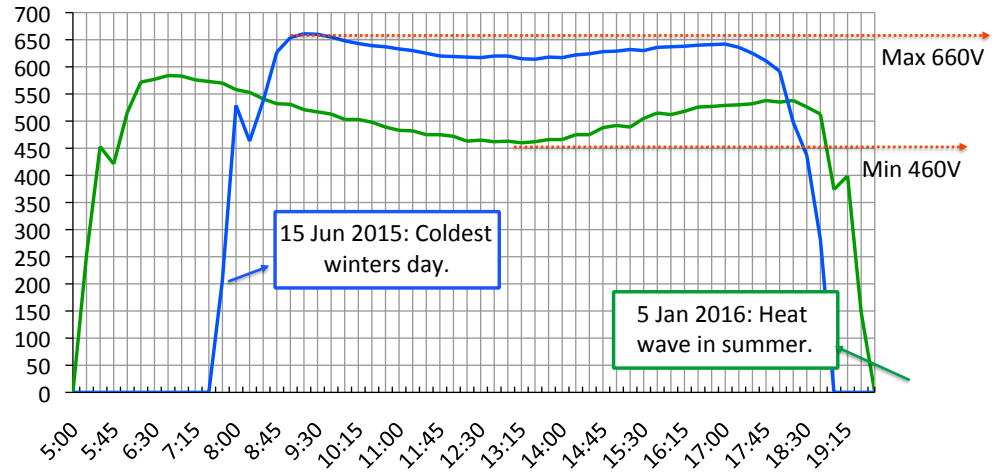
IV Characteristics

The I-V characteristics of a solar module, or cell, shows the current generated by the device and the voltage across its terminals when full sun is shining on it. If the solar modules terminals are connected to a variable resistance R, the operating point can be determined from the resulting I-V characteristics of the module. When R is small the solar module behaves as a constant current source. When R = 0 this creates a short circuit and the greatest value of the current is generated by the module. This is known as the short circuit current, Isc. At Isc terminal voltage is zero. On the other hand, if R is large approaching infinity, the module will behave as a constant voltage-source, creating a maximum open-circuit voltage, Voc. At Voc generated current is zero.

Effect of temp. on PV panels



Hot vs Cold days - String Voltage

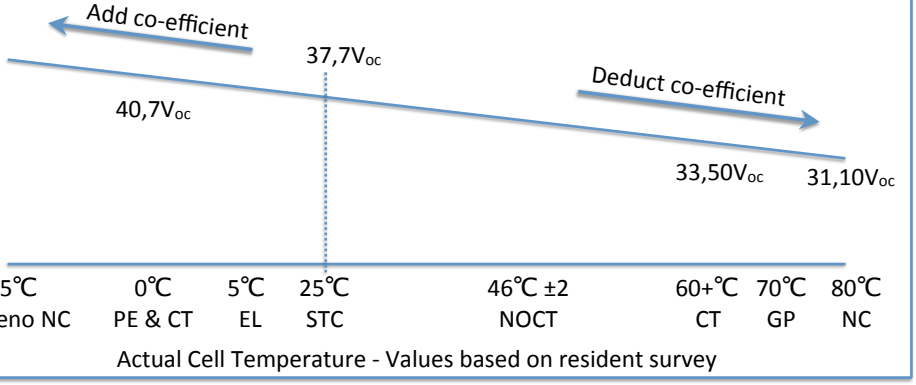


20 modules in a string - 4 strings / mppt - 3 mppt's per inverter

Source: www.pqrs.co.za

Temperature co-efficient

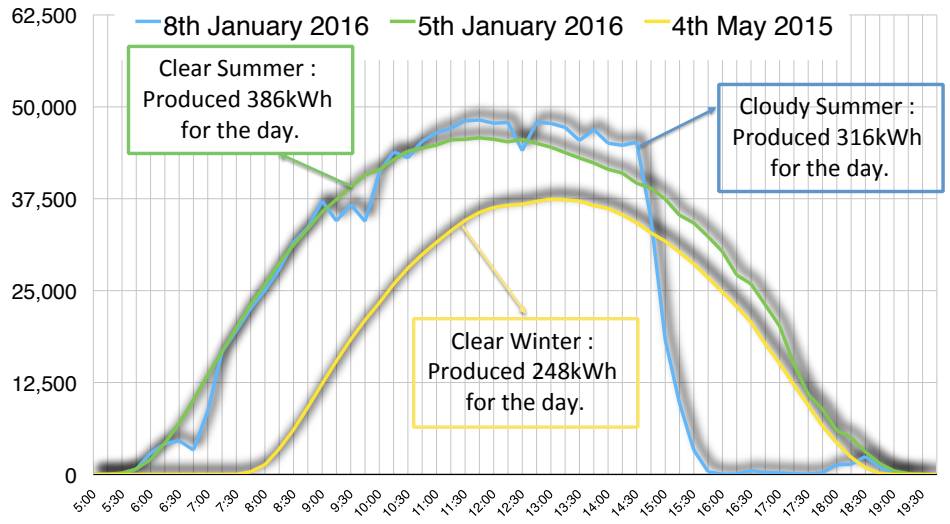
- -0,32%/℃ 260W YGE 60 cell
- Eff of temp = 37,7V_{oc} x 0,32%
  - = 120mV



Actual Cell Temperature - Values based on resident survey

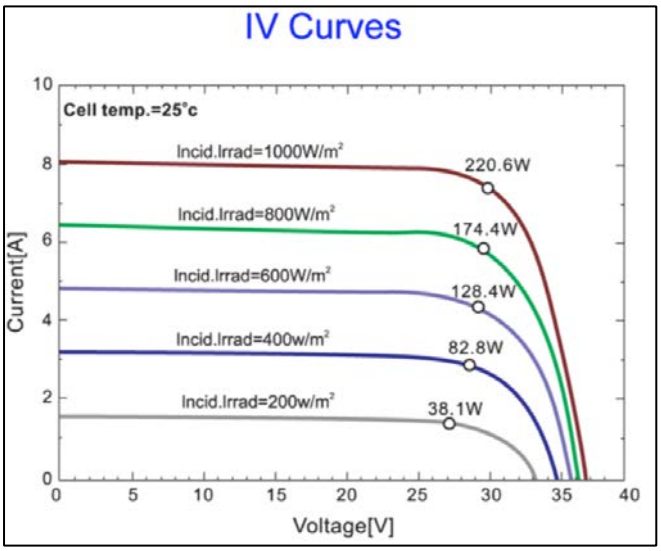
Source: www.pqrs.co.za

Sunny vs rainy days



Source: www.pgrs.co.za

Effect of Light intensity on current and voltage

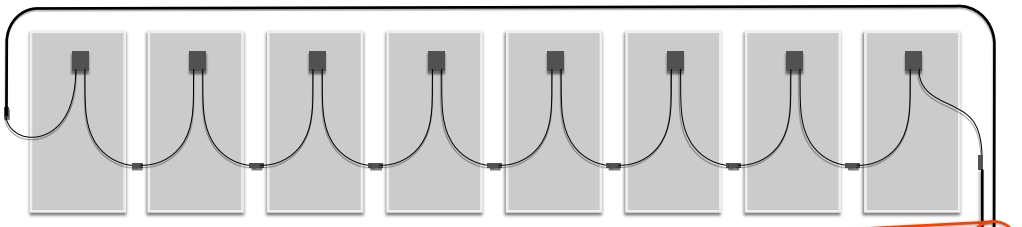


Min & Max Current - Edge of cloud effect

Source: www.pqrs.co.za A maximum value of 1195W/m^2 was observed on 31/7/2015(PE)

Series Configuration

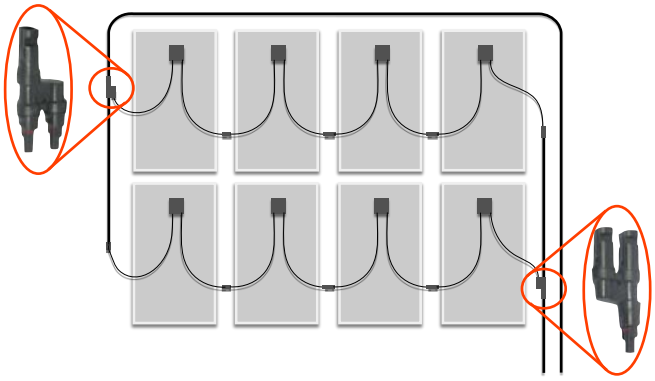
- When connecting in series the voltage is multiplied by the number of panels to get to the system voltage.
- The inverter or charge controller needs to be able to operate in the system voltage temp ranges



Modules in Series	V_{oc} Ave. Per cell	Module V_{oc}	-15°C	80°C
36 Cell X 8 Modules	0,6	21,6	193	144
54 Cell X 8 Modules	0,6	32,4	290	216
60 Cell X 8 Modules	0,6	36	322	240
72 Cell X 8 Modules	0,6	43,2	387	288

Values are estimated and have been calculated using a temp co-eff. of 0,30%/°C

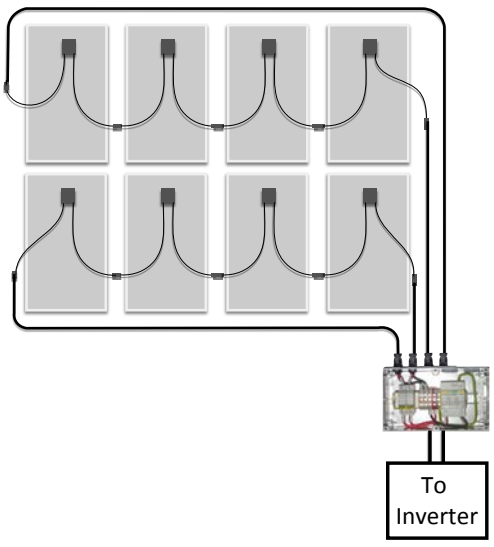
Parallel Configuration



- **Using Branch connectors**
- Same power being produced as previous slide
  - Lower Voltage
  - Current X 2 of a single string

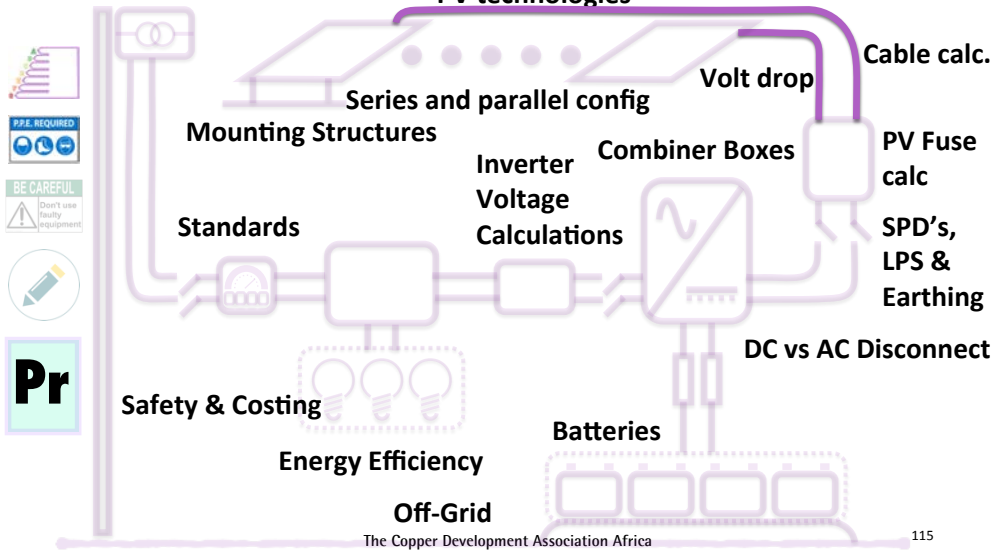
Modules in Series	V_{oc} Ave. Per cell	Module V_{oc}	-15°C	80°C
36 Cell X 4 Modules	0,6	21,6	96	72
54 Cell X 4 Modules	0,6	32,4	145	108
60 Cell X 4 Modules	0,6	36	161	120
72 Cell X 4 Modules	0,6	43,2	193	144

Parallel Configuration



- **Using a combiner box**
- Same power being produced as previous slide
- Offers the advantage of
  - individual string disconnection
  - Housing for SPD's
- Why are fuses technically not required for this particular 2 string configuration?

Volt Drop Calculations



Conductors

- International Annealed Copper Standard (IACS)

Metal / Material	Conductance IACS
Silver	*105%*
Copper	*100%*
Gold	*70%*
Aluminium	*61%*
Brass	*28%*
Zinc	*27%*
Nickel	*22%*
Iron	*17%*
Iron	*17%*
Tin	*15%*
Phosphor Bronze	*15%*
Lead	*7%*
Nickel Aluminium Bronze	*7%*
Steel	*3 to 15%*

Solid or stranded?

- Solid wire is cheaper, but does not put up with the constant flexing of power cords.
  - Solid core wire in our walls where it does not need to move and cost matters
  - Stranded wire in our power cords where a solid wire would quickly harden and break from continuous flexing.
- Why would wire work harden, embrittle and break?
  - Strand diameter relative to the bend radius is what determines how much strain is imparted into the wire. Solid wires have large strand diameters and see lots of strain. Stranded wires have strands with small diameters.
- Welding & battery cables use thin strands to compensate for movement

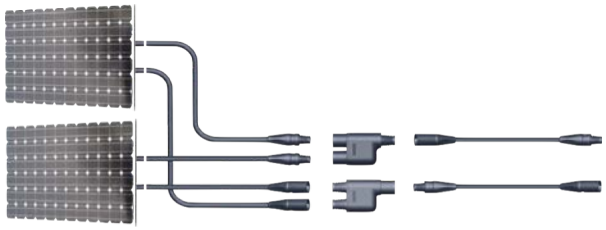
Solar cable & conductors

- General Cable
- Halogen-free wiring will typically have a higher continuous use temperature rating, and is more suitable for pv operating environments.(Popular sizes 4 & 6mm)
- Rated from 900 – 1500V
- Flexible tinned multi stranded wire

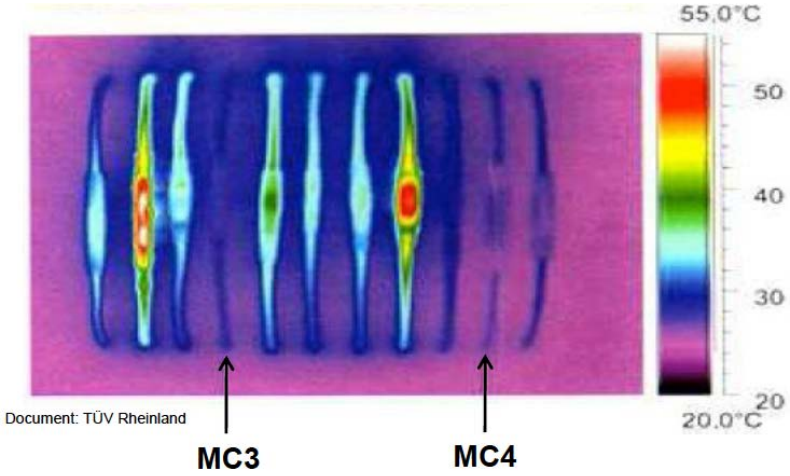
Crosslinked Special Polyolefin
- 36 Shore D
- Halogen free
- Weather- and UV-resistant
- Ozone resistant

Terminating Solar cable

- MC4 type connectors are rated
  - 22A-30A 4mm²-6mm²(please check particular brand)
  - For safety reasons do not cross mate coupler brands
  - Use only PV certified cables (tinned multi-stranded, double insulated)
  - Avoid colour cables (long term UV resistance)



Terminating solar Cable



Volt drop assumptions

- Table 6.2(b) Single core PVC insulated cable Page 101 SANS10142-1 2006
- Voltage drop per amp per meter
- Assuming that ambient is +-30°C & Conductor temperature does not exceed 70°C
- 3% max volt drop recommended for solar with ABB calculating around 1% for ABB recommended cable sizes
  - The following tables provide values of volt drop assuming:
    - Multi-core armoured PVC insulated cables are used.
    - Buried in the ground
    - A volt drop of less than 5% will be achieved
    - All circuits are fully loaded
    - All conductors are copper
    - Harmonic current distortion has not been considered.

Volt drop - 12V – Guide only

		Column nr											
		1	2	3	4	5	6	7	8	9	10		
		Circuit rated at 12V in amps											
Conductor size		1	2	4	6	8	10	15	20	25	30	40	50
	1	7	3.5	1.75	1.18	.88	.71						
	1.5	10.9	5.45	2.73	1.82	1.36	1	.73					
	2.5	17.55	8.82	4.41	2.94	2.2	1.75	1.18	.58				
	4	28.57	14.29	7.14	4.76	3.57	2.86	1.9	1.43	1.14			
	6	42.86	21.4	10.7	7.1	5.4	4.3	2.8	2.1	1.7	1.4		
	10	70.6	35.3	17.6	11.7	8.8	7.1	4.7	3.5	2.8	2.4	1.8	
	16	109.1	54.5	27.3	18.2	13.6	10.9	7.3	5.5	4.4	3.6	2.7	2.2

- Maximum Length in meters of copper cables at a given load with a specific sized conductor.
- Table according to SANS 10142-1:2006 Page 308

Volt drop Calculation 4mm²

- Assumptions & Figures correspond to SANS 10142-1 Page 305 & table 6.2

$$V_d = \left(\frac{mV/A/m}{1000}\right) x\ A\ x\ m$$

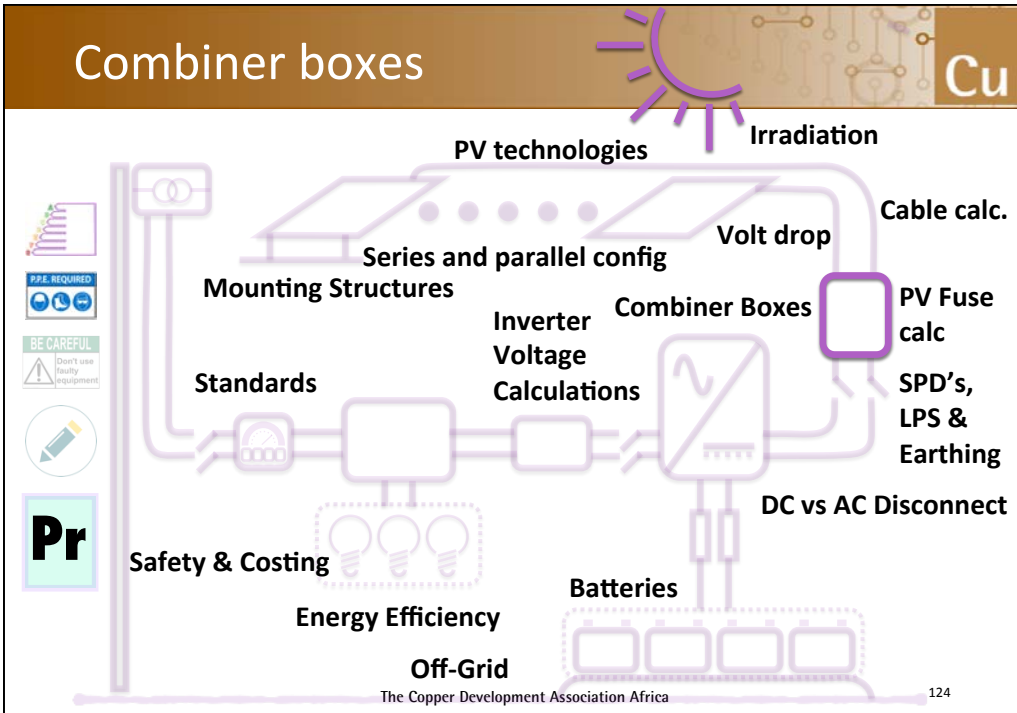
Convert from mV to Volts.

Max distance = 20m @ 110V

Vd(Volts)	L(Metre)	3% Drop	5% Drop
1,65	10	55	33
3,3	20	110	66
4,95	30	165	99
6,6	40	220	132
8,25	50	275	165
9,9	60	330	198
11,55	70	385	231
13,2	80	440	264
14,85	90	495	297
16,5	100	550	330

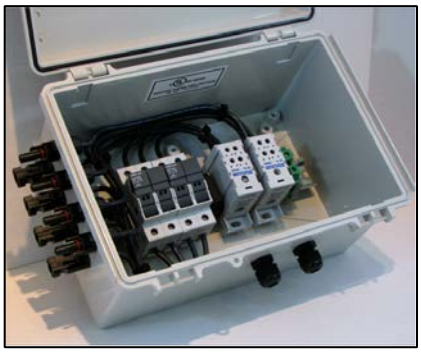
- 4mm cable volt drop = 11mV/a/m
- 6mm cable volt drop = 7.3mV/a/m

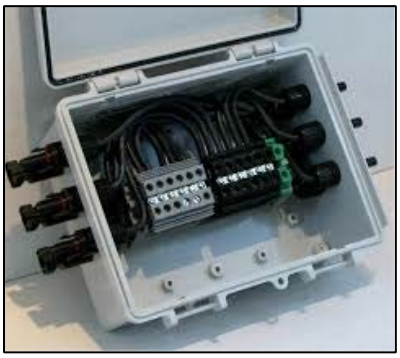
Combiner boxes



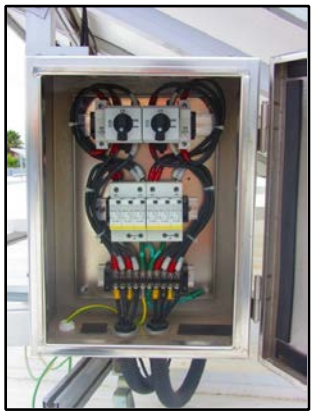
Combiner box

- Black cable only in a DC network. Is it allowed?

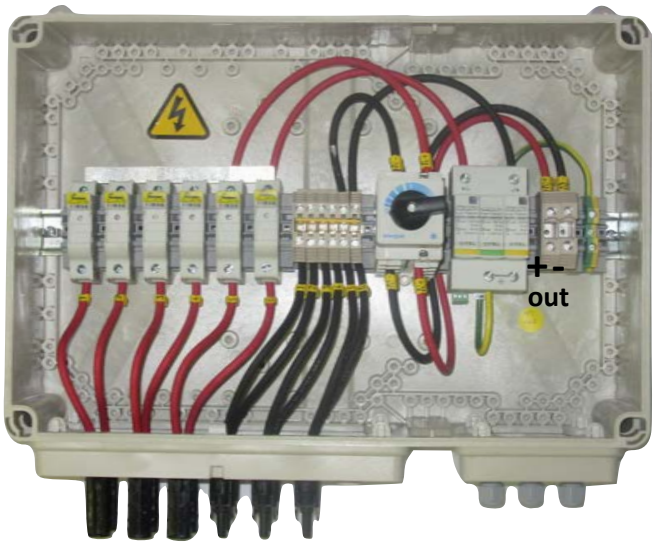




Combiner box



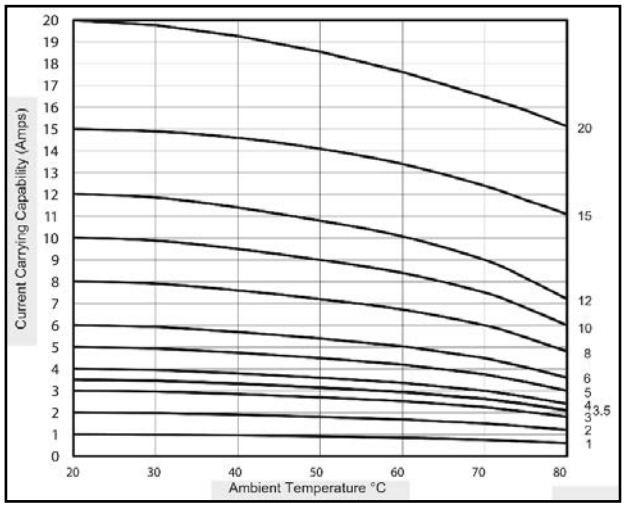
Combiner box - 6 string



Temp inside housings

- BT Consult conducted a study to determine the temperature inside housings for electrical equipment.
  - Findings were that internal housing temperature was between 8-10^{o}C higher than outside ambient temperature.
  - This value has reference to the fuse derating temperature as per the next slide.

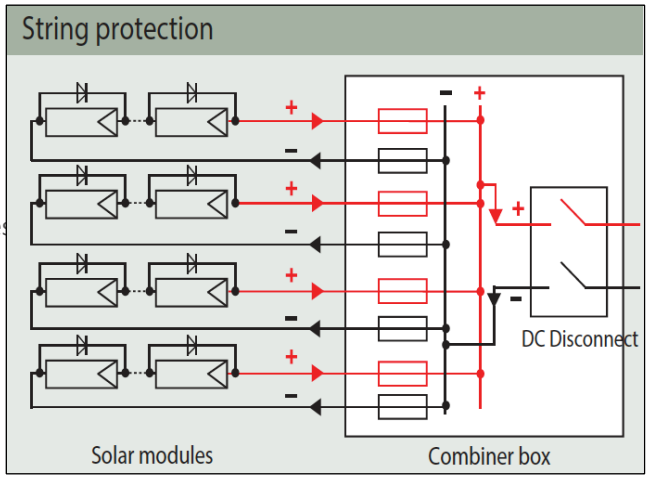
Fuse derating



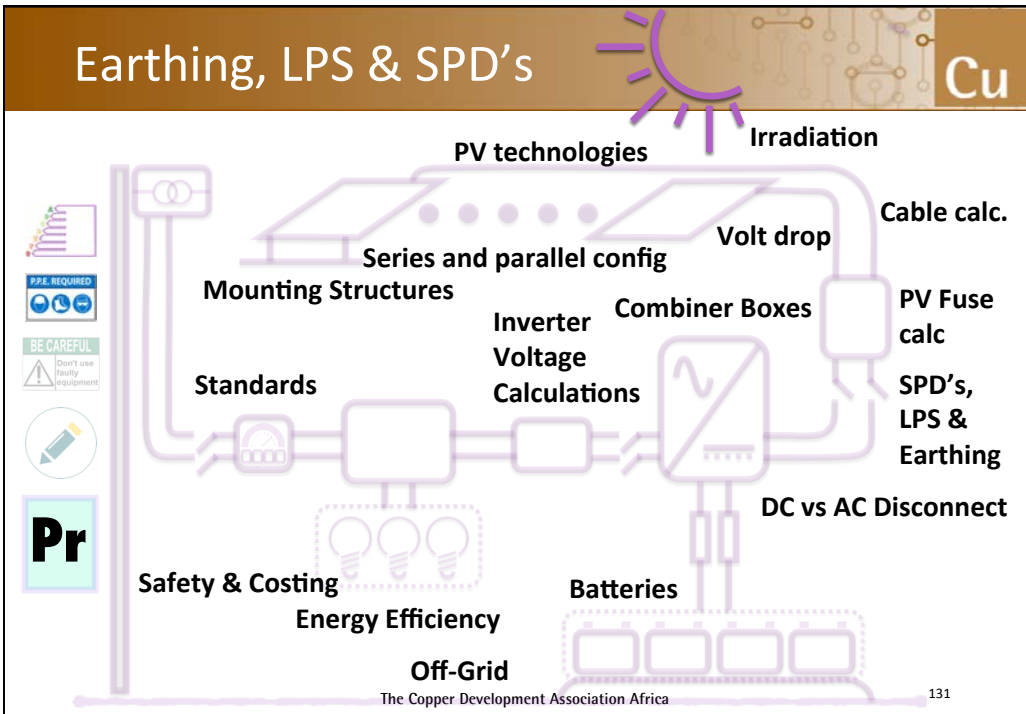
- Fuse calculations:
- I_{sc} x 1,56
  - Edge of cloud
  - Fuse Derating
- 1 string not required
- 2 string not required
- 3 string maybe
- 4 string yes
- (n-1)Isc * 1,25

Calculating String fuses

- Capability of the fuse should be
- Where
  - Voc = Open Circuit Voltage
  - Ns = Number of modules in a string
- Fuse Voltage Capability
  - = 1,2 x V_{oc} x N_s
- Current Capability
  - = 1,56 x Isc



Earthing, LPS & SPD's



Earthing / Grounding

- The simple definition of an earth is:
  - to connect the electric circuit or equipment to the earth's conductive surface.
- Systems are earthed because of:
  - personal safety and protection in the event of accidental contact
  - equipment safety and protection in the case of a lighting strike, surge and or fault conditions.

Earthing / Grounding

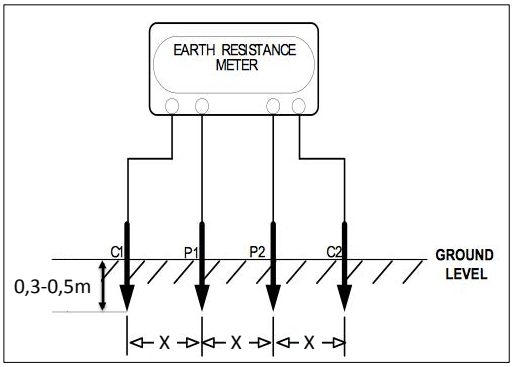
- Earthing can take the form of:
  - Simple spike in the ground
  - Multiple spikes in the ground
  - Mesh / Grid networks
  - Chemical Earth
- The type of earth chosen should match the application
  - Residential, Commercial, Agricultural
  - Grid tied vs Off-grid

Soil resistivity

- Soil resistivity values are critical to design an adequate earthing system and will show
  - to what extent the soil will resist the flow of electricity
- "Good" conductors have low resistance
- "Bad" conductors have high resistance
- "Very bad" conductors are used as insulators.
- Commonly used symbol for resistivity is Rho - "ρ"

Testing soil resistivity

- Wenner (4 Wire Test) Most commonly used
- Current is applied at C1 & then C2
- A potential is measured at P2 & then P1 across spikes
- X should be spaced equally



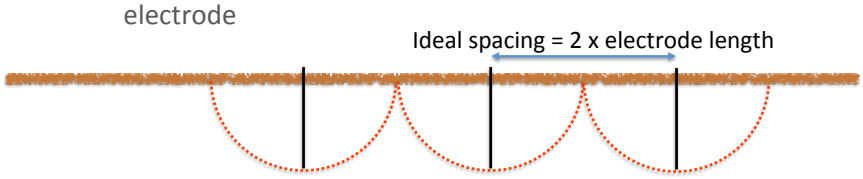
Soil resistivity & grounding (60325)

- Soil types
  - High alkalinity lowers soil resistivity and increases soil corrosivity.
  - Acidic soils are corrosive, neutral soils are optimal.

Type of soil	Ohm m (soil resistivity)
Very moist soil	*30*
Farming and clay soil	*100*
Sandy clay	*150*
Moist sandy soil	*300*
Concrete 1:5	*400*
Moist Gravel	*500*
Dry Sandy soil	*1000*
Dry Gravel	*1000*
Stoney Soil	*30000*
Rock	*10 000 000*

Earth Spikes

- The definition of a ground electrode is:
  - a conductor or group of conductors in intimate contact with the earth for the purpose of providing a connection with the soil.
- "Sphere of influence" is:
  - is commonly thought to be a radius around the ground rod equal to its length
  - Calculated where $V=5 \times L^3$ (simplified)
  - where V is the volume of soil and L is the depth of the electrode



Sphere of influence

- For additional earth spikes to be effective they must be installed outside of the other spike's sphere of influence.
- Ground Potential Rise
  - Occurs in the event of a large current induced into earth when the ground cannot immediately reduce the potential to Zero.

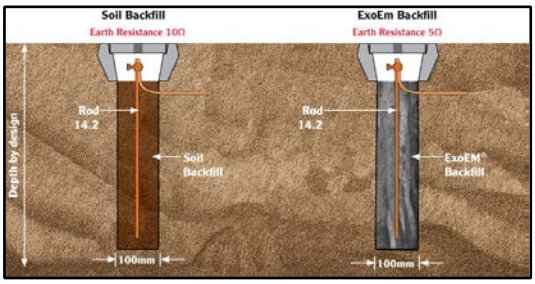
Earthing

- The quality of the earth is a function of:
  - Ground Temperature
  - Moisture
  - Salt content
  - Earth spike Diameter
  - Earth Spike depth
  - Number of spikes
  - Earth/Soil Type (clay, sand, stone)

- Values could change as a result of site conditions e.g. paving added to a parking area could lead to reduced moisture as water is guided away to storm water infrastructure

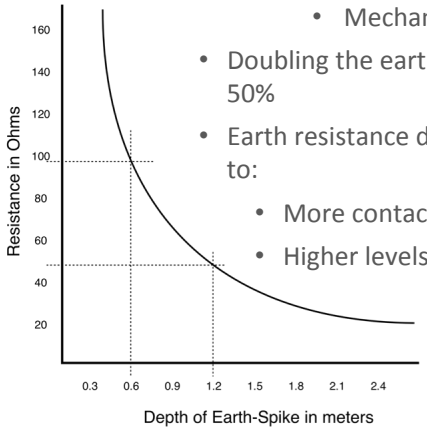
Earthing

- Chemical compounds to improve grounding
  - Chemically treat the soil (Chemical earth) use Magnesium chloride (Not Sodium chloride)
  - Bentonite(white premixed solution), Mitronite (carbon / charcoal), ExoEm Backfill



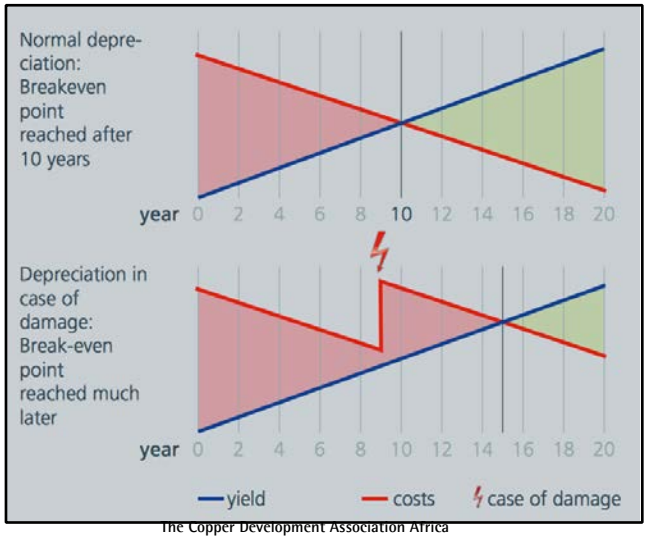
Improving Grounding

- Doubling the earth spike diameter reduces resistance by 10%
  - increases material usage X4. (Not cost effective)
  - Unless it is done for
    - Mechanical strength or Durability (acidic conditions)
- Doubling the earth spike length reduces resistance by 40 – 50%
- Earth resistance decreases with depth of electrode in soil due to:
  - More contact with soil
  - Higher levels of moisture

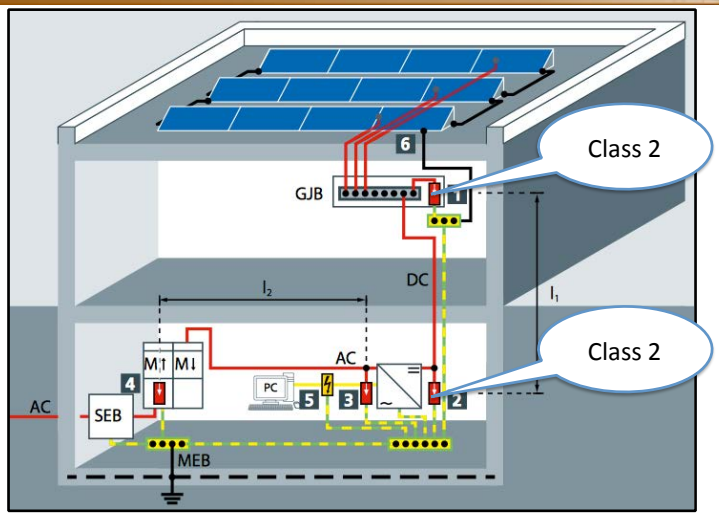


Why use Surge Protection

- Courtesy DEHN

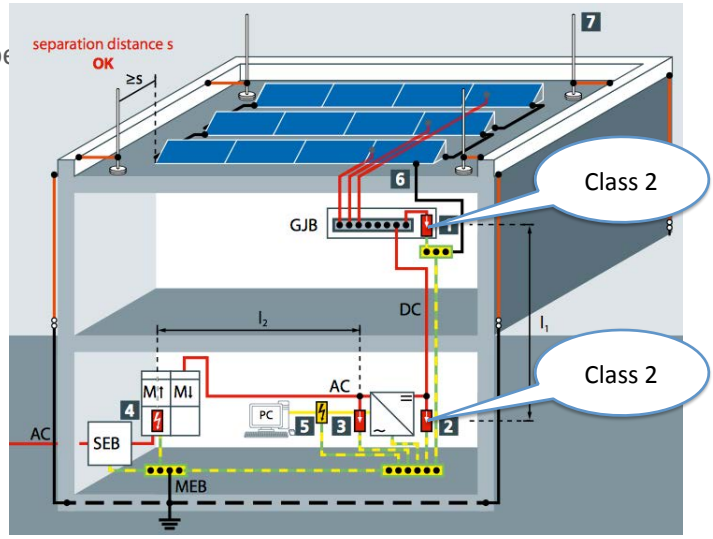


Surge protection without LPS (62305)

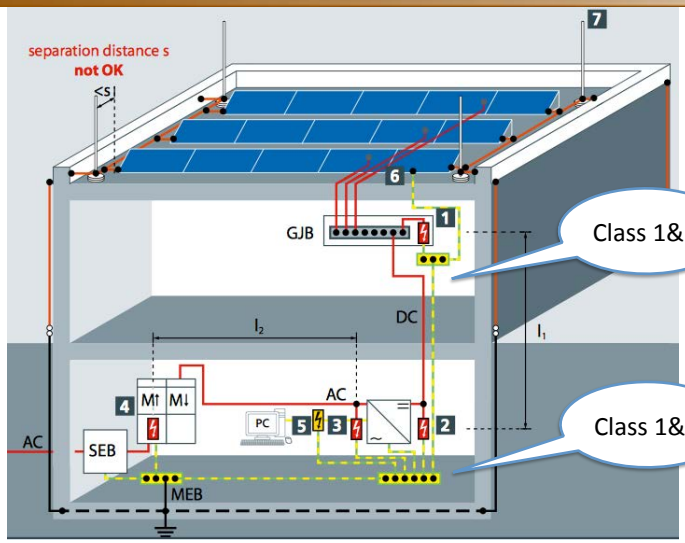


Surge Protection with LPS

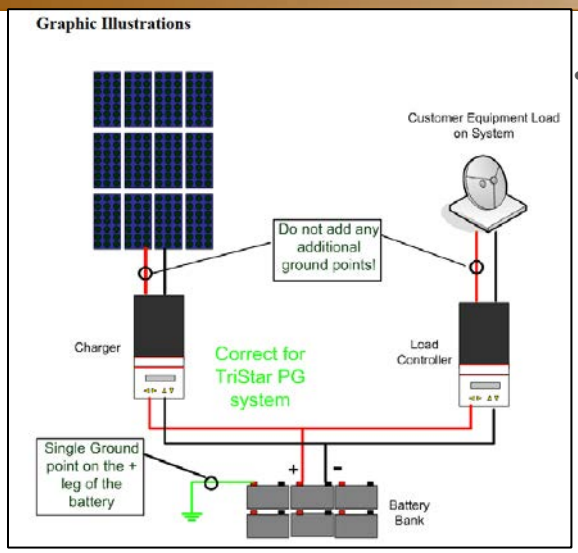
- Sepe



Surge Protection with LPS



TS 45 Tristar – Positive Grounding

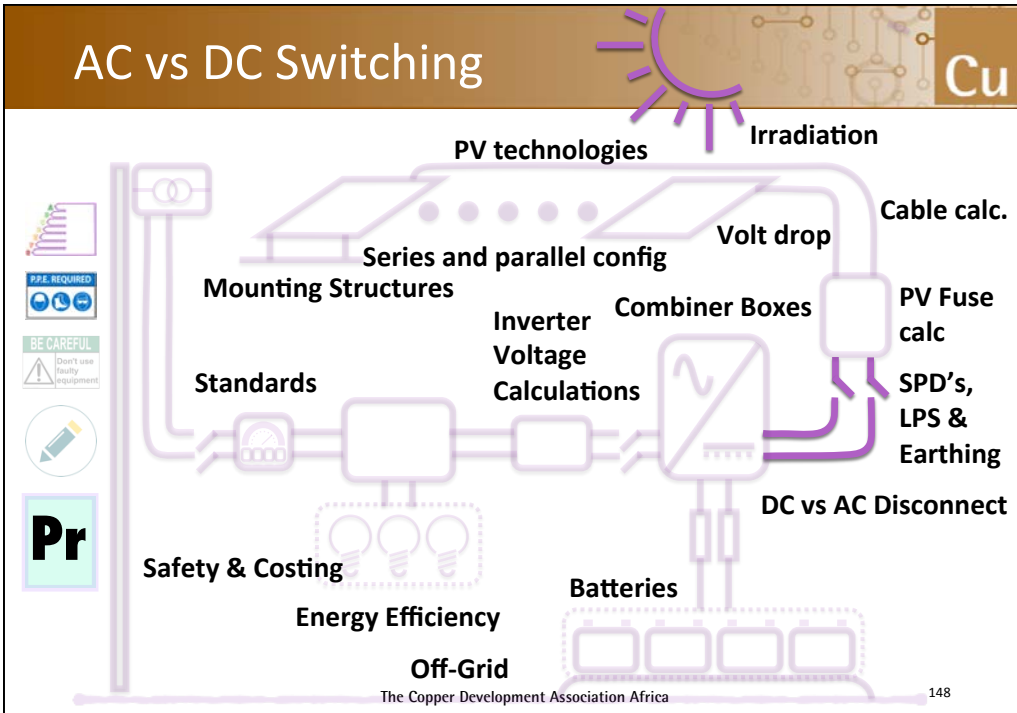


- Telecoms requirement = positive grounding

Summary - Earthing / Grounding

- SPD's before and after inverter
- Class 1 & 2 when separation distance is not OK
- The maximum fault current is calculated / estimated
- Then the maximum fault current through a single earth spike is calculated
- And then the minimum number of earth spikes are calculated based on the available information over a 1 or 3 second dissipation period

AC vs DC Switching



Breaking the current

- Fuse Wire / Fuses – Melt or disintegrate
- Circuit breakers
  - Can be reset
  - Do not use a CB with an AC rating on a DC Circuit

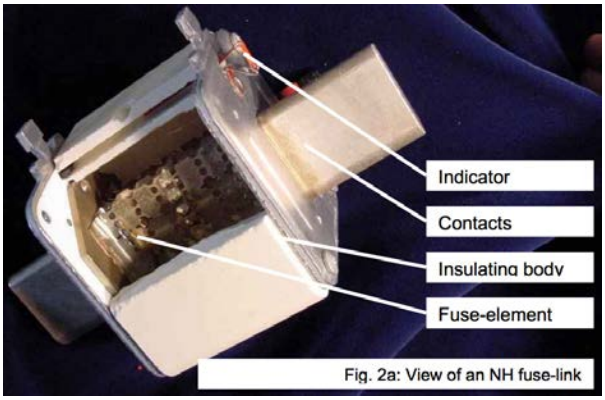
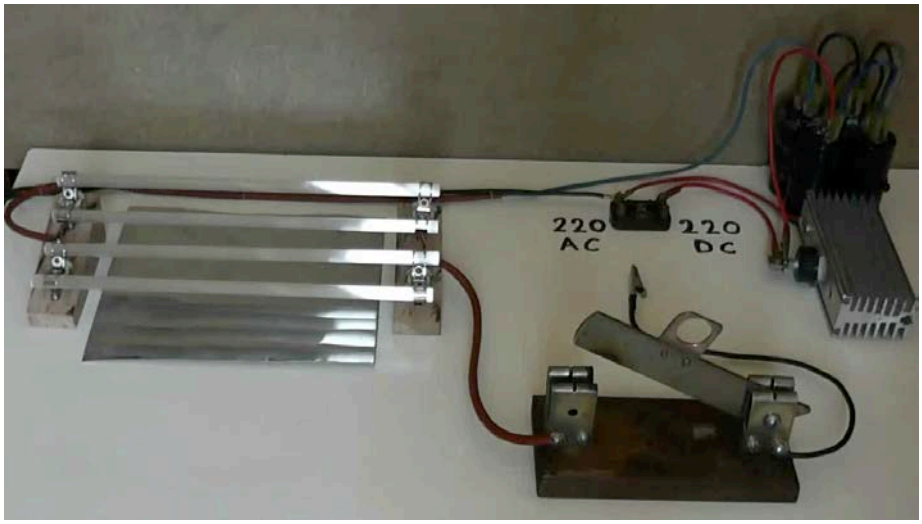


Fig. 2a: View of an NH fuse-link

Circuit breakers

- Difference between AC & DC CB's
  - How they extinguish an arc
    - Arc chutes may be spaced further apart.
  - Whenever a load is connected and disconnected, an arc is produced.
  - The arc generated in DC is much larger than AC.
  - AC Breakers not rated for DC will fail in a DC network
  - Technical term is 'spark gap technology'

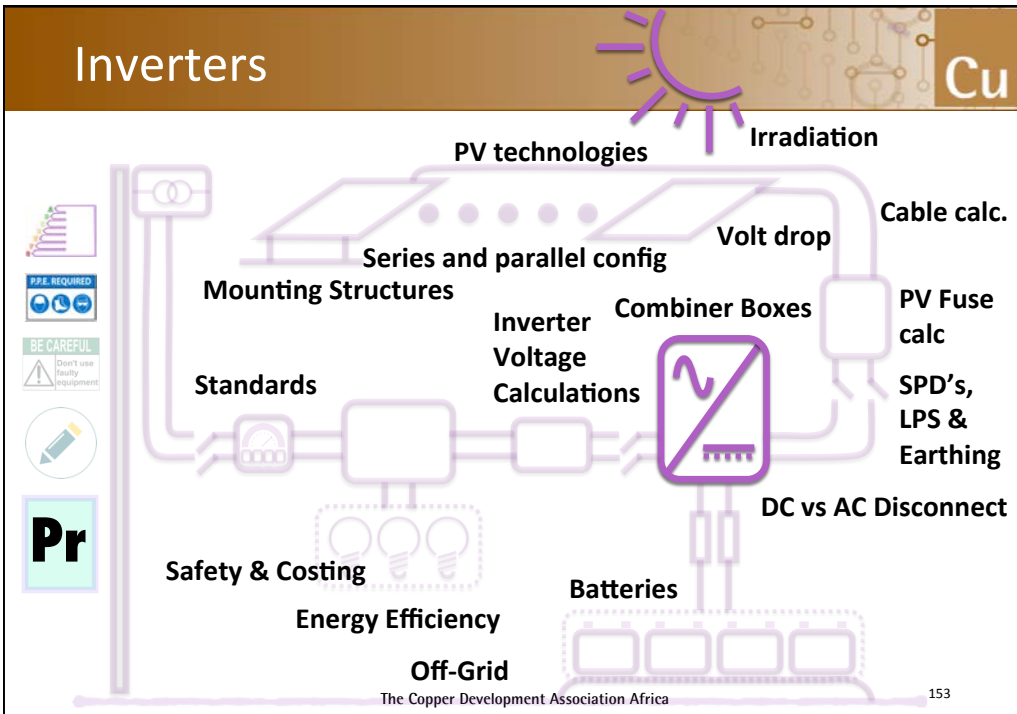
The difference in breaking AC & DC - video



Arc Flashes

- 5 to 10 arc explosions occur in electric equipment in the U.S. every day
- More than 2000 people are treated annually in burn centers with arc flash injuries
- Arc Flash cause numerous deaths each year. Deaths from arc flash has been on the decline due to safety training, regulations, PPE and proper labeling of equipment.
- Electrical arcs produce some of the highest temperatures known to occur on earth, up to 19426_oC which is 4 X the temperature of the surface of the sun.
- All known materials are vaporized at this temperature which causes a sudden expansion of air. Blast pressure waves have thrown workers across rooms.
- Arcs spray molten droplets of metal at speeds that exceed 1120km/h which can easily penetrate the body.
- Fatal burns can occur even more than a meter away with clothing being ignited up to 3 meters away.
- The arc blast can have a sound magnitude of 140dB at a distance of 60cm from the arc resulting in hearing loss.
- Arc flash can be caused by something as simple as a rodent, tool or other element in the breaker area which compromises the distance between energized components,
- 2 out of 3 electrical injuries are the result of inappropriate action of a worker.

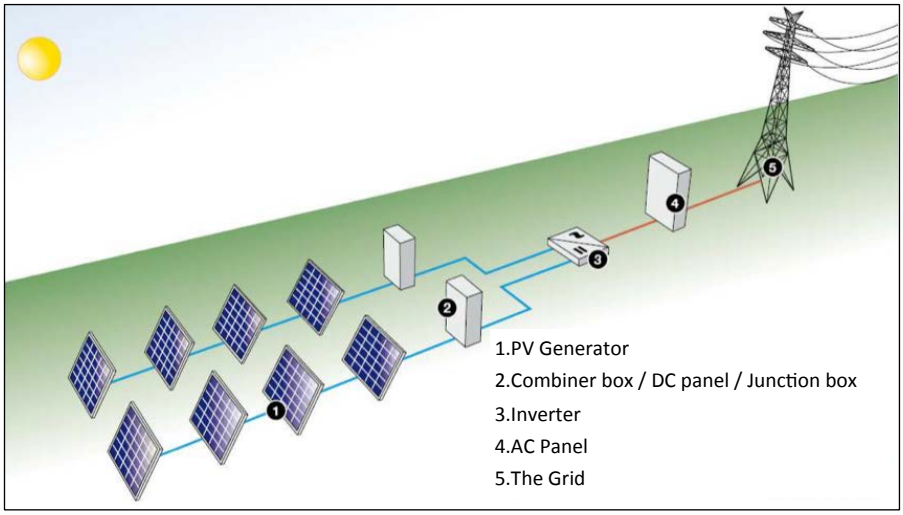
Inverters



Inverter Range

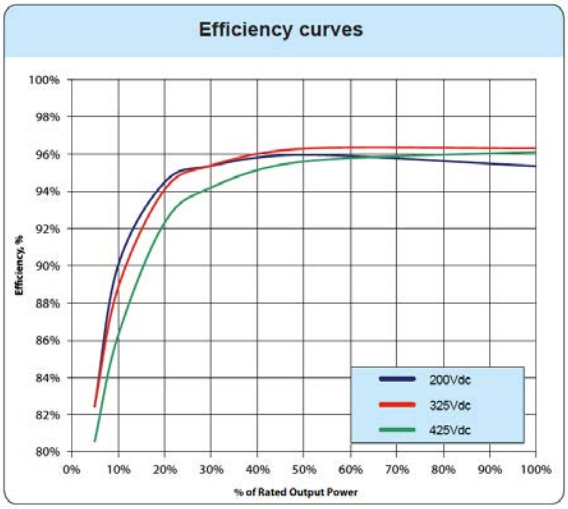
- **Grid-Tied**
  - Micro vs Power Optimiser
    - Optimised AC vs Optimised DC
  - String
    - Standard & Hybrid
  - Centralised (150kW+)
- **Off-grid**
  - Modified sine wave
  - Pure sine wave

Grid tied inverter Basic network structure

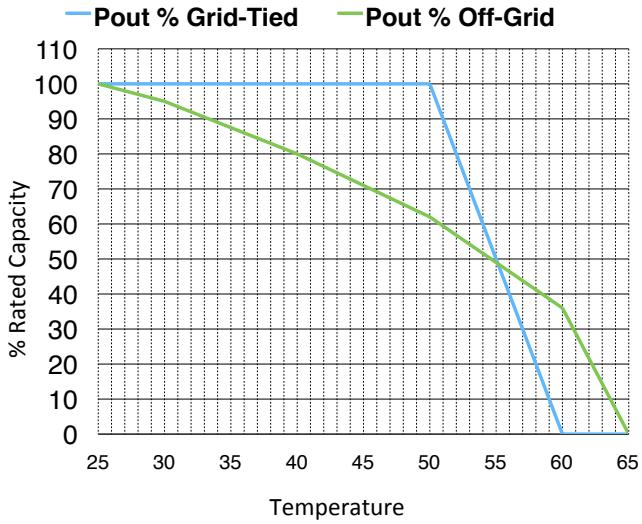


Grid tied Inverter Efficiency

- Suppliers claim high efficiencies, note that the efficiency is related to the % output power vs Input voltage



Inverter Characteristics at Temp



- Both types will only deliver 50% of the rated capacity at 55°C

MPPT inputs

- Take care to ensure correct input topology
- Check string inputs vs MPPT inputs.

Consumer point of supply

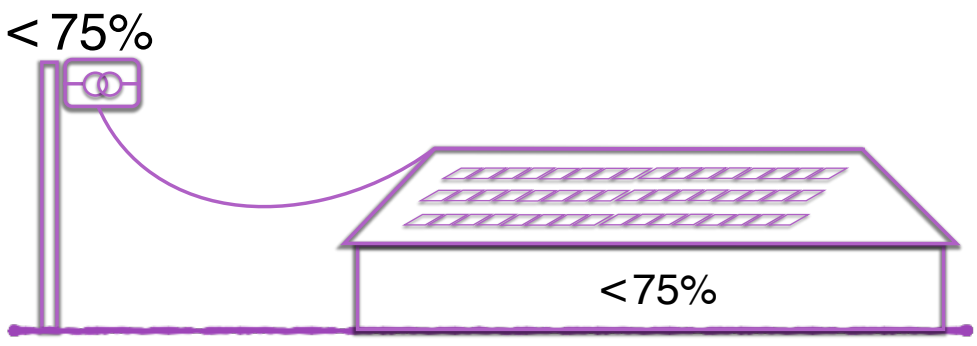
Maximum Solar PV system sizes

Domestic Grid tied installations

Table 1 — Maximum individual generation limit in a shared LV (400 V/230 V) feeder

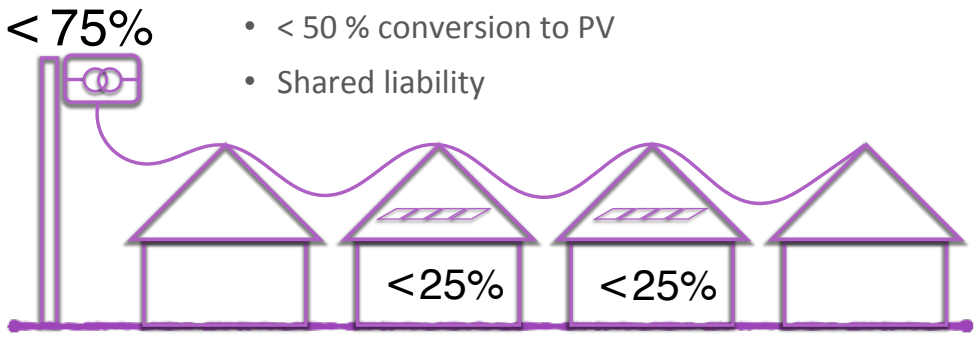
1	2	3	4
Number of phases	Service circuit-breaker size	NMD kVA	Maximum individual generation limit kVA
1	20 A	4,6	1,2
1	60 A	13,8	3,68
1	80 A	18,4	4,6
3	60 A and 80 A	41,4	13,8 (4,6 per phase)

Dedicated Feeder NRS 097

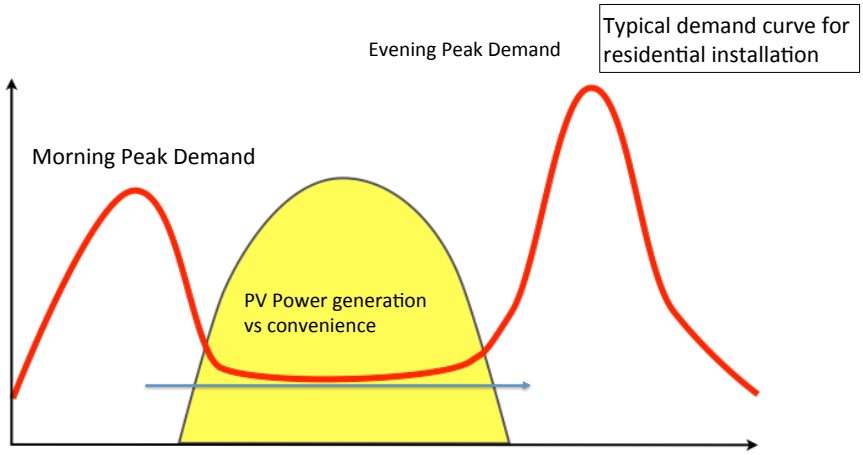


Shared Feeder NRS 097

- Maximum PV System sizes
- LSM > 7
- < 50 % conversion to PV
- Shared liability

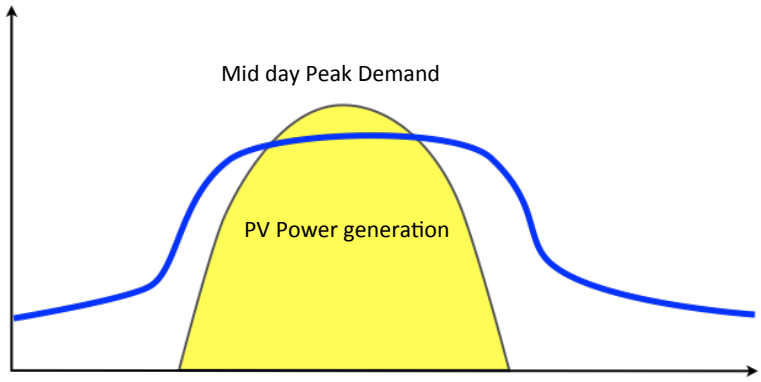


Inverter / system size selection



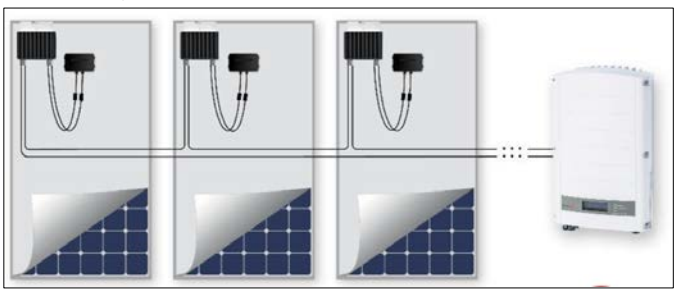
Inverter / system size selection

Typical demand curve for office block installation

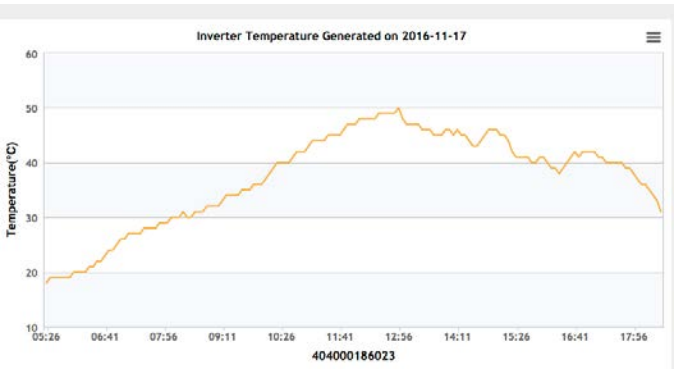


Power Optimizer

- Maximised DC generation sent to inverter (SolarEdge)
- Data logging: https://monitoringpublic.solaredge.com/solaredge-web/p/home/public?locale=en_US
- Distributed by:
  - Maxx, Rubicon, Kathea, Dako, Enel,
  - Segen, Elcosmea, Greenbuilt



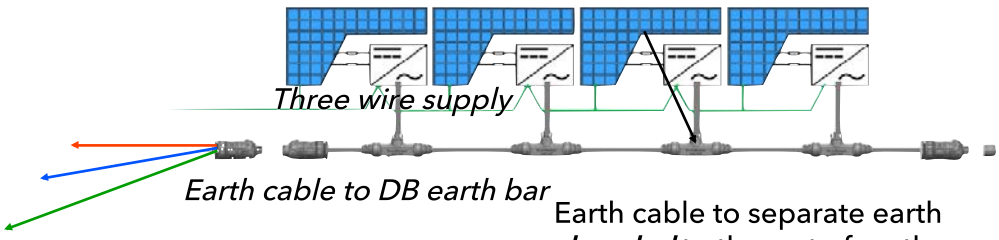
Micro Inverters - Grid tied



- Variety of archite
  - Individually f
  - Clustered
- Increase charging efficiency especially in shaded areas
- Changes DC to AC at the point of generation
- Aimed at reducing installation and cabling cost.

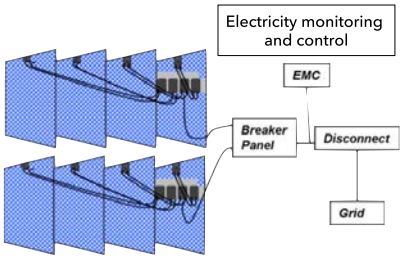
Micro inverters (individual) string

- Yingli (APS), ITS, Bright Black (Enphase), Genergy, Tigo, IEnergy (EcoSales)
- String connected in parallel
- Max 4,8kW on a string depending on brand



Grid tied

- Micro cluster



String inverters - General

- Connects in parallel to mains
- Inverter startup voltages and currents vary depending on brand
- Synchronization to the grid occurs automatically
- In terms of capacity there is no limit to the number connected to the mains
  - Electrical infrastructure may limit max. number of inv in parallel
- Power produced is limited to the lowest output panel as a result of the series string configuration

String inverters

- Kaco has 900 inverters connected in parallel in the Northern Cape onto a single installation
  - –Only 31 inverters can be connected onto Management system
- Largest local available string inverters = 60kW(Kaco)
- A utility plant in Northern Cape has 300 x 250kW inverters in parallel
- Clearwater mall & JSN Motors

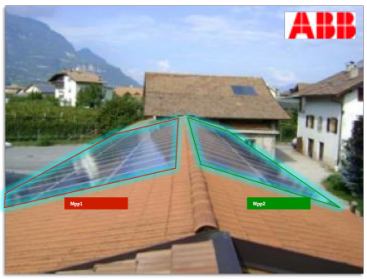
String inverters

- JFY Grid tied inverter

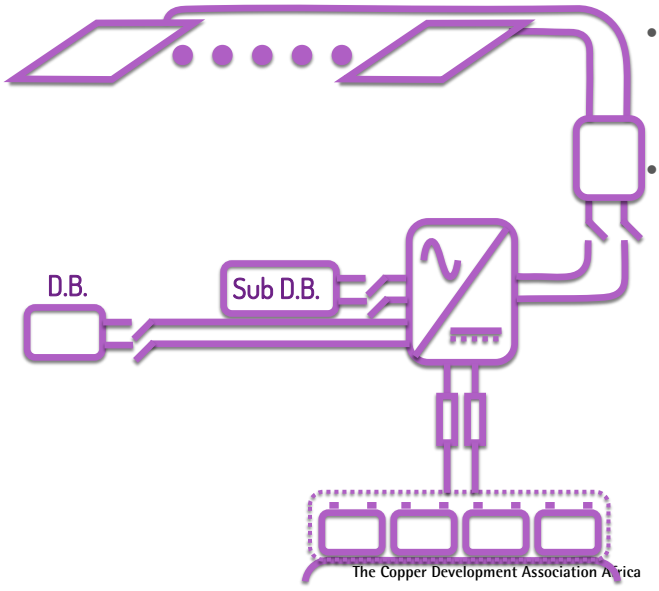
MODEL	JSI-1100TL Pro
Max. DC Input Power(W)	1250
Max DC Voltage(Vdc)	450
MPPT Operating Range(Vdc)	60~450
Number of Parallel Inputs	1
Number of MPPT Trackers	1
Max. Input Current(A)	12
Nominal Output Power(W)	1100
Max. Output Power(W)	1100
Nominal Output Current(A)	4.8
Max. Output Current(A)	5.7

Double MPPT

- Strings with varying orientation
- 2 Strings with modules from different manufacturers
- Data logging Rubicon CT
  - http://home2.solarlog-web.com/plants.html?c



Hybrid Inverter

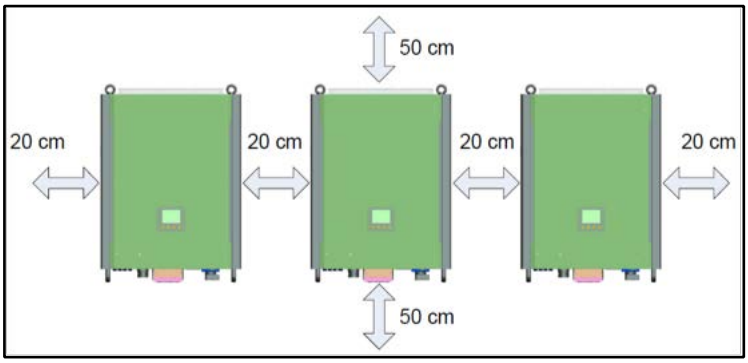


- Basically a string inverter with Battery charging capacity
- Limited battery storage
  - Imeon, Infini, Goodwe
  - Luminous, Schneider
  - Ingeteam

Hybrid inverter

Infini

- 5kW 1 phase up to 6 units parallel output
- 10KW 3 phase up to 3 units parallel output



Hybrid inverter

Imeon 3.6

SOLAR INSTALLATION	
Maximum input power	3150 W
Start-up voltage	150 V
Number of MPPT inputs	1
MPPT voltage range	120V – 450V
Maximum input current	18 A
Maximum input voltage	510 V
Maximum efficiency	DC to AC : >95,5% (94,5% EU)
Solar production use	Programmable priorities (PV / Storage / Grid)

Observe maximum capacity by multiplying Max input current and max input voltage

Battery Charging

- Very important for the Hybrid background settings.
  - Adjust the cable resistance in order to ensure the correct charging voltage.
  - Some can be paralleled up to six units.
  - Some can be controlled not to feed back into the grid (Grid-Limiting)
    - Additional equipment
      - Meter
      - Modbus
      - costs about R4k

Bi Directional Chargers

- MPPT's can be added to increase charging capacity

- Courtesy suncolect.com

Bi-directional chargers

- Bi-directional charging
- 2 x 5kW Axpert inverters paralleled
- Master vs slave config

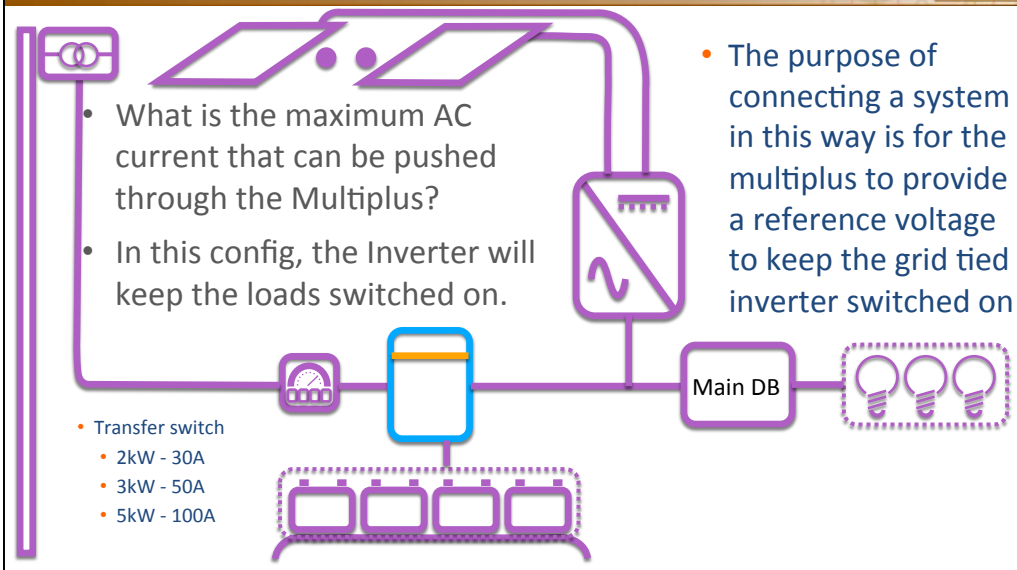
Axpert parallel installation

- Disadvantages
  - Instruction manuals do not provide adequate information
- Advantages
  - Inexpensive
  - Very few returns
- Available in the market under various brand names
- Courtesy BlueSun Solar EC

Grid & Off Grid System integration

- Grid tied inverters with charger where the output frequency shift can be manipulated
- Use a grid tied inverter synchronized to a configurable charger to produce a “hybrid” solution.

AC Coupled Grid tied inverter

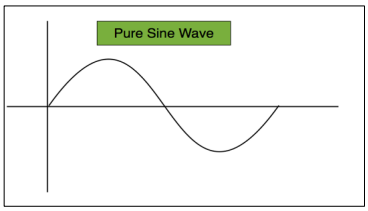


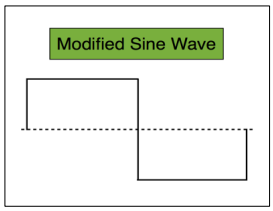
- What is the maximum AC current that can be pushed through the Multiplus?
- In this config, the Inverter will keep the loads switched on.

- The purpose of connecting a system in this way is for the multiplus to provide a reference voltage to keep the grid tied inverter switched on

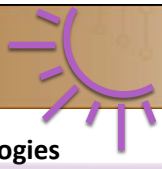
Off-grid Inverters

- Usually this sign is what you see when you buy an off-grid inverter
- Modified sine wave inverters do not always produce good results with different types of electronic equipment.





Support Structures



PV technologies

Irradiation

Cable calc.

Volt drop

Series and parallel config

Mounting Structures

Inverter Voltage Calculations

Combiner Boxes

PV Fuse calc

Standards

SPD's, LPS & Earthing

DC vs AC Disconnect

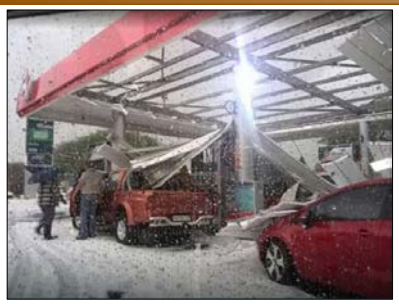
Safety & Costing

Batteries

Energy Efficiency

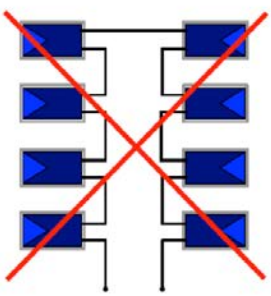
Off-Grid

Understand the risk

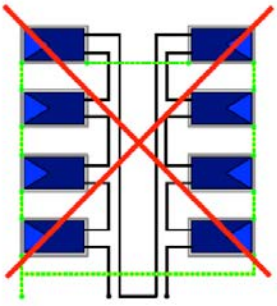


Avoid loops - Induced voltages

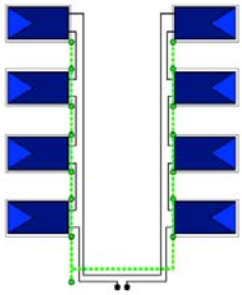
Avoid inductive loops



Loop between polarities



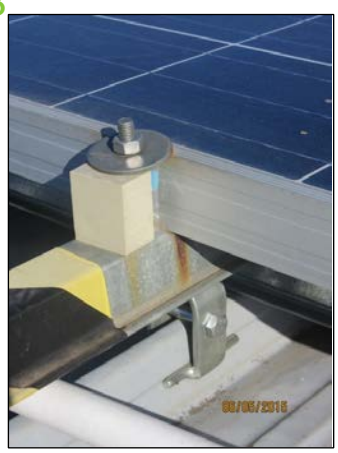
Loop between one polarity and grounding



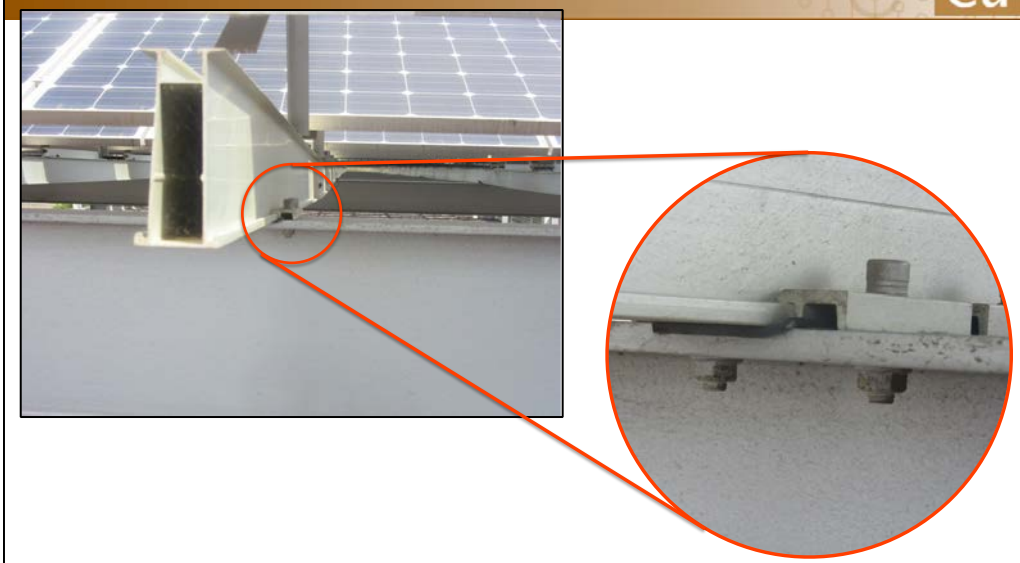
Correct wiring

Bi-Metallic reactions

8 month old installation - JHB



Magnet group Durban - Insulated H/W



Support systems - Industry trends

- Aluminium/stainless brackets coastal
- Galv/aluminium inland

Support systems – Klip-lok roofing

Custom made - Midrand Mustek

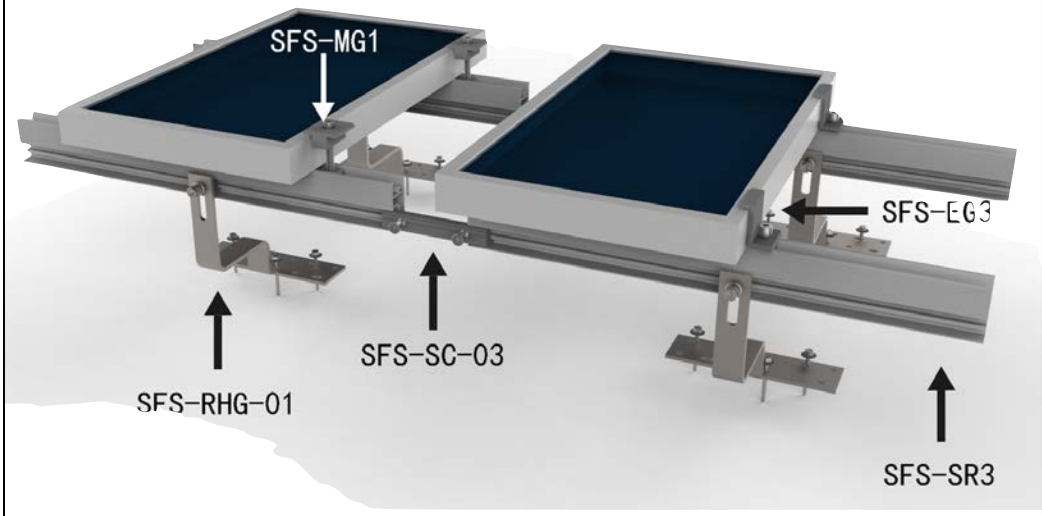
Safintra - Clearwater Mall

System in Kyalami

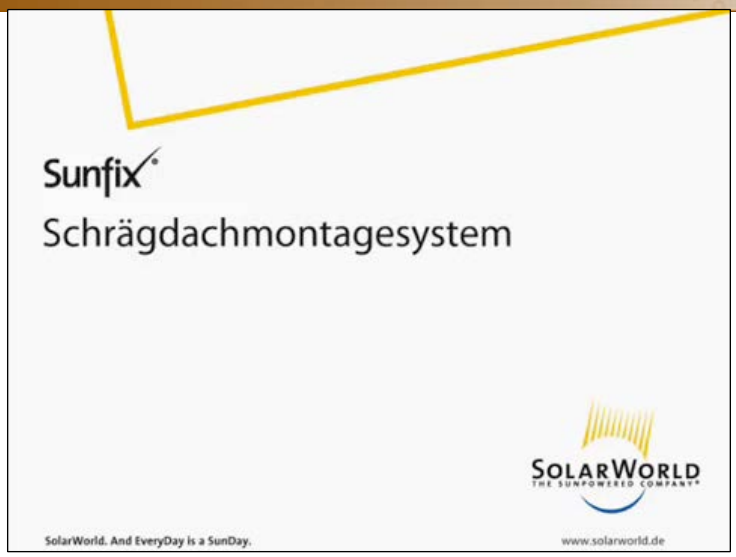
PowAsnap - ARaymond - Video

[redacted]

Mounting structure codes



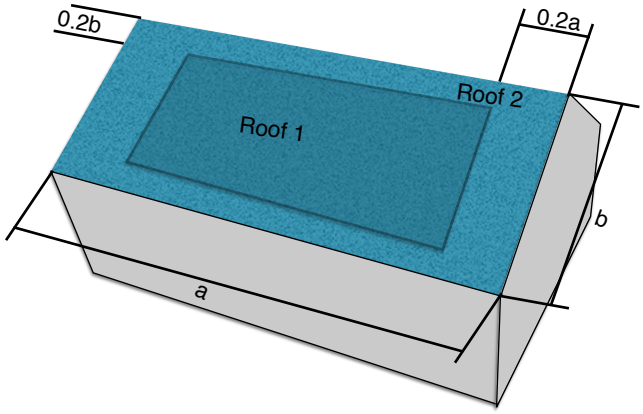
Structural support and fitment



- Pitched roof structural support
- Video by Solarworld

Spacing and support calculation

The diagram below shows the area of higher wind loadings within 0.2a and 0.2b of a roof edge or ridge



Roof design - Pitched roof

- The Wind Region has nothing to do with surrounding topography or buildings.
- · Most area is designated Region A which indicates a Regional Ultimate Basic Wind
- Velocity of 45msec.
- · Some areas are designated Region B (57msec). Local authorities will advise if this
- applies in your area.
- · Region C areas (66msec) are generally refered to as Cyclonic .Most Region C zones
- end 100km inland.
- · Region D (80msec) is worst Cyclonic Region

SunRack Pitched Roof Planning and Installation Guide

Roof height	Wind Region A		Wind Region B		Wind Region C		Wind Region D	
	Roof 1	Roof 2	Roof 1	Roof 2	Roof 1	Roof 2	Roof 1	Roof 2
5 meters	2130	1500	1690	1200	1380	980	1080	
10meters	1940	1370	1540	1090	1260	890	990	
15meters	1840	1230	1460	980	1190	800	940	
20meters	1740		1380		1130		890	

Roof design - Flat corrugated iron roof

- The Wind Region has nothing to do with surrounding topography or buildings.
- · Most area is designated Region A which indicates a Regional Ultimate Basic Wind
- Velocity of 45msec.
- · Some areas are designated Region B (57msec). Local authorities will advise if this
- applies in your area.
- · Region C areas (66msec) are generally refered to as Cyclonic .Most Region C zones
- end 100km inland.
- · Region D (80msec) is worst Cyclonic Region

Roof height	Region A&B		Region C		Region D	
	Roof 1	Roof 2	Roof 1	Roof 2	Roof 1	Roof 2
5 meters	1320	990	770	550	770	
10meters	1200	900	700	500	700	
15meters	1140	810	665	450	665	
20meters	1080		630		630	

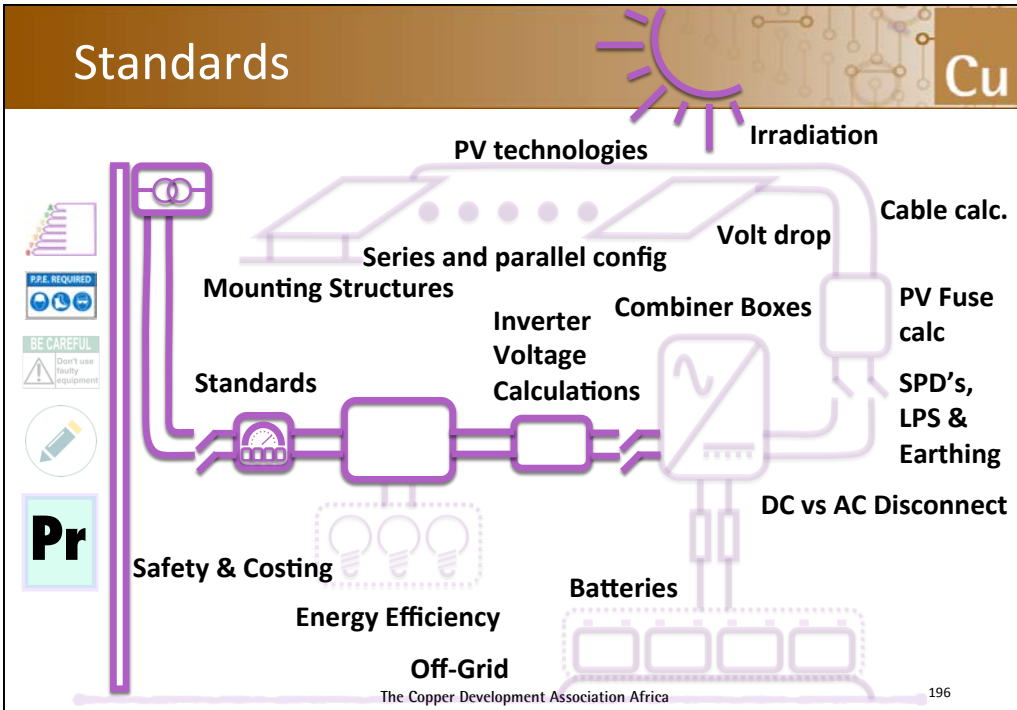
Spacing and support calculation

P6 RAIL

WIND SPEED (KPH)*	SPAN/ CANTILEVER (M) KPH	0		49		98		147	
		SPAN	CANTILEVER	SPAN	CANTILEVER	SPAN	CANTILEVER	SPAN	CANTILEVER
	144	1829	914	1524	813	1372	660	1219	610
	160	1524	813	1473	711	1219	610	1168	584
	176	1473	711	1372	660	1219	610	1118	559
	192	1372	660	1372	660	1168	584	1067	533
	208	1219	610	1219	610	1118	559	1016	508

- Preformed Line Products
- Aluminium Rail

Standards



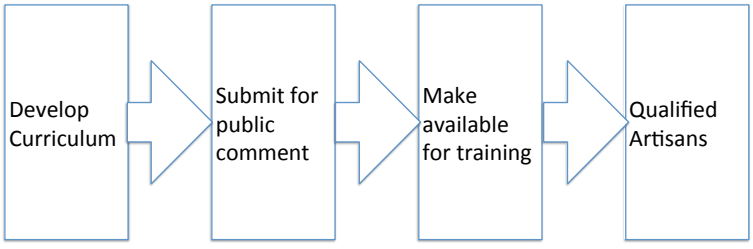
Solar PV Service Technician(Separate Trade)

1. Occupational Tasks

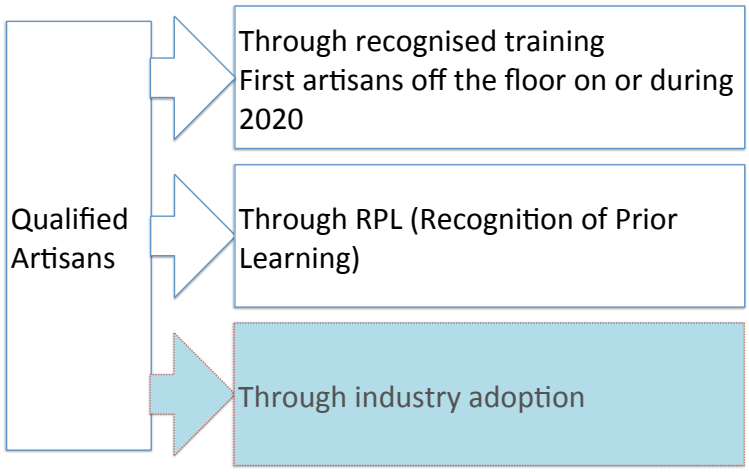
2. Planning and preparing for maintaining, testing, diagnosing, repairing and replacing PV system electrical and mechanical components (Level 4)
3. Inspecting, testing, diagnosing, replacing and maintaining PV panels (Level 5)
4. Inspecting, testing, diagnosing, replacing, repairing and maintaining inverters in PV systems (Level 5)
5. Inspecting, testing, diagnosing, replacing and maintaining batteries and charge controllers and repairing charge controllers in PV systems (NQF Level 5)
6. Inspecting, testing, diagnosing, replacing, repairing and maintaining transformers in PV systems (Level 5)
7. Inspecting, testing, diagnosing, replacing and maintaining cables, cable inter-connections, smart boxes, PV junction/string boxes, string diodes, connectors and fuses in PV systems (Level 5)
8. Inspecting, testing, diagnosing, replacing, repairing and maintaining switchgear and control gear in PV systems (Level 5)

Merseta Occ nr.313109001 Process

Simplified Training Process



Merseta Occ nr.313109001 Process



How do i qualify as an electrician

- Influx of diverse range of occupations in energy sector
  - Many not skilled in electrical trade
- RPL vs standard apprenticeship route
  - 4 years experience with >N2 Electrical
  - 6 years experience with no academic electrical background
- Merseta, Ceta, EWseta
  - Same certificate & Red Seal
- Register with D.o.L
  - = single phase tester
- Electrical trade = N4
  - Unlocks more opportunities, i.e. N4 electrical academic online

Legal, Standards & Regulatory Framework

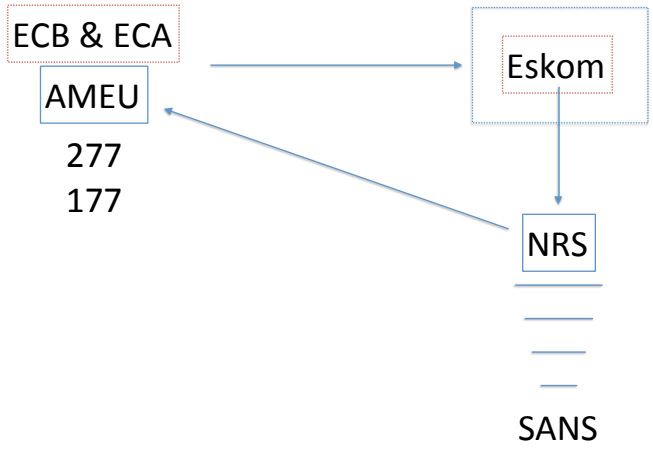
- Line diagram
- Commissioning report
- Standard operating procedure
- Maintenance Procedure
- Lock out or disconnection procedure
- Electrical C.o.C

Compulsory Standards related to solar

- LOA's are required by all manufacturers and importers of commodities that fall under the scope of the compulsory specifications prior, to the sale of the product.

- National Regulator for Compulsory Standards
  - Letter Of Authority
- SANS IEC 61010 - Safety requirements for electrical equipment for measurement,control and laboratory use
- SANS IEC 61558 - Safety requirements for power transformers, power supplies,reactors and similar products
- VC8075 - Compulsory Specification for the Safety of Electric Cables with Extruded Solid Dielectric Insulation for Fixed Installations (300/500V to 1900/3300V)
- VC8077 - Compulsory Specification for the Safety of Medium-Voltage Electrical Cables.

Solar standards developed by Utilities



Labelling - NRS 097-2-1:2010

- 4.2.7 Labelling
- 4.2.7.1 A label on the distribution board of the premises where the embedded generator is
- connected, shall state: “ON-SITE EMBEDDED GENERATION (EG) CONNECTED. THE EG IS
- FITTED WITH AN AUTOMATIC DISCONNECTION SWITCH WHICH DISCONNECTS THE EG IN
- THE CASE OF UTILITY NETWORK DE-ENERGIZATION.”
- 4.2.7.2 The label shall be permanent, coloured red, and with white lettering of height at least 8 mm.

Harmonics - NRS 097-2-1:2010

- 4.1.6.4 Total harmonic current distortion shall be less than 5 % at rated generator output in accordance with IEC 61727. Each individual harmonic shall be limited to the percentages listed in table 1.

Current distortion limit as a function of harmonics (Source: IEC 61727:2004)

1	2
Odd harmonics	Distortion limit
3rd through 9th	Less than 4,0 %
11th through 15th	Less than 2,0 %
17th through 21st	Less than 1,5 %
23rd through 33rd	Less than 0,6 %
Even harmonics	Distortion limit
2nd through 8th	Less than 1,0 %
10th through 32nd	Less than 0,5 %

Utility compatibility – NRS 097-2-1:2010

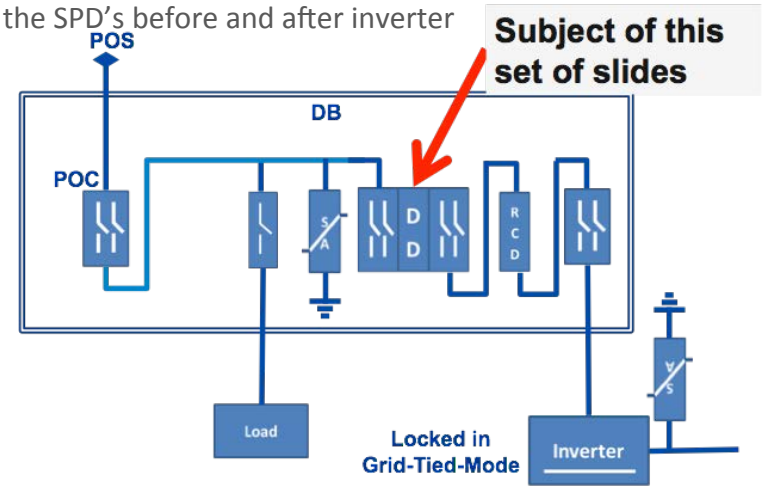
- 4.1.1.6 The maximum size of the embedded generator is limited to the rating of the supply point on the premises.
- 4.1.1.7 Embedded generators larger than 10 kW shall be of the three-phase type.
- A customer with a multiphase connection shall split the embedded generator over all phases if the EG is larger than 6 kW.

Synchronisation - NRS 097-2-1:2010

- 4.1.8.2 Automatic synchronization equipment shall be the only method of synchronization.
- 4.1.8.3 The limits for the synchronizing parameters for each phase are
- a) frequency difference: 0,3 Hz,
- b) voltage difference: 5 % = 11,5 V per phase, and
- c) phase angle difference: 20°.

RCD Type B

- Note the SPD's before and after inverter



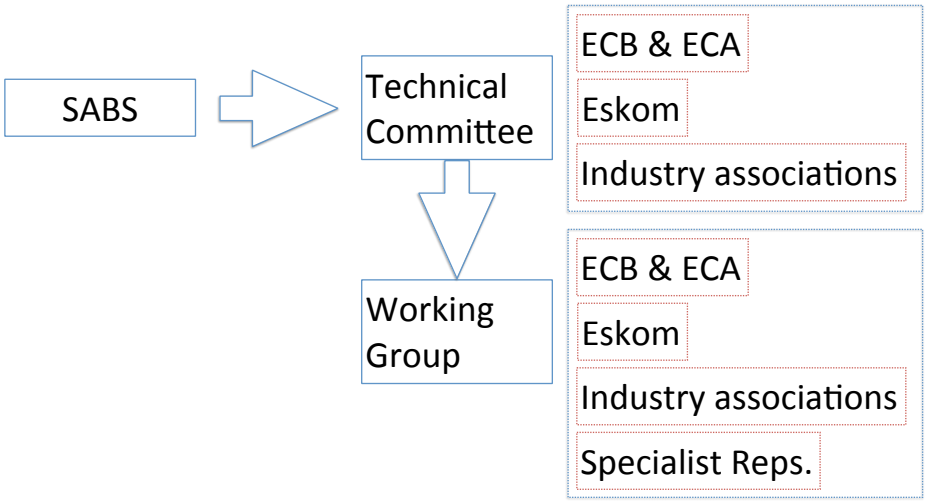
NRS Standards applied

- https://www.capetown.gov.za/en/electricity/Application%20Forms/Approved%20Photovoltaic%20%28PV%29%20inverter%20ito%20NRS%20097-2-1-2010%20%2802%20Nov%202015%29.pdf

K502525870001	RCD or RCM Type B required on supply side
K502525870001	RCD or RCM Type B required on supply side
K502525870001	RCD or RCM Type B required on supply side

- Product: KLNE
- Model: Solartec D15000
- Test House: TUV Rheinland
- Requirement: RCD Type B required on the supply side

Solar standards developed by Industry

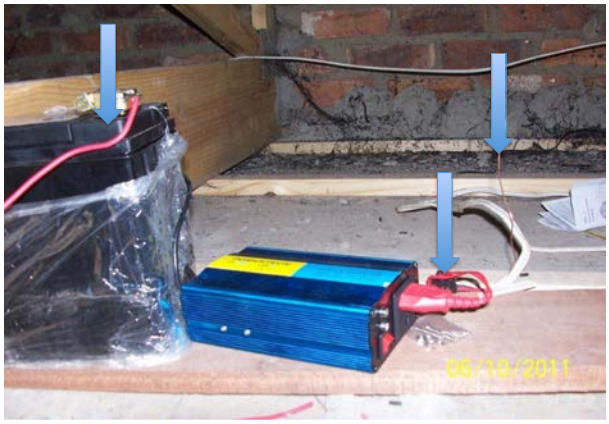


Standards being developed by industry

- The adoption of IEC 60364-7-712
- SANS 61215 PV Module standard
- SANS 62040
- Local standard development ?
  - Same colour cable on DC
  - DC Fuse size calculation
  - Testing procedure on PV
  - Additional DB
  - Surge protection before and after
  - Level of electrician to sign-off battery installations
    - Hazardous locations

Photos of faulty installations

How not to install a PV system



- No earth leakage
- Battery stored in ceiling +50'C
- No earthing
- Incorrect cable termination
- Wire sizing?

Source: www.pqrs.co.za

How not to install a PV system

- We can see:
  - Shade to the left of the panel
  - Standard twin & earth used
  - Top left cable going through the roof material

Source: www.pqrs.co.za

How not to install a PV system

Source: www.pqrs.co.za

How not to install a PV system

- Wood as a mounting structure(EVA - EC)
- Overlap & overhang(MP)

Source: www.pqrs.co.za

Solar Panels can burn

Source: www.pqrs.co.za

Loose fitted modules

- Hoop Iron used to support Modules

Source: www.pqrs.co.za

Electrical safety and maintenance

- Copper pipe used as lugs
  - Photo taken in the Eastern Cape

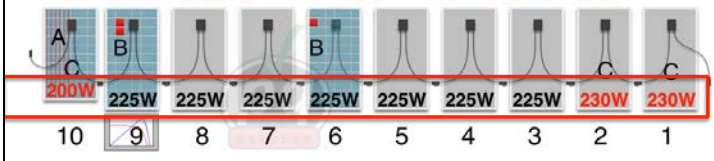
- O & M
  - Cleaning and access?

Source: www.pqrs.co.za

Actual installations Northern Cape

Source: www.pqrs.co.za

2kWp system Somerset West



•Growing culture in SA to use optimizers in order to compensate for shading, hence shading is deemed to be "acceptable".

Module mismatch in string inverter
Module sizing should be equal.
Performance severely affected

O&M
Domestic environment do not buy into maintenance agreements, sell remote monitoring device in order to monitor performance periodically

Source: www.pqrs.co.za

12kWp System Kyalami - Cable sizing & Termination

- MC4 couplers were cut and ferruled in order to parallel modules
  - Not recommended as this may negate module warrantees.
  - May affect O&M, testing & product durability

SANS 10142-1 6.2.5.2 Once current-carrying capacity has been determined and correction factors had been considered, carry out voltage drop calculations to determine voltage drop which should be within the allowed 5 %. (very inefficient for PV systems)

Good PV Practice suggests 1-3% (volt drop)	Electrical Installation Standard accepts 5%

Source: www.pqrs.co.za

The Copper Development Association Africa

30kWp system Franschoek

Unintentional shading
Lack of knowledge

Module life possibly affected by long term overheating of cells due to shading

O&M
Apart from design, this section of the installation can't be inspected or maintained with ease, consider leaving space to move between modules.
No spacing between modules makes visual inspection difficult

Row spacing inadequate,
12 X 300W modules producing 400W

Source: www.pqrs.co.za

The Copper Development Association Africa

250kWp system JHB

All shaded modules are part of the same string

Source: www.pqrs.co.za

Intentional shading

The engineer involved in this project combined the same modules affected by shade into the same string

Although deemed good from a design point of view. Could affect long term life & performance of

O&M
Neighboring construction site resulted in dust deposits which required regular cleaning.
Increase frequency of visual inspection to ensure optimum performance

500kWp system in Fourways

Source: www.pqrs.co.za

Ongoing maintenance

- No space for cleaning modules
- DB Board cb's overheated & tripped continuously
- Inverters overheated
- Conductors from panels to inverter overheated 230m 6mm²

Only in the Northern Cape

Technical data for calc examples

Task 3

Conext RL

Device short name	RL 3000 E
Electrical specifications	
Input (DC)	
MPPT voltage range, full power	160 - 500 V
Operating voltage range	90 - 550 V
Starting voltage	100 V
Max. input voltage, open circuit	550 V
Number of MPPT	2
Max. input current per MPPT	10 A
Max. short circuit current per MPPT	13.9 A
Nominal input power	3.2 kW
Max. DC input power per MPPT	3.2 kW
DC connection type	MC4, 2 pairs (1+1)
DC switch	Integrated (optional)

1. Calculate the minimum number of 12V panels required to start up the Schneider inverter

References

- Earthing Section:
  - http://www.nia.org.za/webfiles/conferences/2012/Papers/Monday,%203%20September/M206%20-%20High%20voltage%20pylon%20earth%20measurements.pdf
  - http://www.iiser.org/researchpaper%5CSOIL-RESISTIVITY-AND-SOIL-pH-PROFILE-INVESTIGATION-A-CASE-STUDY-OF-DELTA-STATE-UNIVERSITY-FACULTY-OF-ENGINEERING-COMPLEX.pdf
  - www.copper.org
  - http://electrical-engineering-portal.com/how-to-determine-correct-number-of-earthing-electrodes-strips-plates-and-pipes-part-1
  - http://www.solarabcs.org/about/publications/reports/module-grounding/pdfs/IssuesRecomm_Grounding2_studyreport.pdf
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- Batteries
  - http://fortune.com/2015/05/18/tesla-grid-batteries-chemistry/
- PV Fuse selection Section:
  - http://solar.org.au/papers/08papers/408.pdf
  - http://www.bre.co.uk/filelibrary/pdf/rpts/Guide_to_the_installation_of_PV_systems_2nd_Edition.pdf
  - http://www1.cooperbussmann.com/pdf/4897c8fb-c785-4993-a4d6-1fddf120cf70.pdf

THE END

THANK YOU!!

(Please see supplemental slides)

Measurement

- Class A, B or S testing equipment (IEC 61000-4-30); in S.A. Testing equipment is Classed as class i, ii or iii.
- Standard Multi meters & True RMS Testers
- Power analyzers
- Municipal Readings
- Meters with Current transformers.