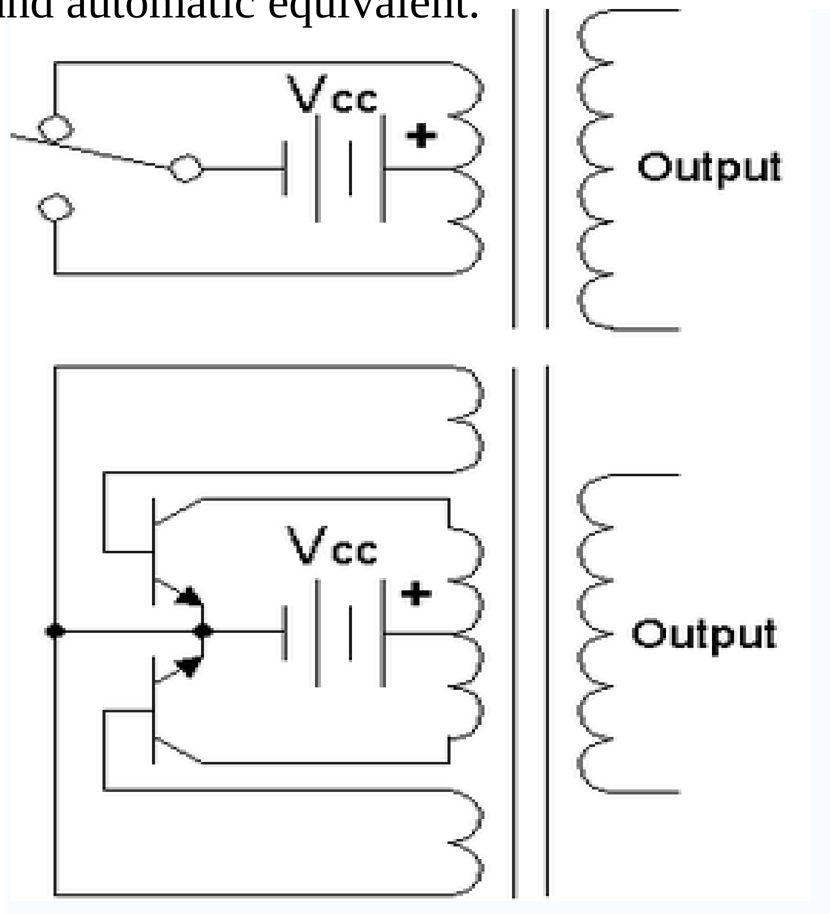
- **Define Inverter**
- An inverter is an electrical device that converts direct current (DC) to alternating current (AC); the resulting AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits.
-

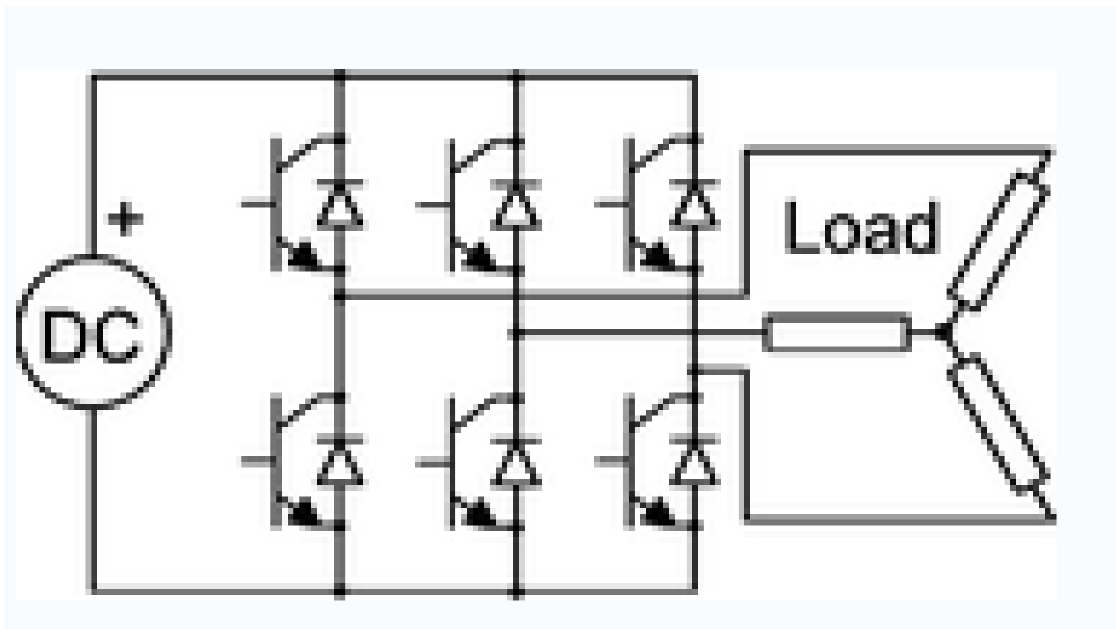
Sketch the basic circuit diagram of inverter

Simple inverter circuit shown with an electromechanical switch and automatic equivalent.



Sketch 3-phase inverter with wye connected load

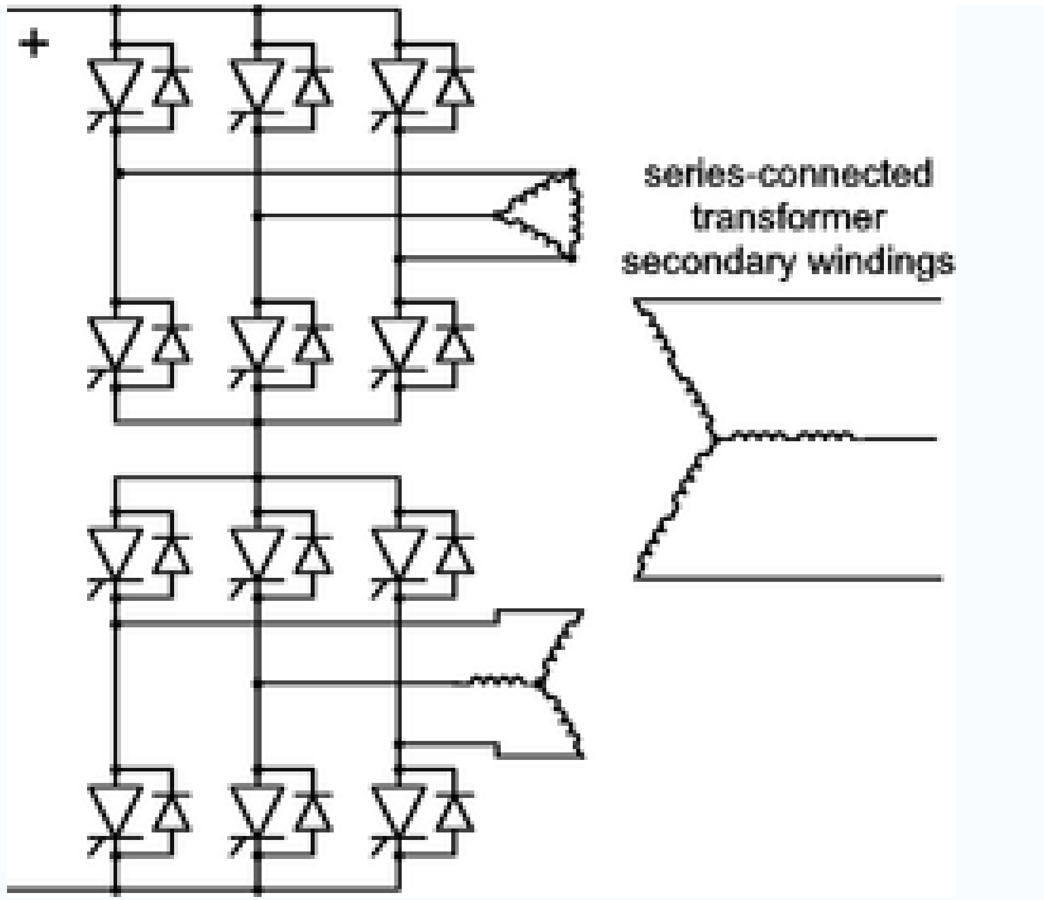
- Three-phase inverters are used for variable frequency drive applications and for high power applications such as HVDC power transmission. A basic three-phase inverter consist of three single phase inverter switches each connected to one of the three load terminals.



Explain controlled rectifier inverter

- Since early transistors were not available with sufficient voltage and current ratings for most inverter applications, it was the 1957 introduction of the thyristor or silicon controlled rectifier (SCR) that initiated the transition to solid state inverter circuits.
- The commutation requirements of SCRs are a key consideration in SCR circuit designs. SCRs do not run off or commutate automatically when the gate control signal is shut off. They only run off when the forward current is reduced to below the minimum holding current, which varies with each kind of SCR, through some external process. For SCRs connected to an AC power source, commutation occurs naturally every time the polarity of the source voltage reverses. SCRs connected to a DC power source usually require a means of forced commutation that forces the current to zero when commutation is required. The last complicated SCR circuits employ natural commutation rather than forced commutation. With the addition of forced commutation circuits, SCRs have been in the types of inverter circuits described above.

Explain controlled rectifier inverter



12-pulse line-commutated inverter circuit

What is Grid Intertie inverter?

- A grid intertie or grid interactive inverter is a pure sine wave inverter that has had additional circuits added that allows it to synchronize with and feed power back to the grid or utility company. This type of inverter may operate in conjunction with batteries which would provide backup power as described above or may function without batteries allowing power to be fed directly from solar modules or a wind generator.

Why do industries need sine wave inverters?

- It depends on what type of equipment you wish to operate from your inverter. One thing is sure: if you once buy a quality sine wave inverter, you can connect any type of mains equipments later on. Square wave or modified sine wave inverters have their limitations. Square wave or modified-sine wave inverters have the lowest cost and efficiency and are not manufactured by us. The price of better quality sine wave inverters is low enough to make non-sine wave inverters an unattractive choice. After all, it is a one-time investment which would ensure that you will be able to operate any kind of 230Vac equipment, trouble-free

Explain oscillator with electrical equivalent circuits

- Resistors, inductors, capacitors and amplifier with high gain are basic components of an oscillator. In designing oscillators instead of using discrete passive components (resistors, inductors and capacitors), crystal oscillators are a better choice because of their excellent frequency stability and wide frequency range. An oscillator can be composed of an amplifier, A, with voltage gain, a, and phase shift, a, and a feedback network, F, with transfer function, f, and phase shift, b.

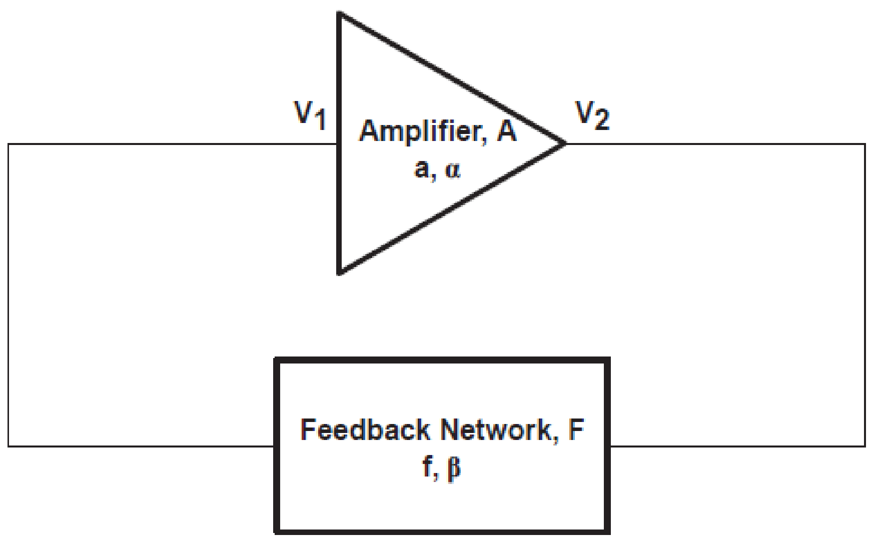


Figure 1. Oscillator

Sketch oscillator using a Schmitt-trigger Input inverter

- A buffer or inverter with a Schmitt-trigger input can be used at the output of the oscillator. Examples of Schmitt-trigger input buffers and inverters are the LVC1G17 and LVC1G14. Figure 24 shows an example circuit.

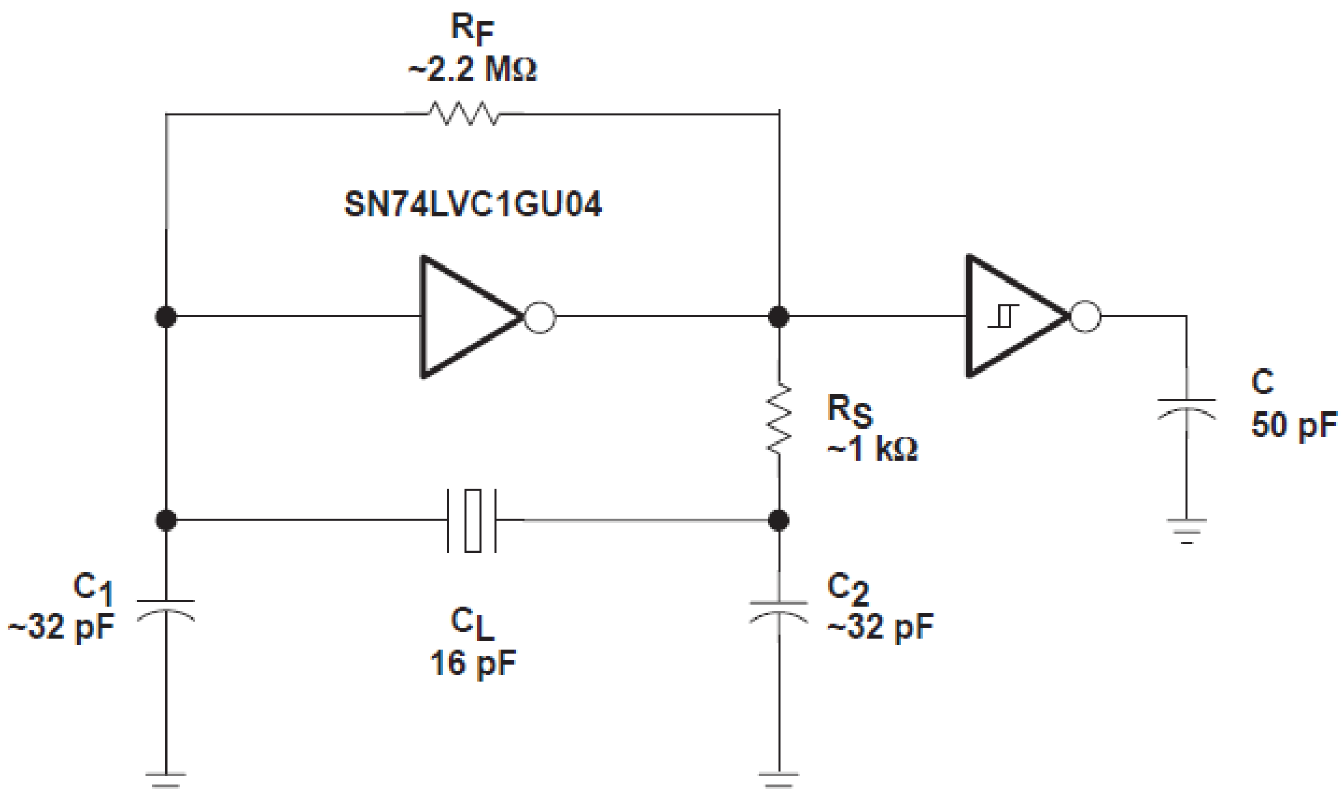
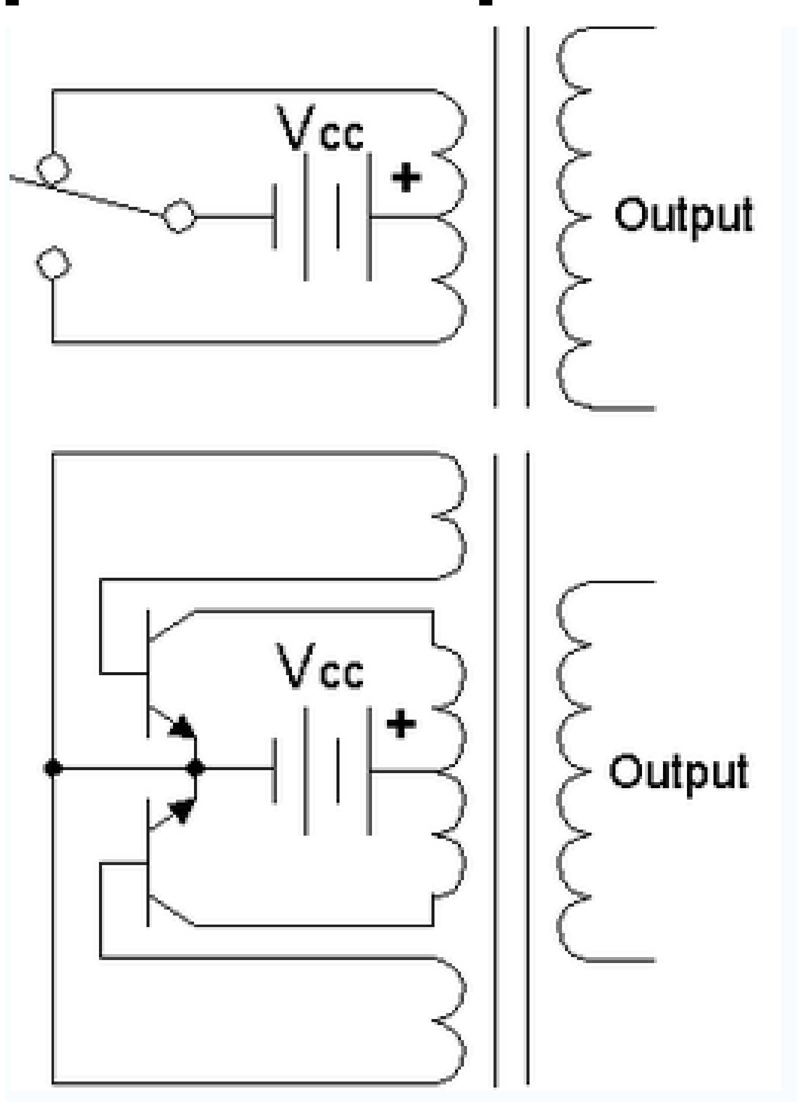


Figure 24. Oscillator Circuit Using a Schmitt-Trigger Input Inverter

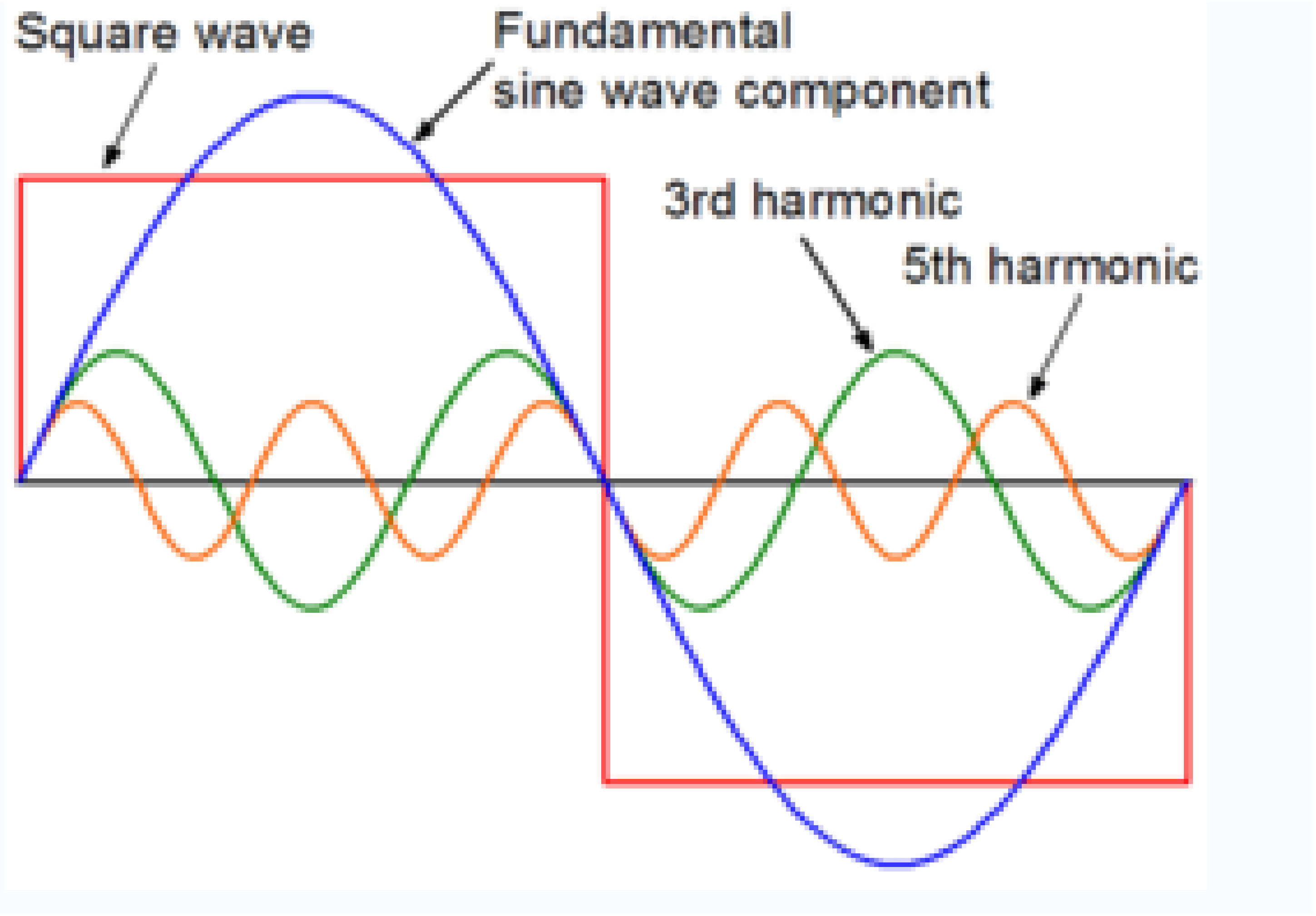
Sketch simple inverter circuit and explain the operation

- In one simple inverter circuit, DC power is connected to a transformer through the centre tap of the primary winding. A switch is rapidly switched back and forth to allow current to flow back to the DC source following two alternate paths through one end of the primary winding and then the other. The alternation of the direction of current in the primary winding of the transformer produces alternating current (AC) in the secondary circuit.
-
- The electromechanical version of the switching device includes two stationary contacts and a spring supported moving contact. The spring holds the movable contact against one of the stationary contacts and an electromagnet pulls the movable contact to the opposite stationary contact. The current in the electromagnet is interrupted by the action of the switch so that the switch continually switches rapidly back and forth. This type of electromechanical inverter switch, called a vibrator or buzzer, was once used in vacuum tube automobile radios. A similar mechanism has been use in door bells, buzzers and tattoo guns. As they became available with adequate power ratings, transistors and various other types of semiconductor switches have been incorporated into inverter circuit designs

Sketch simple inverter circuit and explain the operation



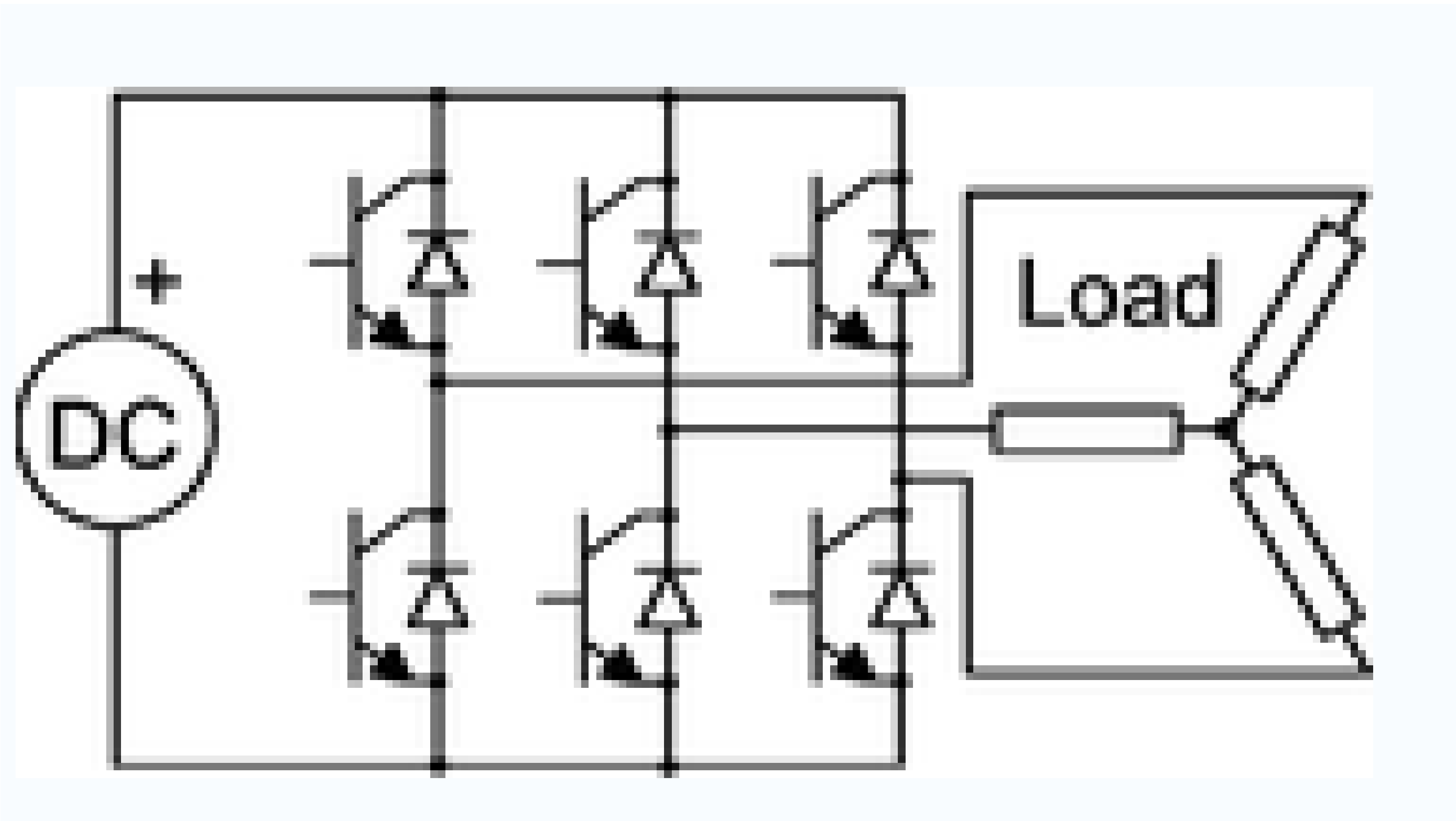
Sketch fundamental sine wave, square wave, 3 harmonic and 5 harmonic



Why sine wave inverter is required for some of electrical appliances and name the equipments requiring sine wave

- In your home the wall outlet socket supplies 230Vac to your household appliances. The waveform of this alternating current is sine wave. Therefore most electrical equipment is originally designed to operate from a sine wave mains power source. It is highly recommended to run the following equipment only from a sine wave power source: TV, radio, sensitive audio or video equipment, measuring instruments, all inductive loads such as Refrigerators, water pumps, power tools, etc.

Sketch 3 phase inverter with star connected load



Grid intertie inverters
Modified sine wave inverter

- **Grid intertie inverters**
- A grid intertie or grid interactive inverter is a pure sine wave inverter that has had additional circuits added that allows it to synchronize with and feed power back to the grid or utility company. This type of inverter may operate in conjunction with batteries which would provide backup power as described above or may function without batteries allowing power to be fed from solar modules or wind generator.

- **Modified sine wave inverter**
- This type of inverter is very high in efficiency and produces a waveform which is an approximation of the pure sine wave waveform that is produced by the utility company. Modern modified sine wave inverters come in two varieties.
- High frequency conversion units which is typical of the design that you will find in inverters that are manufactured overseas in countries like Taiwan and China.
- Low frequency or 60Hz based conversion units that are typical of US designed inverters.

Bubba oscillator
Sine wave generator

- **Bubba oscillator**
- The Bubba Oscillator is a circuit that provides a filtered sine wave of any frequency the user desires based upon the configuration of resistors and capacitors in the circuit. The circuit completes this task with four operational amplifiers that either buffer or amplify the signal. This oscillator is a phase shift oscillator, but unlike other phase shift varieties that require phase shifts of 90 degrees or more, the bubba oscillator only requires a 45 degree shift in order to function. This is because of the four op amps, that when placed in series, produce a total 180 shift.

- **Sine wave generator**
- The first step to creating an accurate pulse width modulation signal using analogue circuitry is to construct an accurate representation of the signal you wish to duplicate. In the case of a pure sine wave inverter the team wanted to construct a 60 HZ sine wave output. Therefore an oscillator was needed to produce a stable 60HZ sine wave that had little distortion so that the output could be as accurate as possible. A Bubba oscillator was chosen as the means to produce this signal because of its ability to produce a stable sine wave that contains very little distortion.

Sketch carrier sine wave generator and explain it.

- Generating a sine wave at 60Hz requires both the reference sine wave and a carrier wave at the switching speed of the power supply. When the oscillator was first pieced together, all that was being output was a 6 volt signal, all of the calculations were correctly made and all of the components were correct in their choosing, therefore the team had to understand why the circuit wasn’t running. In order to understand if the circuit was operating at all, the power to the circuit was turned on and off while attached to an oscilloscope. While doing this the team noticed that there was some oscillation present but it would attenuate to the 6 volt signal in under a second.

Sketch carrier sine wave generator and explain it.

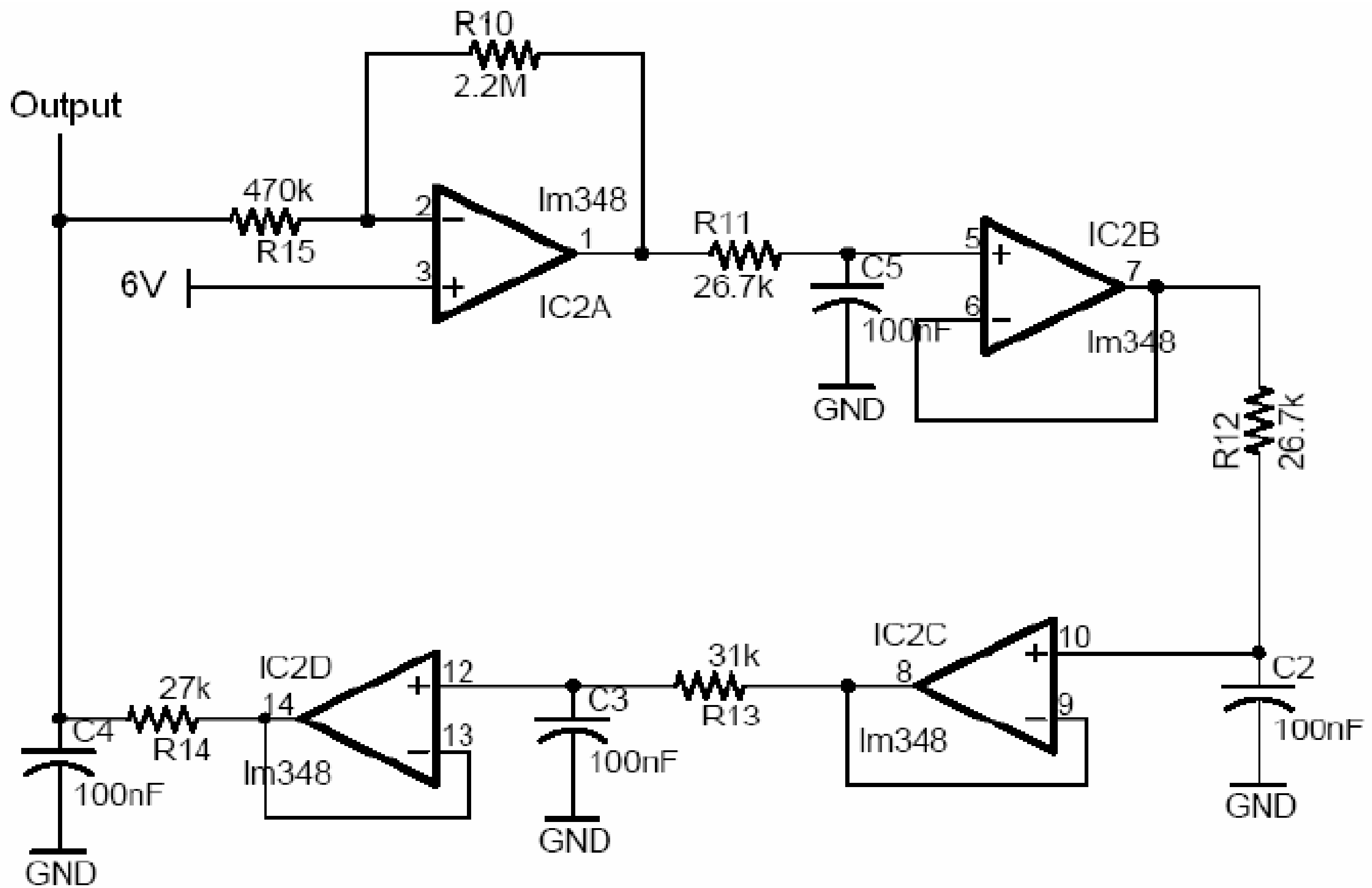


Figure 28: New Sine Wave Oscillator Circuit Diagram

Carrier wave generator

- Generating a sine wave at 60HZ both the reference sine wave and a carrier wave at the switching speed of the power supply. Carrier waves can either be sawtooth (or) triangular signals.
-

Carrier wave generator

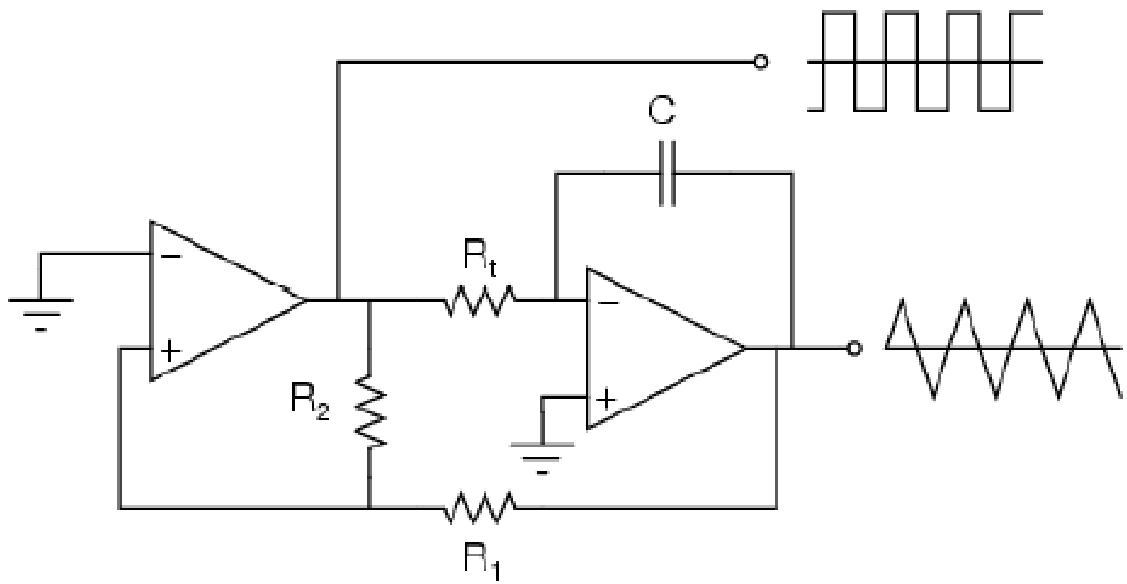


Figure 16: Triangle Wave Generator [14]

- The above circuit will oscillate at a frequency of 1/4RtC, and the amplitude can be controlled by the amplitude of R1 and R2. The frequencies that can be generated by this circuit depend greatly on the slew rate of the operational amplifiers. Using a TL-084, output waves with frequencies of up to 40KHz can be generated. Speeds of 50KHz require an op-amp with a faster slew rate. Using the TL-084 op-amp, with Rt=1K, R1=R210K, and C=0.1uFthis generates square and triangle waves oscillating at 5KHZ.

Sketch grid connected micro-inverter and installation for residential system

EXAMPLE INSTALLATION DIAGRAM

1. Enphase Micro-Inverter system mounts to racking beneath each solar module
2. AC power and performance data sent via AC wiring to the load center and communications gateway
3. Envoy Communications Gateway
4. Standard Ethemet Router
5. Enphase Enlighten Monitoring can be viewed from any web browser and provides monitoring and analysis of system performance

Please contact us for a detailed diagram or visit enphaseenergy.com

Grid connected photovoltaic systems are the most common type of grid connected system. As electricity produce during the day time is either used (or) directed basic into the electricity grid, and at night, Electricity is purchased from the grid. There is no need for an expensive battery bank.

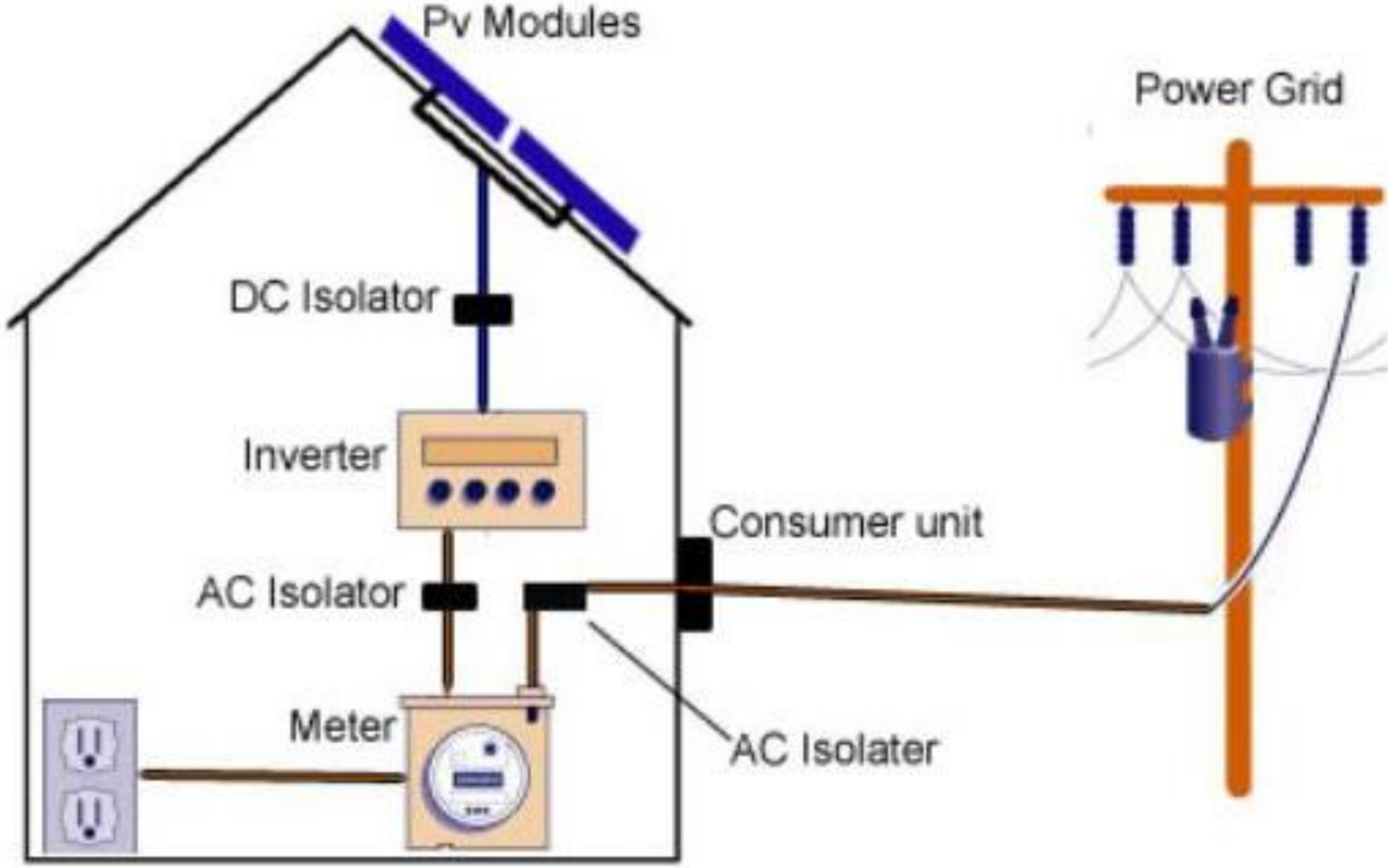


Figure 2 A schematic of a photovoltaic grid-connected system. (courtesy of Ecolution).

Single inverter grid connected system

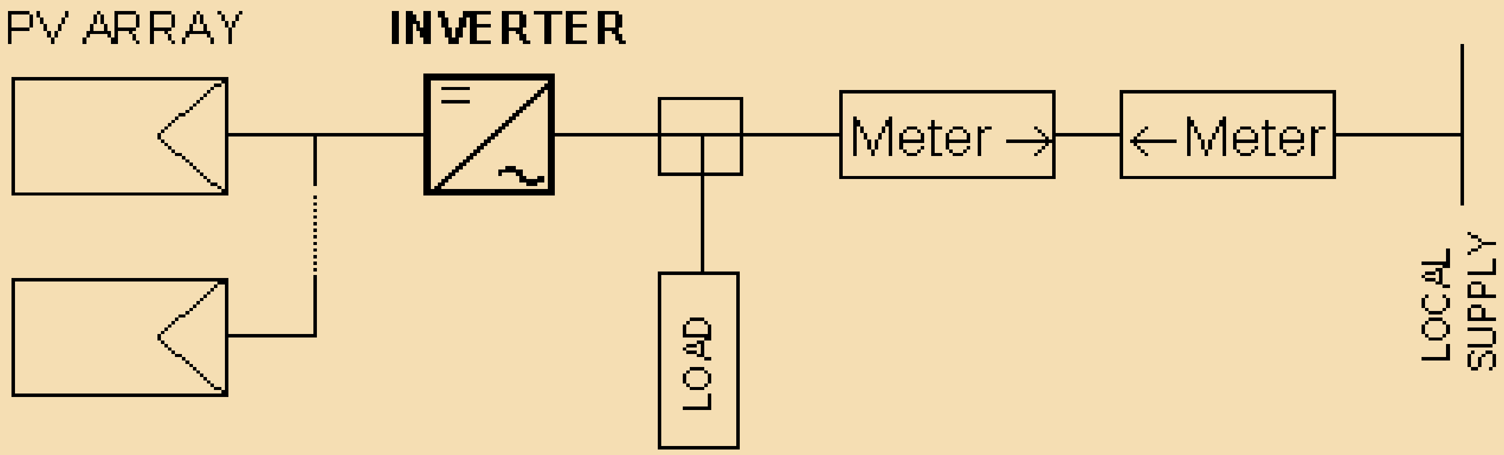


Fig. 1.Single inverter Grid Connected System.

Multiple inverters of the same rating to cover the full range of power levels with better inverter saturation.

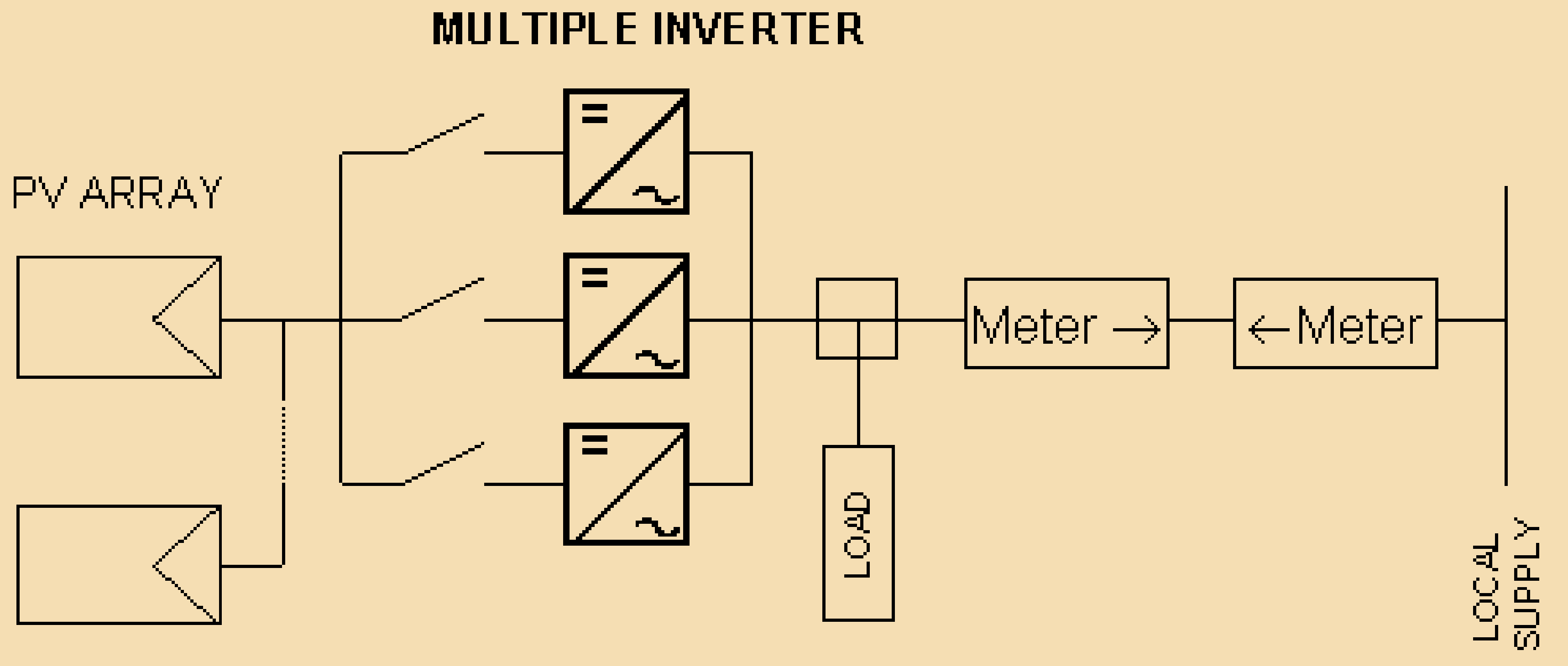


Fig. 3.Grid Connected PV System with Multiple Inverter.

Power surge

- A surge is a transient electrical fluctuation that happens in a fraction of a second and can cause serious damage to electronic and electro mechanical equipment.
- They can be caused by lightning strikes and local power utility company “spikes” which can enter your business or home through the electrical system. Many people believe the most important issue is power loss or blackouts, yet the truth is that the majority of power fault are cause by power surges or noise transients.
- Power surges and noise transients are caused by:
- Lightning strikes
- Substation switching
- Variable speed drives
- Electric motors

Sketch PV modules & grid connected system.

- The classical connection between photovoltaic array and AC grid is shown in Figure 1. The main objective, from this interfacing, is to feed all the collected energy at the PV plant to the commercial AC grid.
- This is achieved by the followings:
- - PV array is responsible to transform the sun light to electricity. - MPPT controller, this is used to maximise the power coming from PV array at any atmospheric conditions.
- - Inverter, this is a device with transform DC input to an AC output at the same

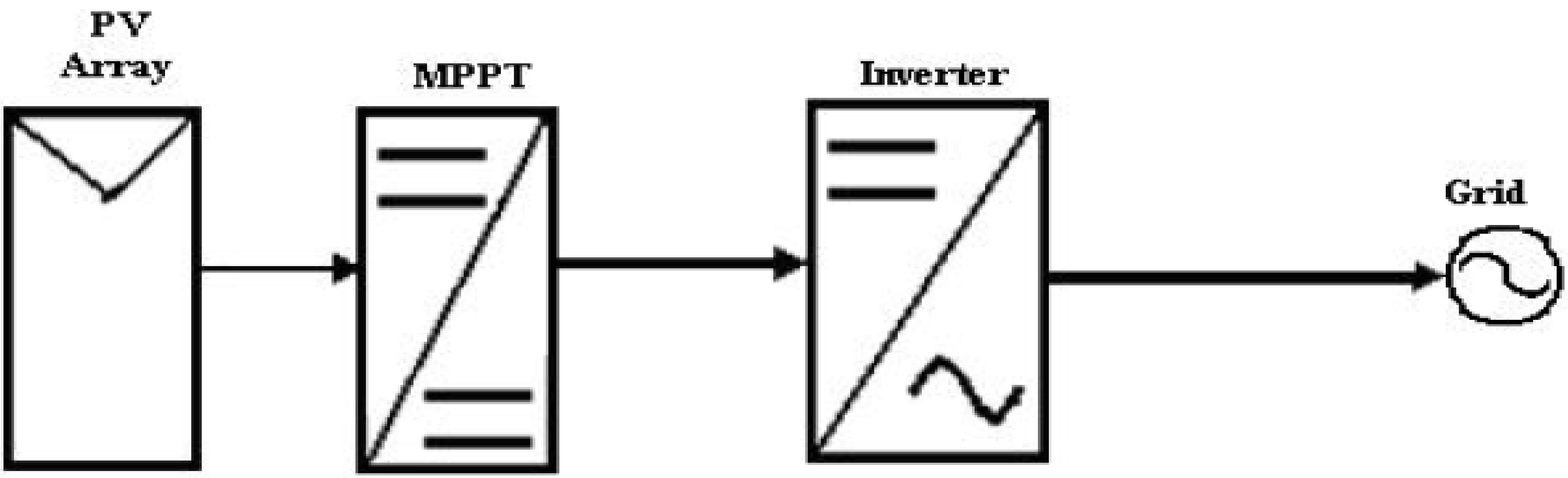


Fig. 1: PV grid connected system

Explain pure sine wave inverter with block diagram

- The inverter will converts 12 Volt dc from battery into 110 Volt ac, 50Hz, sine wave.

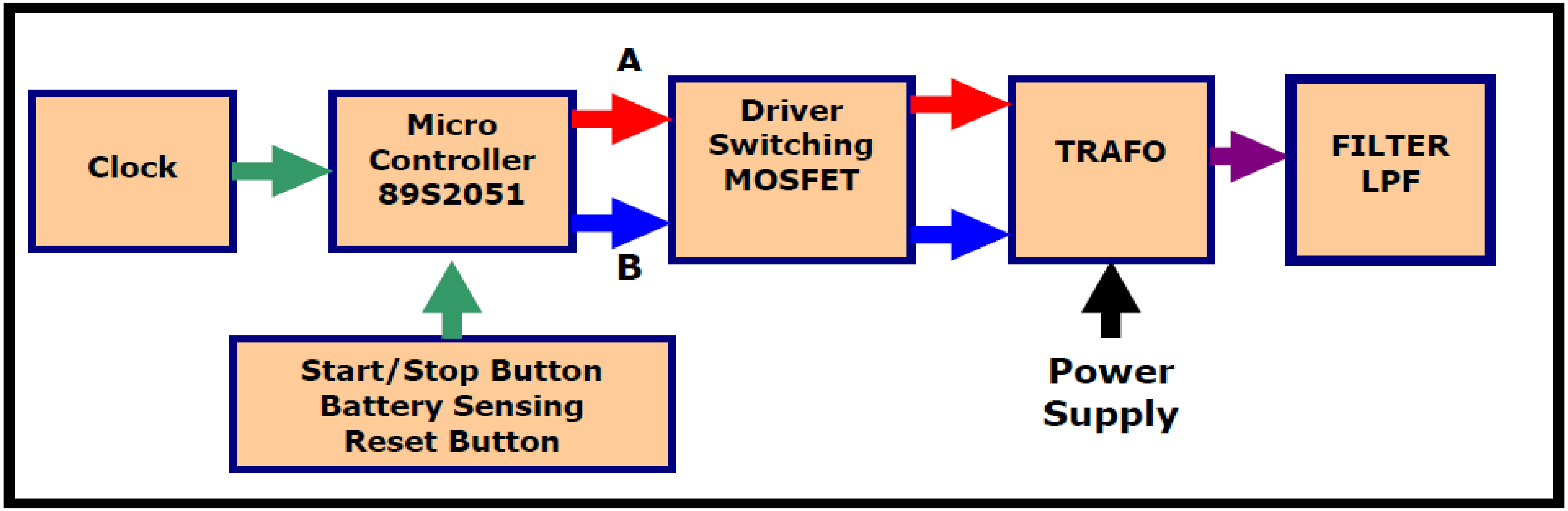


Figure 2. Block diagram of pure sine wave inverter

Sketch the schematic circuit diagram of pure sine inverter

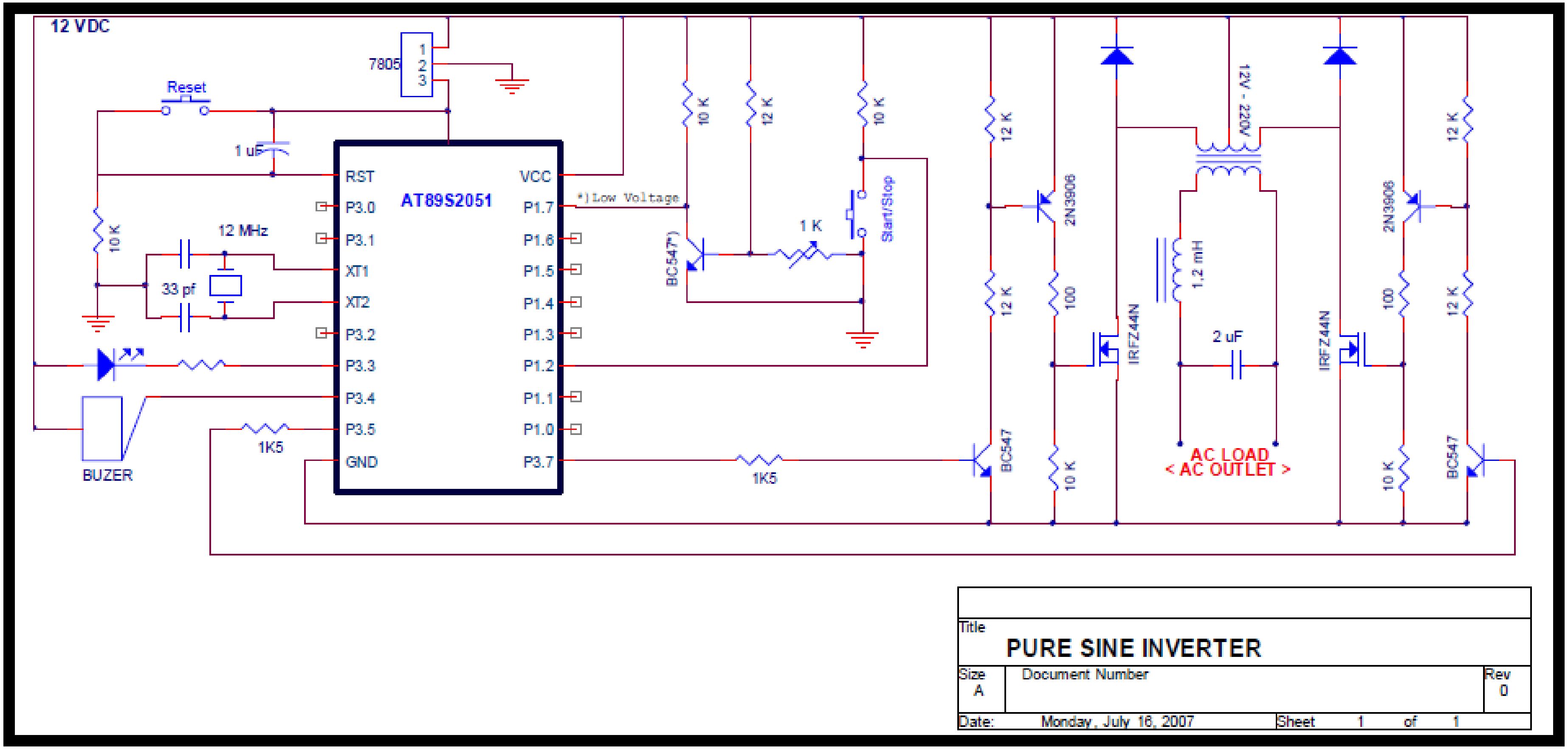


Figure 3. Schematic of Pure Sine Inverter

Pulse Width Modulation

- In electronic power converters and motors, PWM is used extensively as a means of powering alternating current (AC) devices with an available direct current (DC) source or for advanced DC/AC conversion. Variation of duty cycle in the PWM signal to provide a DC voltage across the load in a specific pattern will appear to the loads as an AC signal, or can control the speed of motors that would otherwise run only at full speed or off.

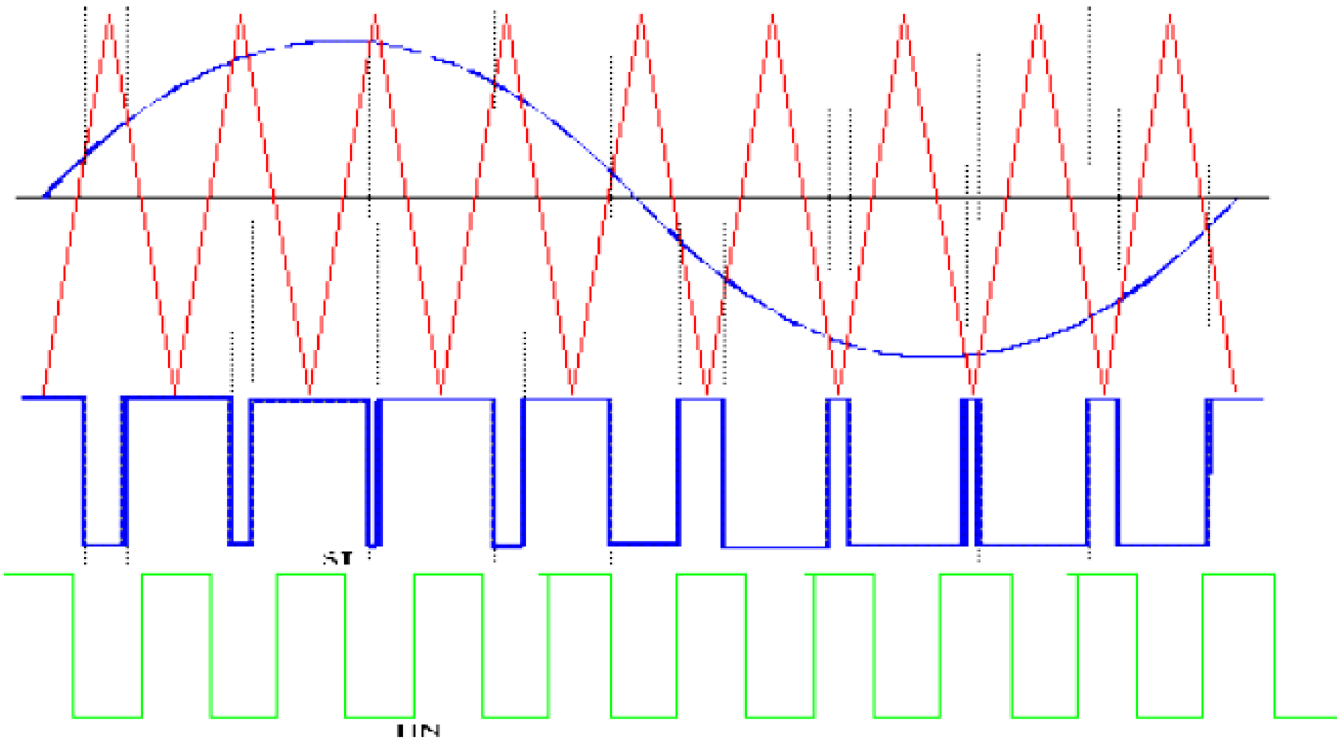


Figure 3: Pulse Width Modulation

Bubba Oscillator

- The Bubba Oscillator is a circuit that provides a filtered sine wave of any frequency the user desires based upon the configuration of resistors and capacitors in the circuit. The circuit completes this task with four operational amplifiers that either buffer or amplify the signal. This oscillator is a phase shift oscillator, but unlike other phase shift varieties that require phase shifts of 90 degrees or more, the bubba oscillator only requires a 45 degree shift in order to function. This is because of the four op amps, that when placed in series, produce a total 180 shift.
-
- The bubba oscillator offers a few features that other oscillators cannot; the biggest factor is that the frequency stability holds while still giving a low distortion output. The reason for this involves the four filters that the signal passes through, providing a clear and stable signal at point P5, as shown in Figure 4.

Bubba Oscillator

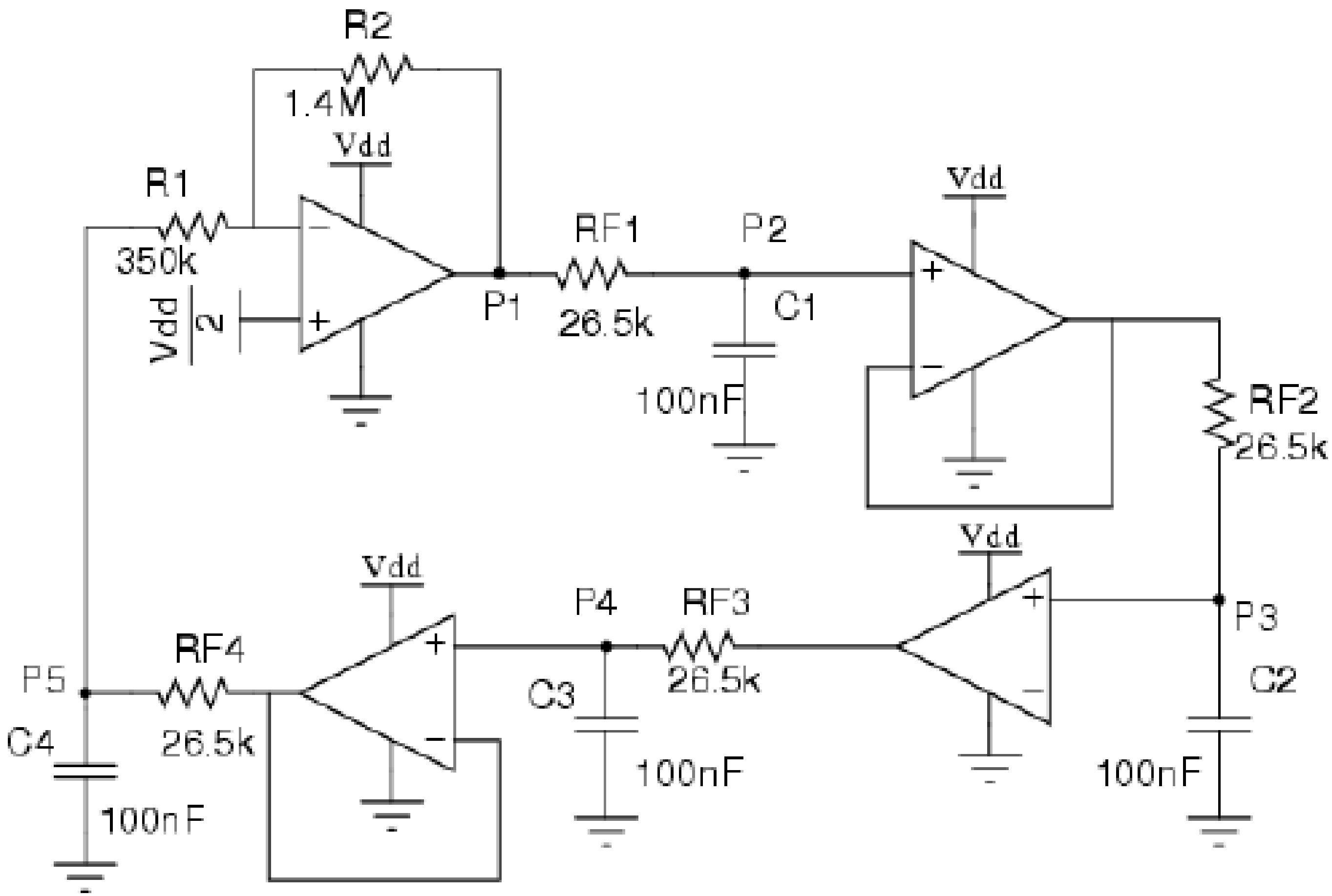


Figure 4: Bubba Oscillator Schematic

H-Bridge or full-bridge converter

- An H-Bridge or full-bridge converter is a switching configuration composed of four switches in an arrangement that resembles an H. By controlling different switches in the bridge, a positive, negative, or zero-potential voltage can be placed across a load. When this load is a motor, these states correspond to forward, reverse, and off. The use of an H-Bridge configuration to drive a motor is shown in Figure 7.

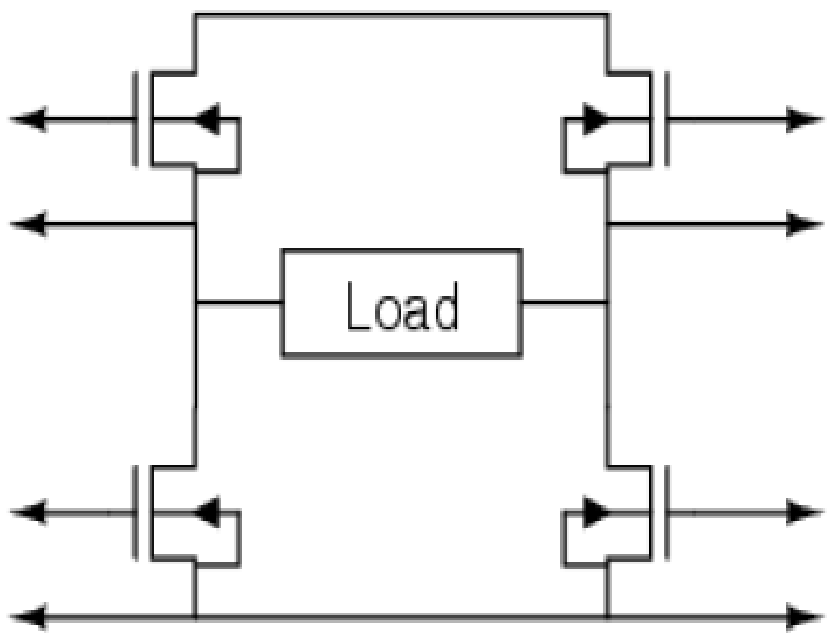


Figure 7: H-Bridge Configuration using N-Channel MOSFETs

H-Bridge circuit

- As shown in Figure 7 the H-Bridge circuit consists of four switches corresponding to high side left, high side right, low side left, and low side right. There are four possible switch positions that can be used to obtain voltage across the load. These positions are outlined in Table 1. Note that all other possibilities are omitted, as they would short circuit power to ground, potentially causing damage to the device or rapidly depleting the power supply.
-
- Table 1: Valid H-Bridge Switch States

H-Bridge circuit

High Side Left	High Side Right	Low Side Left	Low Side Right	Voltage Across Load
On	Off	Off	On	Positive
Off	On	On	Off	Negative
On	On	Off	Off	Zero Potential
Off	Off	On	On	Zero Potential

MOSFET Drivers

- When utilizing N-Channel MOSFET to switch a DC voltage across a load, the drain terminals of the high side MOSFET are often connected to the highest voltage in the system. This creates a difficulty, as the gate terminal must be approximately 10V higher than the drain terminal for the MOSFET to conduct. Often, integrated circuit devices known as MOSFET drivers are utilized to achieve this difference through charge pumps or bootstrapping techniques. These chips are capable of quickly charging the input capacitance of the MOSFET (Cgiss) quickly before the potential difference is reached, causing the gate to source voltage to be the highest system voltage plus the capacitor voltage, allowing it to conduct. A diagram of an N-Channel MOSFET with gate, drain, and source terminals is shown in Figure 8.

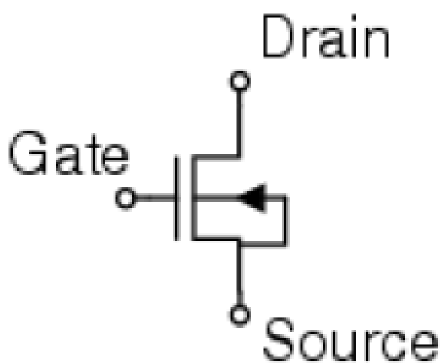


Figure 8: N-Channel MOSFET

Circuit Protection and Snubbers

- One of the major factors in any electronic device is its ability to protect itself from surges that could damage the circuitry. In the case of the inverter, inductive loads can cause special problems because an inductor cannot instantly stop conducting current, it must be dampened or diverted so that the current does not try to flow through the open switch. If not dampened the surges can cause trouble in the MOSFETs used to produce the output sine wave; when a MOSFET is turned off the inductive load still wants to push current through the switch, as it has nowhere else to go. This action can cause the switch to be put under considerable stress, the high dV/dt, dI/dt, V and I associated with this problem can cause the MOSFETs to malfunction and break.

Circuit Protection and Snubbers

- To combat this problem snubber circuits can reduce or eliminate any severe voltages and currents. Composed of simply a resistor and capacitor placed across each switch it allows any current or voltage spikes to be suppressed by critically dampening the surge and protecting the switch from damage. The snubber can become more effectively by the addition of a zener diode so that any large current surge the resistor-capacitor snubber cannot handle gets passed through to ground by the zener diode. The diagram in Figure 9 shows a simple representation of an inductive load (L) over a switch representation, Figure 10 and Figure 11 show how snubbers can be implemented so that a surge will be suppressed.

Circuit Protection and Snubbers

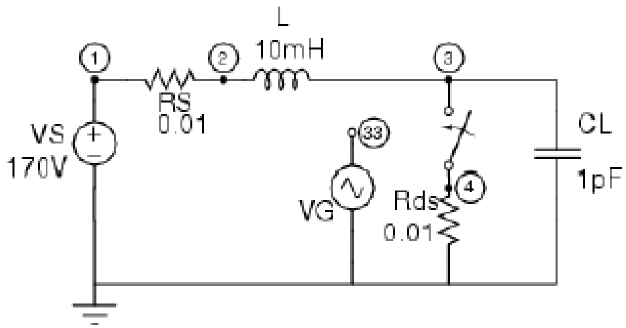


Figure 9: Inductive Load Circuit

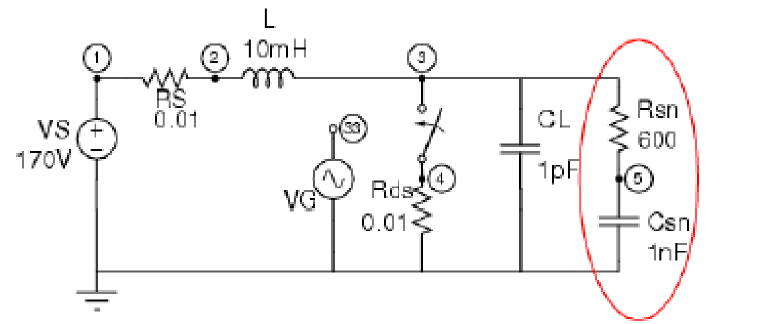


Figure 10: Inductive Load Circuit with Snubber

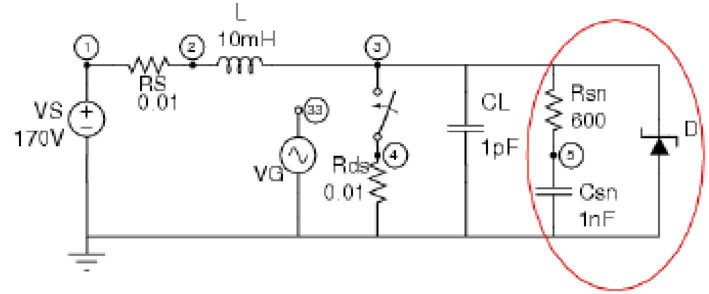


Figure 11: Inductive Load Circuit with Snubber and Zener Diode

Filtering

- Filters come in many different packages, with many different advantages – and disadvantages. For example, a digital filter is easily reconfigurable and can have almost any frequency response desired. If the response is simply low pass/high pass/band pass behaviour with a set frequency, an active filter can be made to have a very sharp edge at the cut-off, resulting in enormous reductions in noise and very little attenuation of the signal. These, however require opamps.Opamps capable of filtering a 120V RMS sine wave exist, but are expensive and lossy, since the opamp must be able to source hundreds of watts, and must be very large to do so without burning. Digital filters have a similar drawback and, designed with TTL and CMOS technology, can only work with small signals. Lastly we come to a passive filter. Generally large in size and very resistive at low frequencies, these filters often seem to have more of a prototyping application, or perhaps use in a device where low cost is important, and efficiency is not.

Filtering

- Given these choices, an application such as high power sine inverter is left with only one viable option: the passive filter. This makes the design slightly more difficult to accomplish. Nothing that passive filters introduce higher resistance at lower frequencies (due to the larger inductances, which require longer wires), the obvious choice is to switch at the highest possible frequency. The problem with this choice, however, is that the switching MOSFETs introduce more switching losses at higher frequencies. This would imply that we should switch slower to improve our switching efficiency, which contradicts the filter's need for a higher frequency.

Methodology

- The construction of the pure sine wave inverter can be complex when thought of as a whole but when broken up into smaller projects and divisions it becomes a much easier to manage project. The following sections detail each specific part of the project as well as how each section is constructed and interacts with other blocks to result in the production of a 120 Volt pure sine wave power inverter.

Sine Wave Generator

- The first step to creating an accurate pulse width modulation signal using analogue circuitry is to construct an accurate representation of the signal you wish to duplicate. In the case of a pure sine wave inverter the team wanted to construct a 60 HZ sine wave output. Therefore an oscillator was needed to produce a stable 60HZ sine wave that had little distortion so that the output could be as accurate as possible. A Bubba oscillator was chosen as the means to produce this signal because of its ability to produce a stable sine wave that contains very little distortion. The circuitry and values chosen are shown in Figure 13 and the opamp chip chosen to complete the task was an LM348 as it is an inexpensive part and meets all the requirements of creating this sine wave.

Sine Wave Generator

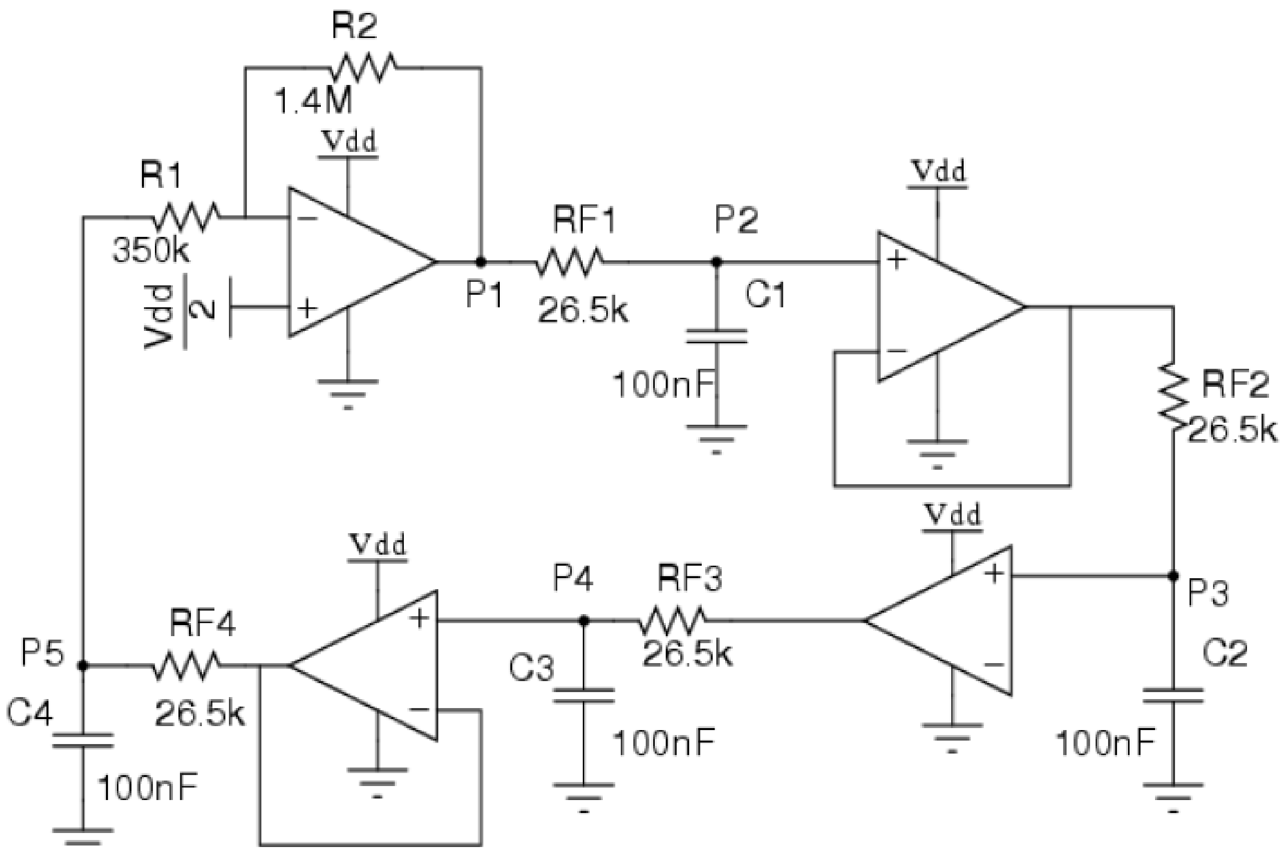


Figure 13: Bubba Oscillator Circuit

Carrier Wave Generator

- Generating a sine wave at 60HZ requires both the reference sine wave and a carrier wave at the switching speed of the power supply. Carrier waves can be either sawtooth or triangular signals; in this case, a triangular wave will be used this wave will be at 50KHZ as determined in optimal power loss simulations. The generation of the triangular carrier wave will be done with analogue components. The circuit for the construction of the triangle wave generator consists of a square wave generator and integrator, as shown in figure 16.

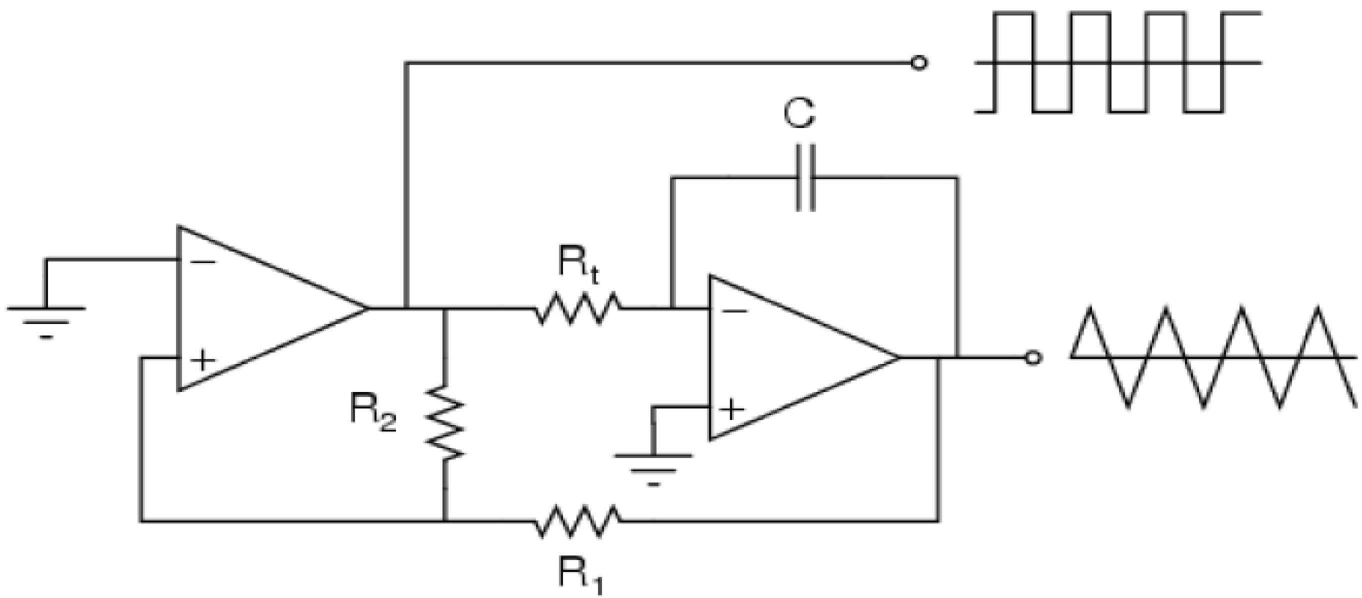


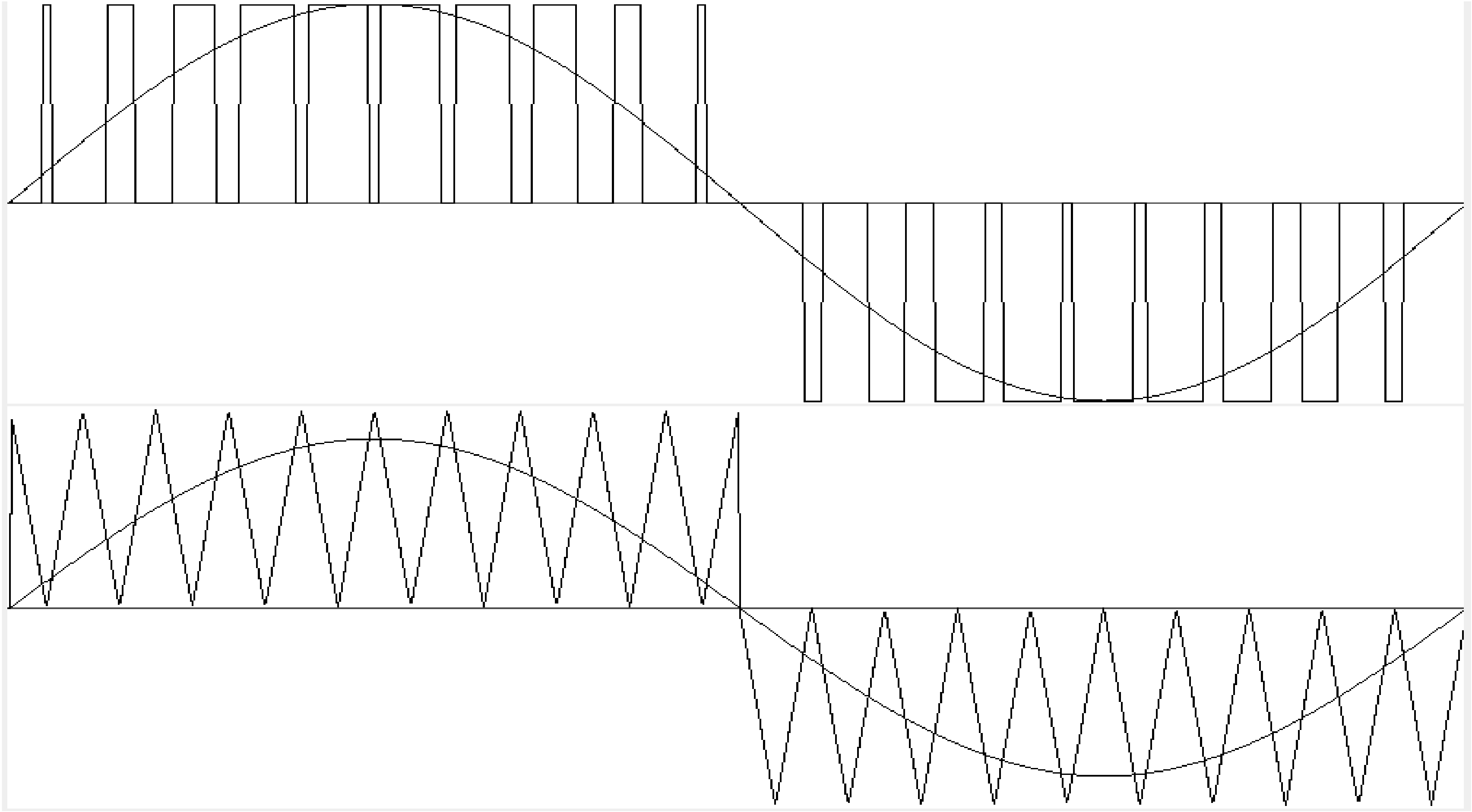
Figure 16: Triangle Wave Generator

Carrier Wave Generator

- The above circuit will oscillate at a frequency of 1/4RtC, and the amplitude can be controlled by the amplitude of R1 and R2. The frequencies that can be generated by this circuit depend greatly on the slew rate of the operational amplifiers. Using a TL-084, output waves with frequencies of up to 40KHZ can be generated. Speeds of 50KHz require an op-amp with a faster slew rate. Using the TL-084 op-amp, with Rt=1K, R1=R2=10K, and C=1uF, this circuit generates square and triangle waves oscillating at 5HZ. The slew rate of this operational amplifier is 12 V/uS and will allow switching speeds up to 43KHz. With an op-amp with a higher slew rate, the capacitor will be replaced with a .01uF capacitor, increasing the frequencies to 50 KHz

Pulse Width Modulation

- Bi-level pulse width modulation is a simple concept, and not difficult to implement. Trilevel PWM is not a far stretch from bi-level, but is significantly more difficult to implement. Below is shown a sample trilevel PWM wave.



Pulse Width Modulation

- The top picture shows the input reference waveform, and the generated PWM signal overlaid. The bottom picture shows the signals which are passed into a comparator to achieve the PWM waveform. The triangular wave is simple to create, utilizing an opamp driver. It must then be modified such that it switches between a mid-to-high triangular wave to a mid-to-low triangular wave. This is accomplished by generating a triangular wave at roughly half the amplitude of the reference sine, centered at the same voltage. This wave is then passed into a voltage summer with a square wave (made from the sine reference, to create one with identical frequency), which creates the modified triangle wave shown.

HBridge Filter

- Generating a sine wave centered on zero volts requires both a positive and negative voltage across the load, for the positive and negative parts of the wave, respectively. This can be achieved from a single source through the use of four MOSFET switches arranged in an H-Bridge configuration. To minimize power loss and utilize higher switching speeds, N-Channel MOSFETs were chosen as switches in the bridge. Level translation between PWM signals and voltages requires to forward bias high side N-Channel MOSFETs, the IR2110 MOSFET driver integrated circuit was chosen. A diagram of the H-Bridge circuit with MOSFETS and drivers is shown in Figure 25.

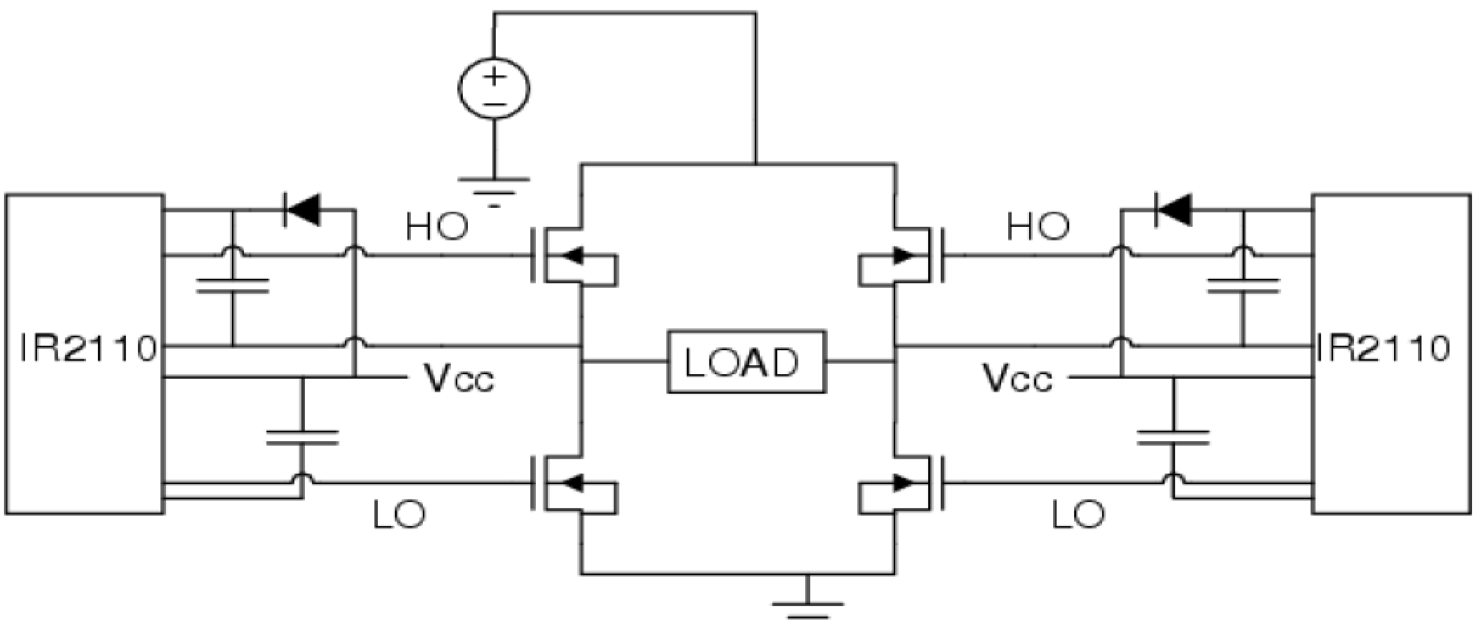


Figure 25: H-Bridge with MOSFET Drivers

Explain the islanding protection of grid connected inverter in photo voltaic system

- The islanding of a grid connected independent generator occurs when a utility is disconnected from the grid line but the photovoltaic grid connected inverter continues to energize the energy to the grid line in the isolated section. The islanding control can be achieved through inverters or via the distribution network. Inverter controls can be designed on the basis of detection of grid voltage or measurement of impedance, frequency variation or increase in harmonics.

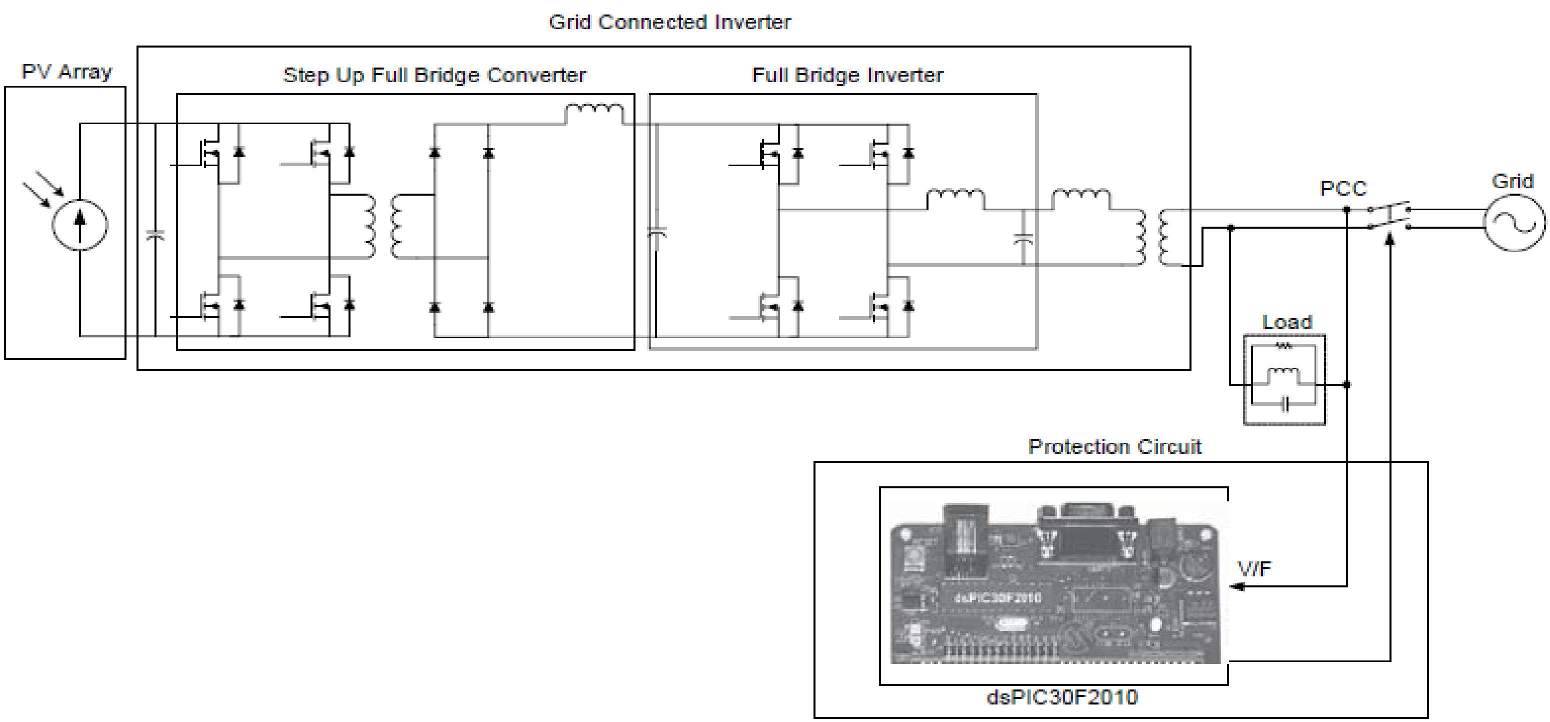


Figure 1: The overall block diagram of photovoltaic generation system and a dsPIC - based islanding detection.

Explain the modelling of grid connected inverter operation

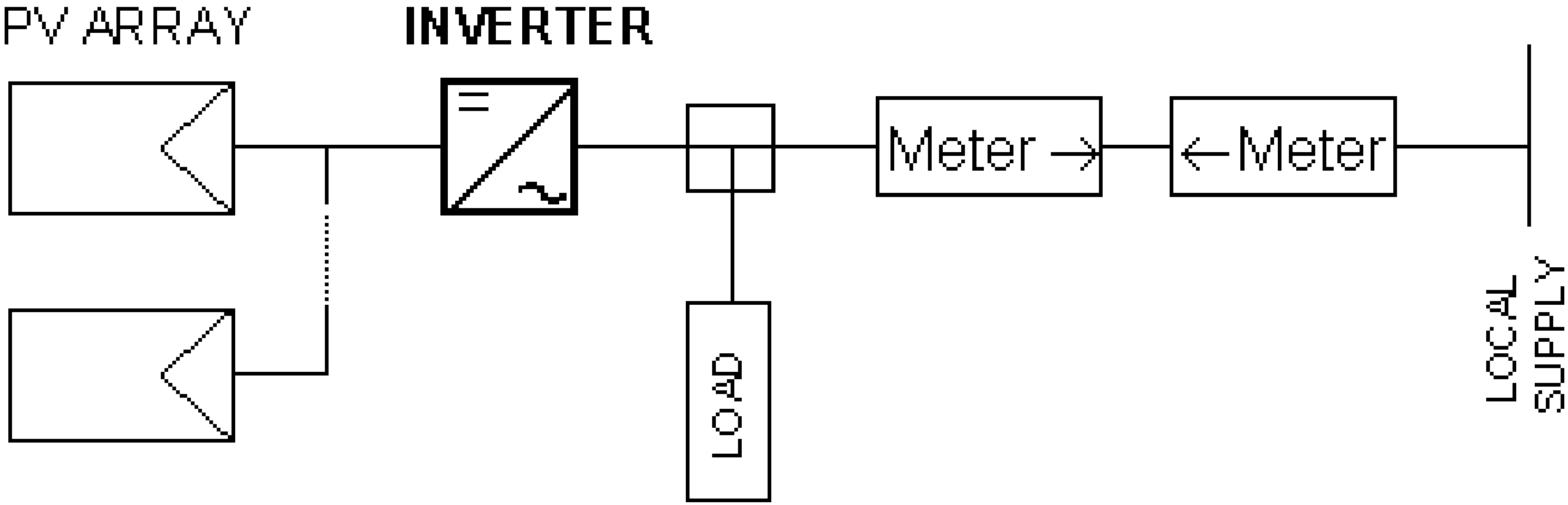


Fig. 1.Single inverter Grid Connected System.

Explain the modelling of grid connected inverter operation

- The basic Grid Connected PV system has the following components:

- **PV ARRAY** or Generator. A number of PV panels connected in series and/ or in parallel giving a DC output of the incident irradiance. Orientation and tilt of these panels are important design parameters, as well as shading from surrounding obstructions.
- **INVERTER**. A power converter that “inverts’ the DC power from the panels into AC power. The characteristics of the output signal should match the voltage, frequency and power quality limits in the supply network.
- **LOAD**. Stands for the network connected appliances in the building that are fed from the inverter, or, alternative, from the grid.
- **METERS**. They account for the energy being drawn from or fed into then local supply network.
- **LOCAL SUPPLY NETWORK**. A single or three phase network managed by a public
  Electricity Supplier. The supply network acts both as a sink for energy surplus in the building or as a backup for low local generation periods.

Transformerless PV inverters

- Most inverters on the market in the mid 1990’s were self or line commutated central inverters, with DC power ratings above 1kW, suitable for PV system configurations with several strings in parallel as shown Figure 1.

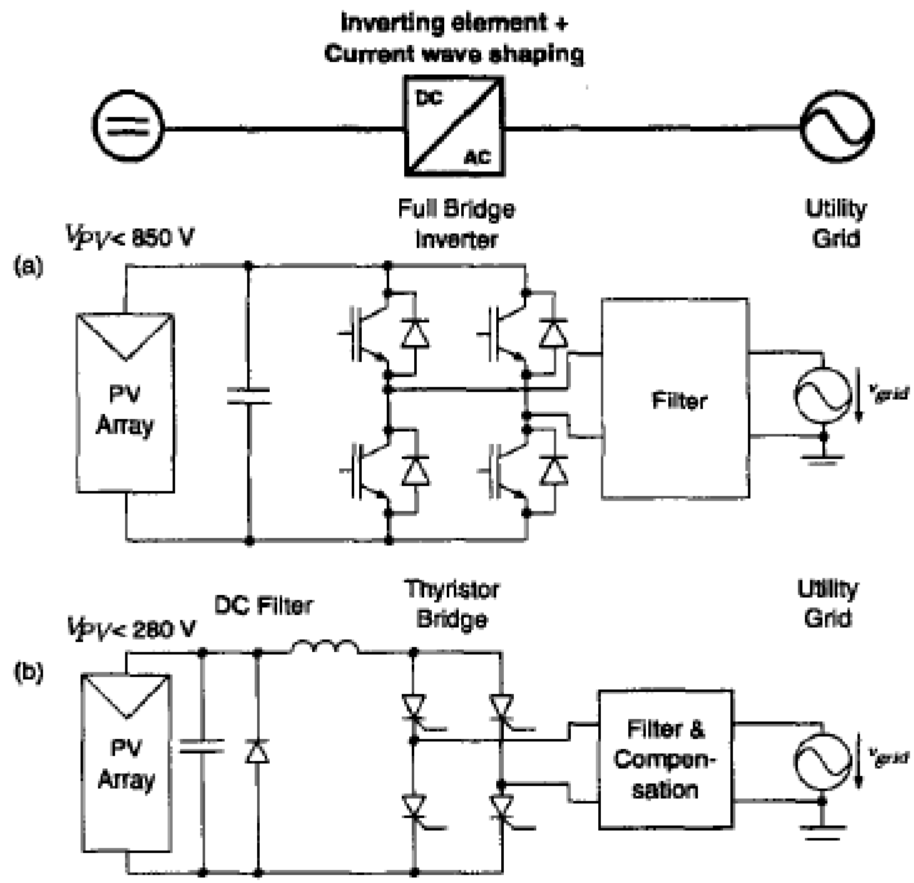
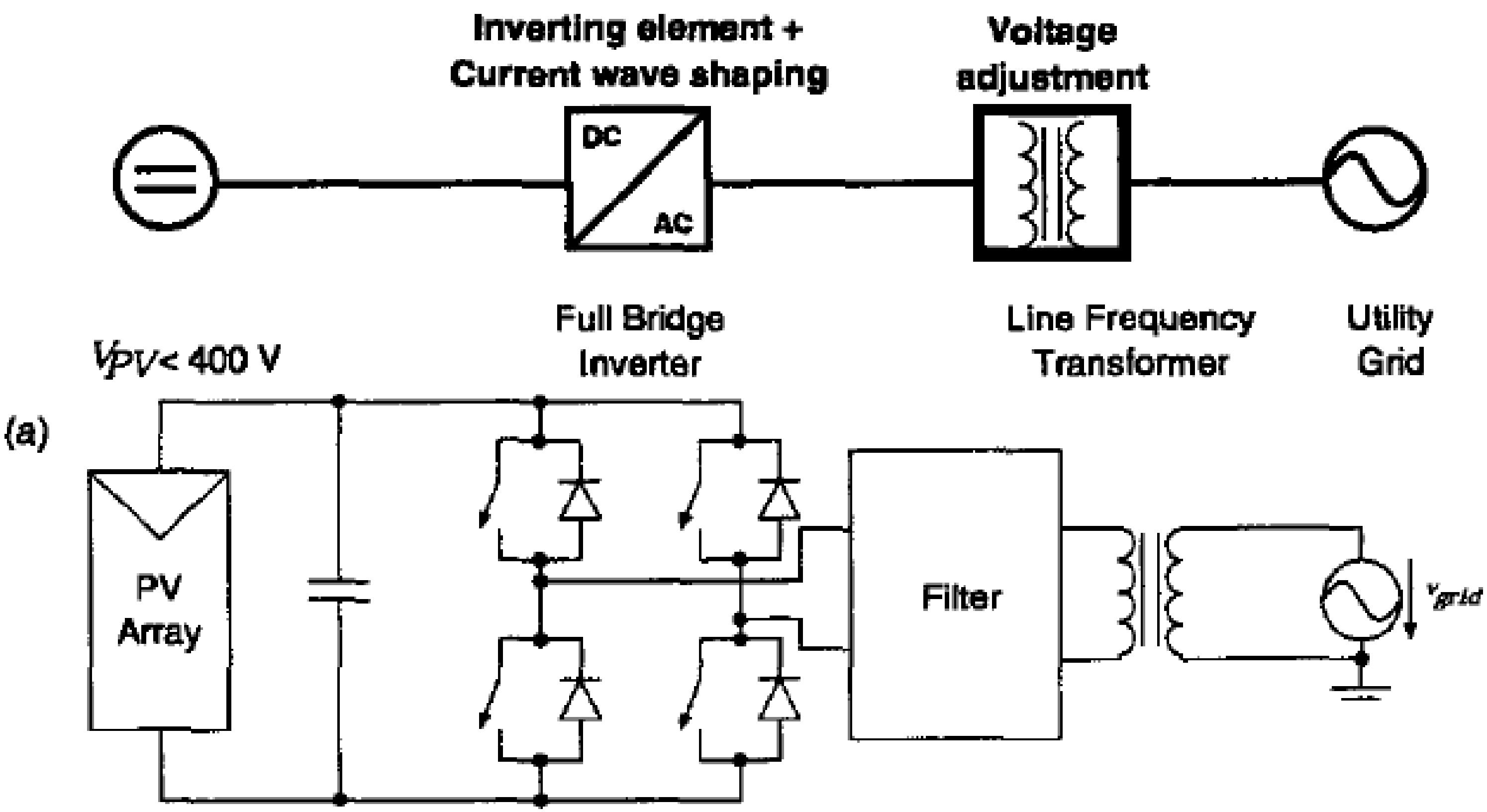


Fig. 2. Transformerless PV inverters (a) step down, (b) line commutated.

Self commutated full bridge

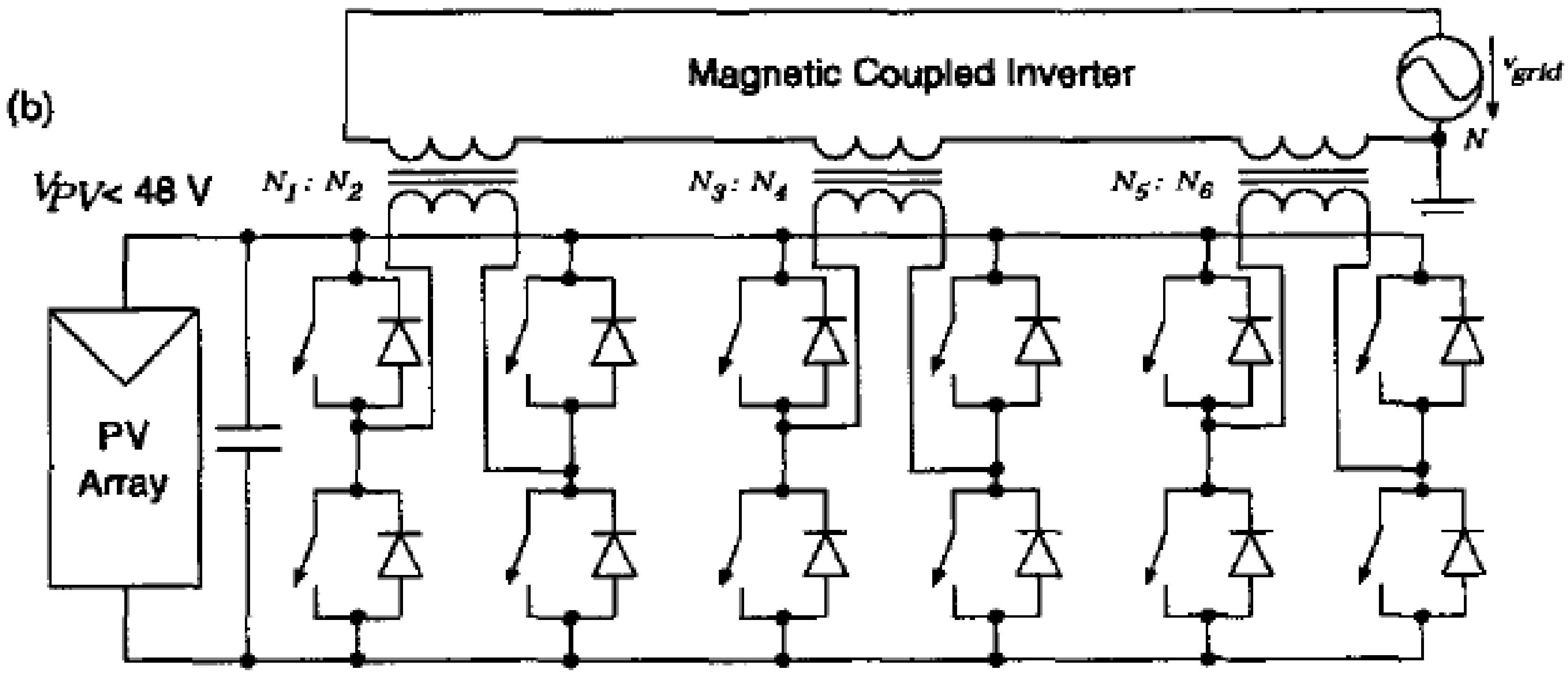
- PV inverters with line frequency transformer (a) self commutated full bridge. These inverters are operating directly on one or several PV modules below 500W. The PV array voltage is generally between 30-150V. These low voltage levels require a voltage adjustment element, which allows for a variety of topologies. Topologies with transformer are shown in Figure 3.



Magnetic coupled

- PV inverters with line frequency transformer (b) magnetic coupled. Figure 3 shows a magnetic coupled inverter available on the American market. The inverter consists of three conventional single phase full bridges each with their midpoints connected to the primary winding of a transformer. The secondary windings of the transformers are connected in series and turns ratios of the transformers are chosen as multiples of each other.
-
- Generally, an inverter of this type having n primary transformer windings is capable of generating 3^n combinations of different voltages across the secondary transformer windings and synthesises the sine wave by means of a stepped waveform (not by means of PWM). The advantage of this circuit is the relatively accurate replica of a sine wave accomplished with low switching frequencies and a cheap and robust full-bridge. A major drawback of the circuit, however, is the need for three transformers.

Magnetic coupled



PV inverter with several conversion stages and high frequency transformer

- Low voltage MOSFET’s which are widely used in large quantities for automotive applications are cheap semiconductor devices. Furthermore the whole control system can be realised on the low voltage side and this topology is also suitable for high current PV modules.
- However some inverter companies follow high-frequency transformer concepts in order to reduce the magnetic components and costs and an example topology is shown in

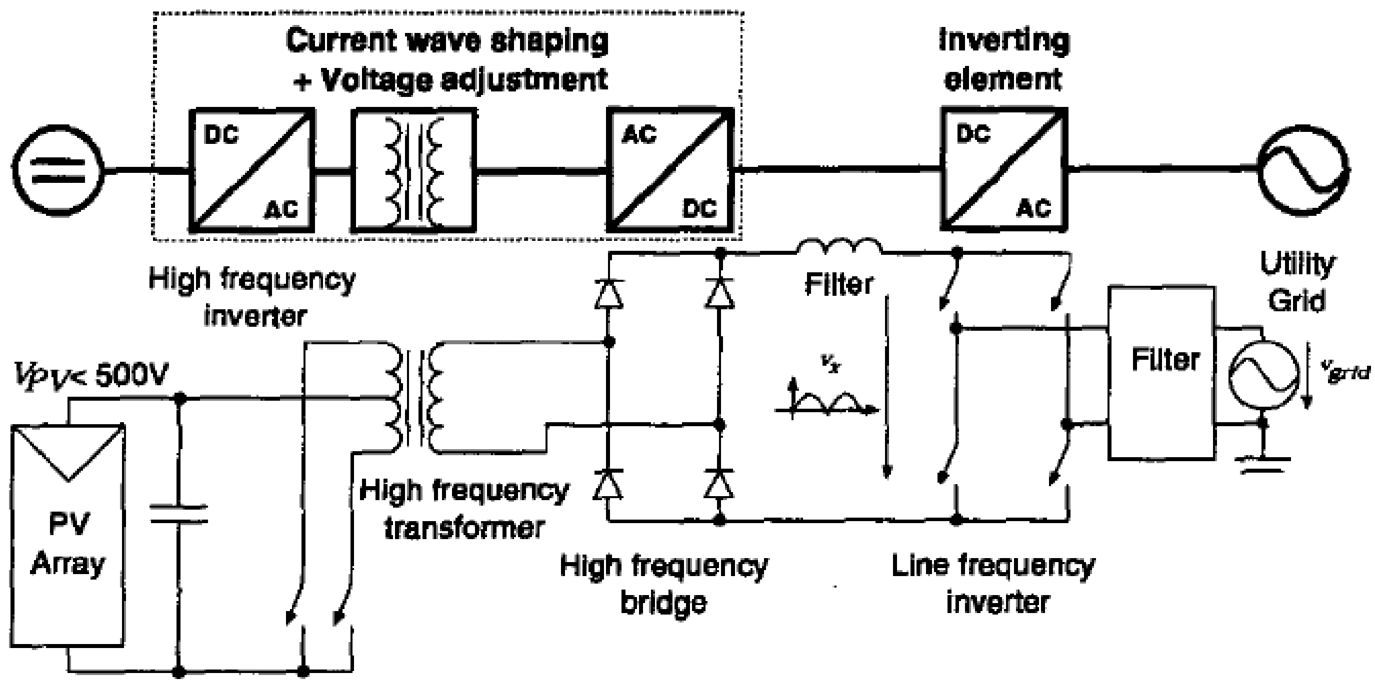


Fig. 5. PV inverter with several conversion stages and high frequency transformer [14].

Transformerless PV inverter with several conversion stages including boost stage

- Figure 6 shows a third topology available on the market which avoids a transformer in order to reduce magnetic components and to increase efficiency. This topology can be used in several European countries e.g. Germany. Other countries require a transformer. While using a boost converter to boost the low PV voltage, shaping and inverting of the output current have to be done in the second converter stage at high voltage level.

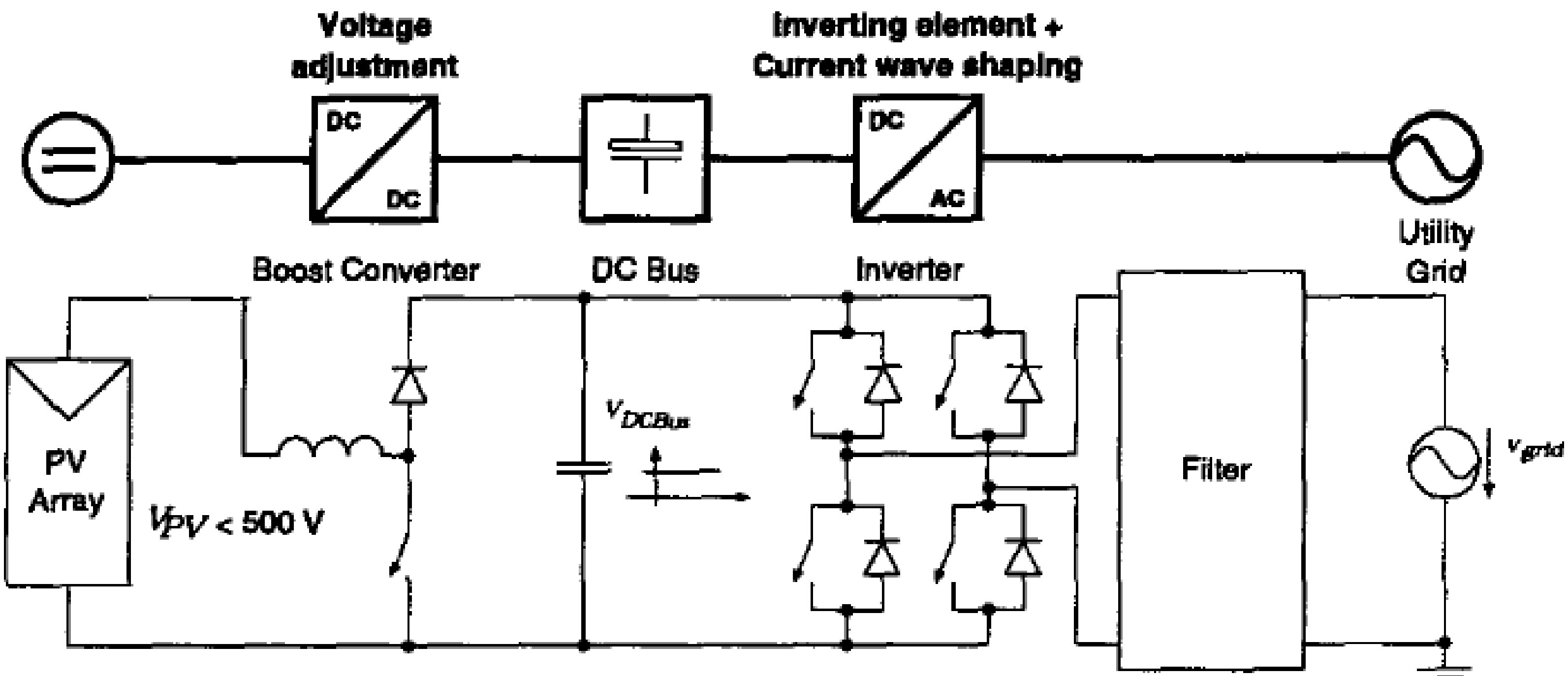


Fig. 6. Transformerless PV inverter with several conversion stages including boost stage.

Multi string inverter

- In order to achieve this goal a new inverter concept has been developed to combine the advantage of higher energy yield of a string inverter with the lower costs of a central inverter. Lower power DC/DC converters are connected to individual PV strings. Each PV string has its own MPP tracker which independently optimises the energy output from each PV string. To expand the system within a certain power range only a new string with a DC/DC converter has to be included.
-
- All DC/DC converters are connected via a DC bus through a central inverter to the grid. The central inverter is a PWM inverter based on the well-know and cheap IGBT technology already used in drive systems and includes all supervisory and protection functions.

Multi string inverter

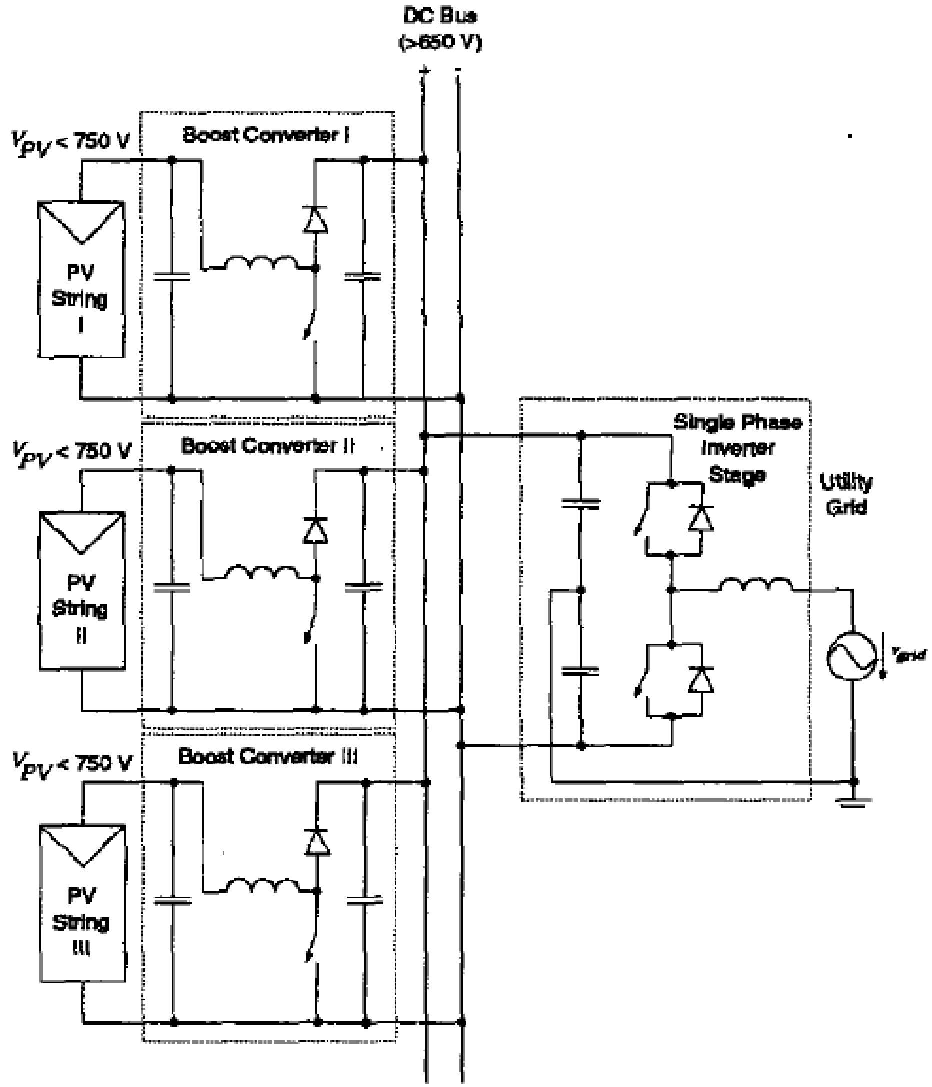


Fig. 7. Multi string inverter [4].

Describe the basic Grid Connected PV system design which has the following components:

- **PV Array**
- A number of PV panels connected in series and/ or in parallel giving a DC output out of the incident irradiance. Orientation and tilt of these panels are important design parameters, as well as shading from surrounding obstructions.
- **Inverter**
- A power converter that “inverts” the DC power from the panels into AC power. The characteristics of the output signal should match the voltage, frequency and power quality limits in the supply network.
- **Load**
- Stands for the network connected appliances in the building that are fed from the inverter, or, alternatively, from the grid.
- **Meters**
- They account for the energy being drawn from or fed into then local supply network.
- **Local Supply Network**
- A single or three-phase network managed by a Public electricity Supplier. The supply network acts both as a sink for energy surplus in the building or as a backup for low local generation periods

Explain surge and lightning protection

- A surge is a transient electrical fluctuation that happens in a fraction of a second and can cause serious damage to electronic and electromechanical equipment. They can be caused by lightning strikes and local power utility company “spikes” which can enter your business or home through the electrical system i.e. Cable television, telephone wiring etc and attack any electrical equipment attached to them.

Grid-Connected Photovoltaic Inverter GC-1000 Model Series

- The GC-1000 is a 1KW DC to AC grid tied inverter designed for residential and commercial on site power generation systems. Manufactured for both indoor and outdoor use, this complete inverter package meets all code requirements and provides maximum efficiency, reliability, and case of installation. The inverter can be purchased as a single unit or as part of a packaged systems which includes a string combiner, GFI protection, and DC and AC disconnects. An optional interactive data monitor is also available.

GC-1000 1kW Grid – Connected Photovoltaic Inverter

- The GC-100 is a 1kW DC to AC grid tied inverter designed for residential and commercial grid-tied, battery less photovoltaic systems. Certified for both indoor and outdoor use, the complete inverter package meets all the code requirements and provides maximum efficiency, reliability, and ease of installation. The package, which includes a string combiner, DC and AC disconnects, and GFI protection, can be purchased in standard and low-voltage configuration. An optional interactive data monitor is also available.

Write the requirements for energy connected to the LV network via inverters

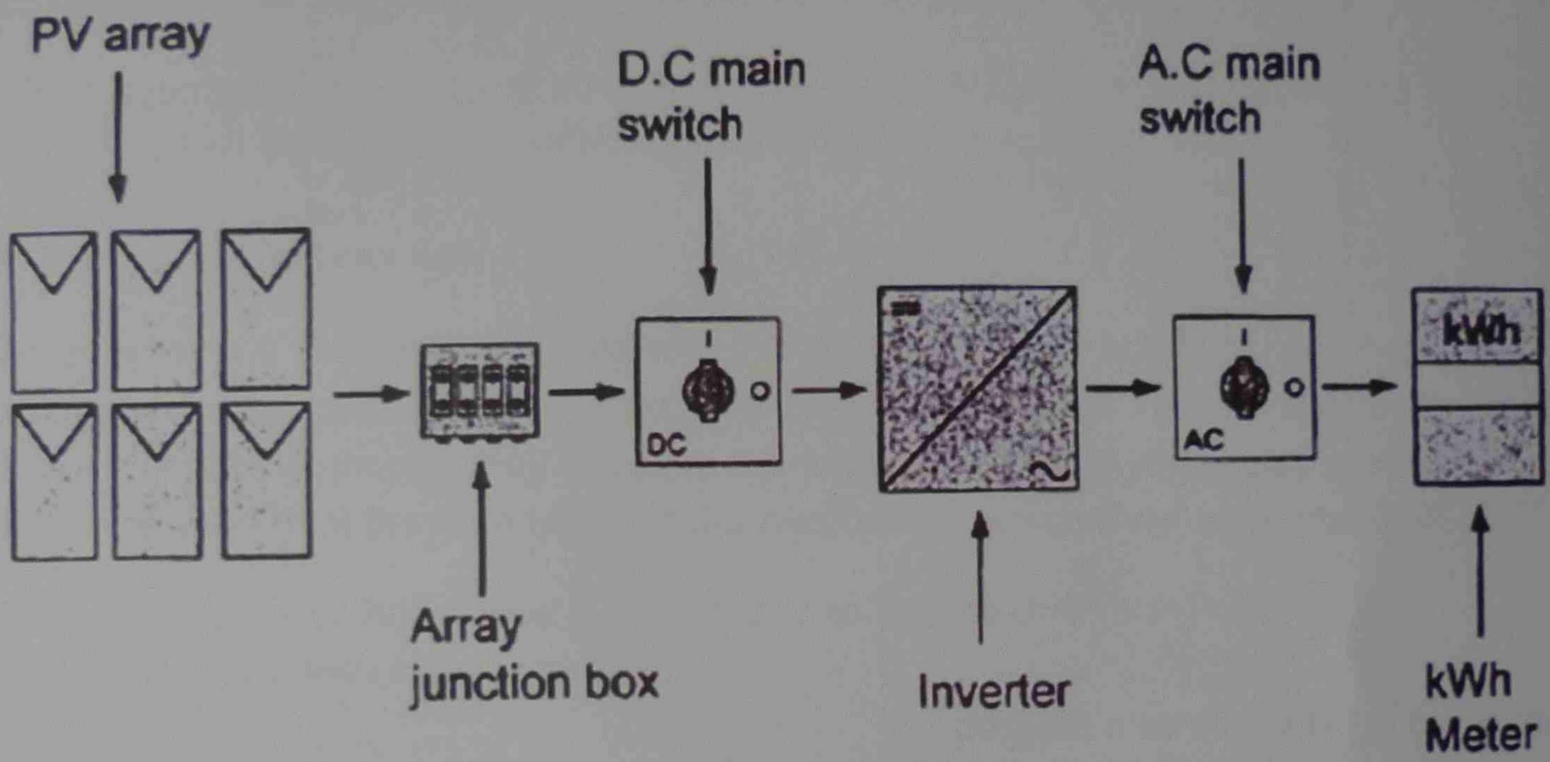
- Standards Australia has released three standards which are pertinent to Grid-Connected inverter systems are:
- AS 4777.1 -2002 Grid Connection of Energy System via Inverter Part (1): Installation Requirements.
- AS 4777.2-2002 Grid Connection of Energy System via Inverters Part (2): Inverter Requirements
- AS 4777.3 -2002 Grid Connection of Energy System cia Inverters Part(3) : Grid Protection Requirements.
- Inverters must be tested against AS 4777.2-2002 by an appropriate laboratory accredited to test to AS 4777 (Clean Energy Council 2008)

Describe islanding detection for photovoltaic grid connected inverter

- Islanding operation can be detected or monitored by passive or active islanding detection method. Passive method includes detecting rate of change of frequency, voltage phase jump and three-phase voltage drop monitoring. With active islanding operation detection method frequency shift, active frequency drift – AFD, E NS (impedance measurement), and reactive power fluctuation are detected and monitored. ENS disconnects inverter from the grid.

AS 1768 Lightning Protection
ASNZS 1170.2 Wind Loads
AS 4777 Grid Connections of Energy Systems via Inverters

The diagram below shows in pictorial form a standard domestic grid connected PV system and its major components



Power in a DC circuit is calculated simply by multiplying voltage times current.

VOLTS x AMPS or

V x I.

EXAMPLE

A solar panel has a output voltage of 30V and a short circuit current of 5.5A. Calculate the power of that module.

30 x 5.5 = 165 Watts

Power in a AC circuit is a little more complex in that the power factor of the circuit load must be taken into account. The power is then calculated by multiplying the product of voltage and current by the power factor.

VOLTS x AMPS x POWER FACTOR or

$P = V \times I \cos\theta$

1.1.2 PARALLEL CIRCUITS

In parallel circuits the voltage is the same as the voltage in any part of the circuit. In the previous example the open circuit voltage would be 30V.

NOTE it is important that panels with different voltages or current / voltage curves should not be connected together in parallel.

If six panels each with a short circuit current of 5.5A were connected in parallel then the total circuit current would be the sum of the individual panel current.

EXAMPLE

$I_T = I_1 + I_2 + I_3 + I_4 + I_5 + I_6$

$= 5.5 + 5.5 + 5.5 + 5.5 + 5.5 + 5.5$

$=$ 33 A *ANSWER*

1.1.3 SERIES CIRCUITS

In a series circuit the total voltage is the sum of all the voltages in that circuit

$VT = V1 + V2 + V3$ etc.

EXAMPLE

A string of six photovoltaic panels are connected in series. Their open circuit voltage is 30V. Find the total circuit voltage.

$V_T = V_1 + V_2 + V_3 + V_4 + V_5 + V_6$

$= 30\ V + 30\ V + 30\ V + 30\ V + 30\ V + 30\ V$

$= 180V$ *ANSWER*

1.2 SERIES PARALLEL CIRCUITS

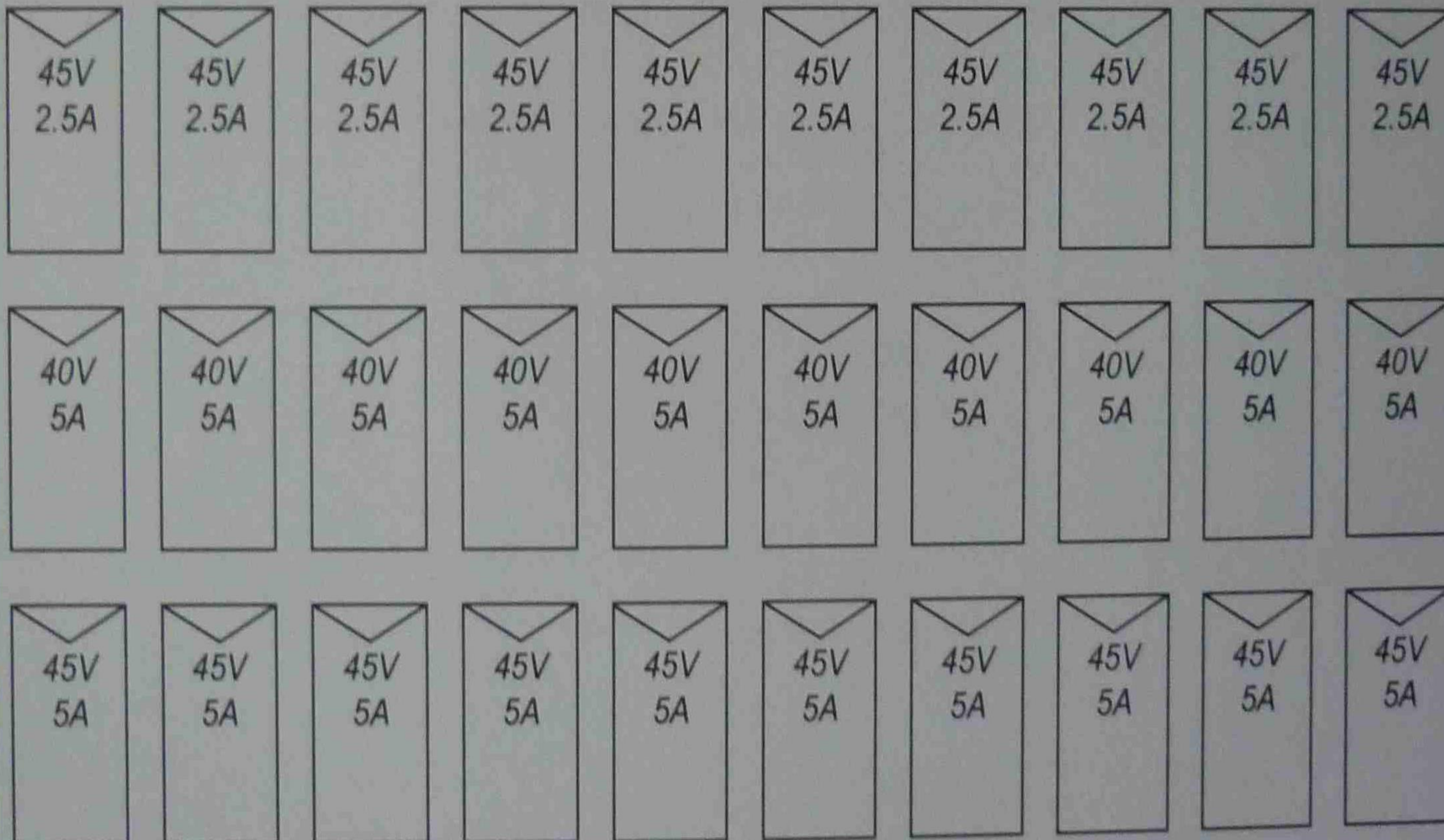
Often it is necessary to combine series and parallel arrangements of panels in order to provide the calculated power output also comply with the voltage requirements of the inverter .

For example, if 10 panels at 200W each were required to provide the power requirements of a 2KW system. If the open circuit voltage of each panel is 45V and the maximum input voltage to the inverter is 280V DC, the panels would need to be connected in a combination of series and parallel.

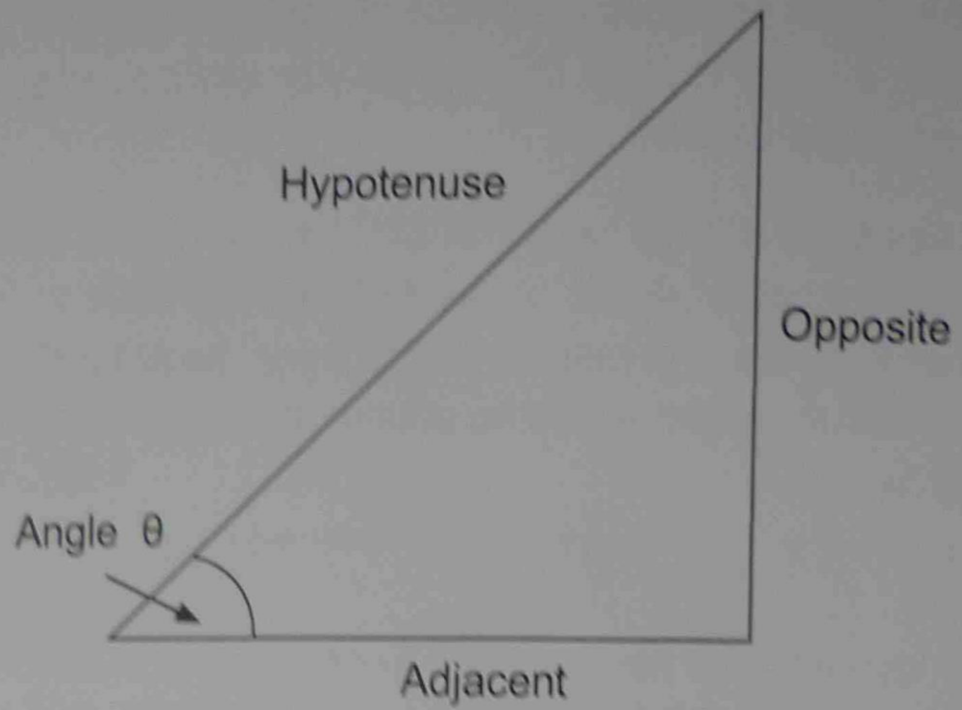
In this case 5 panels times the voltage would be 225V so this would work even if the voltage increased by 10%. Another series connected 5 panels could then be connected in parallel with the other sting and the output voltage would be still 225V and the power would be 2KW and the circuit current would be double. If the panel current (Isc) is 5A the total current would be 10A.

EXERCISE

The following diagram contains ten panels. Each panel is rated at 45V and 5A. Select the row of panels that provide 225V and 10A. Two parrallel strings of 5 panels.



View the triangle below and observe and record the sides of the triangle



If we know the angle θ then we can calculate the ratios of the sides using the following

$$\text{Sine of angle } \theta = \frac{\textit{opposite}}{\textit{hypotenuse}}$$

$$\text{Sin } \theta = \frac{\textit{opp}}{\textit{hyp}}$$

Cosine of angle θ $= \dfrac{adjacent}{hypotenuse}$

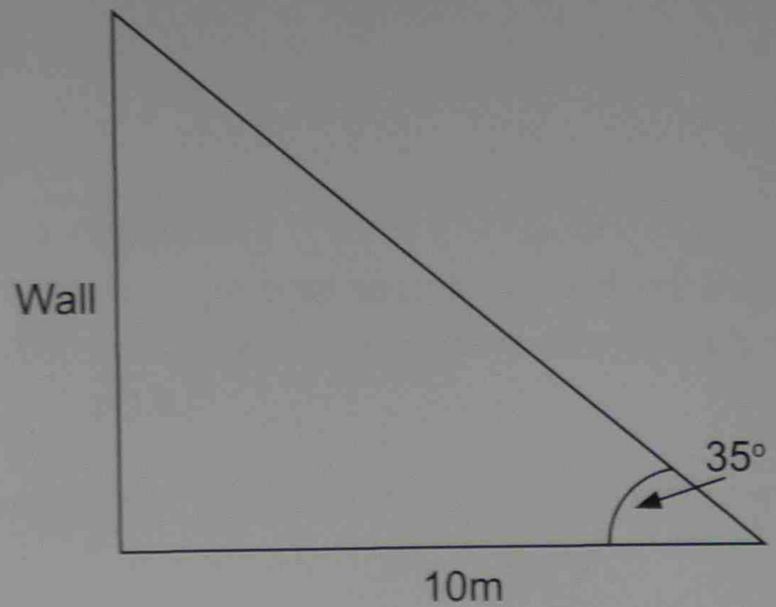
Cos θ $= \dfrac{adj}{hyp}$

Tangent of angle θ $= \dfrac{opposite}{adjacent}$

Tan θ $= \dfrac{opp}{adj}$

EXAMPLE

Find the height of the wall in the following diagram



$$\text{Tan } \theta = \frac{opp}{adj}$$

$$\text{Opp.} = \tan \theta \times adj$$

$$= 0.700 \times 10$$

$$= 7.00 \text{ m} \quad \textit{Answer}$$

1.4.2 APPARENT POWER is measured in volt/amperes and is usually expressed as (VA) Transformers, gen sets etc. are usually rated in VA because the current rating of the output device is the limiting factor for the output of the device.

EXAMPLE

$$S = V \times I$$

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

$$= \frac{1{,}000\ W}{240V}$$

$$= 4.167 \quad \textit{ANSWER}$$

1.4.3 REACTIVE POWER is calculated by using the line current that flows into the reactive components only. Because reactive power does not consume watts then it is measured in volt/amperes reactive or VAR.

$$Q = V \times I \sin\theta$$

Power factor is the ratio of true power to apparent power. If apparent power was multiplied by that ratio the result would be true power.

$$Pf\,(\lambda) = \cos\theta = \frac{R}{Z}$$

1.5.1 PERCENTAGES

Often amounts are expressed as a percentage of the total amount .as voltage may be expressed as a percentage of the total volts .In such a case the calculation would be –

$$\% = \frac{\text{amount}}{\text{(total amount)}} \times \frac{100}{1}$$

EXAMPLE

The voltage drop in the cables of a 240 v circuit was measured to be 15v .Calculate the percent voltage drop ?

$$Vd\ \% = \frac{15}{240} \times \frac{100}{1}$$

$$Vd = 6.25\ \%$$

1.5.2 COMPOUNDING

If a number was to be increased by a certain rate or percentage then the number

would be multiplied by that that rate sample (A). If the number was then to be increased each period by that rate it the number would then be compounded by the number of periods sample (B).

(A) Number x $(1 + r)$

(B) Number x $(1 + r)^n$

EXAMPLE

If electricity was charged at a rate (R) of 15 cents per unit and it was due to rise at a rate of 10% per year for the next five years how much would electricity (Rf) be charged for in five years time ?

$$Rf = R(1 + r)^n$$

$$Rf = 15c(1 + 0.1)^5$$

1.6 PRACTICAL EXERCISE

Go to the Clean Energy Council website and down load

a) A list of approved grid connect inverters.

b) A list of approved panels.

Select a poly crystalline panel of about 100 W and obtain a brochure and specifications for that panel.

Select a 1.5KW inverter from that list and obtain a brochure that contains the panels specifications.

Attach a copy of this information to your answer sheet.

For the inverter write the following:-

Maximum input voltage_______________

Minimum input voltage_______________

Maximum power rating_______________

For the panel write the following:-

Power maximum power point_______________

Short circuit current rating (Isc)_______________

Open circuit voltage (Voc)_______________

Temperature Co efficient of power_______________

2.1 SOLAR GEOMETRY

As the source of energy is dependent on the sun and the installation of solar equipment is dependent on the position of the sun it is important to understand the position of the sun and the importance it has in designing the photovoltaic grid connect system.

In this section you should learn the apparent motion of the sun and be able to determine the suns position in respect to the horizon for any point of latitude and longitude.

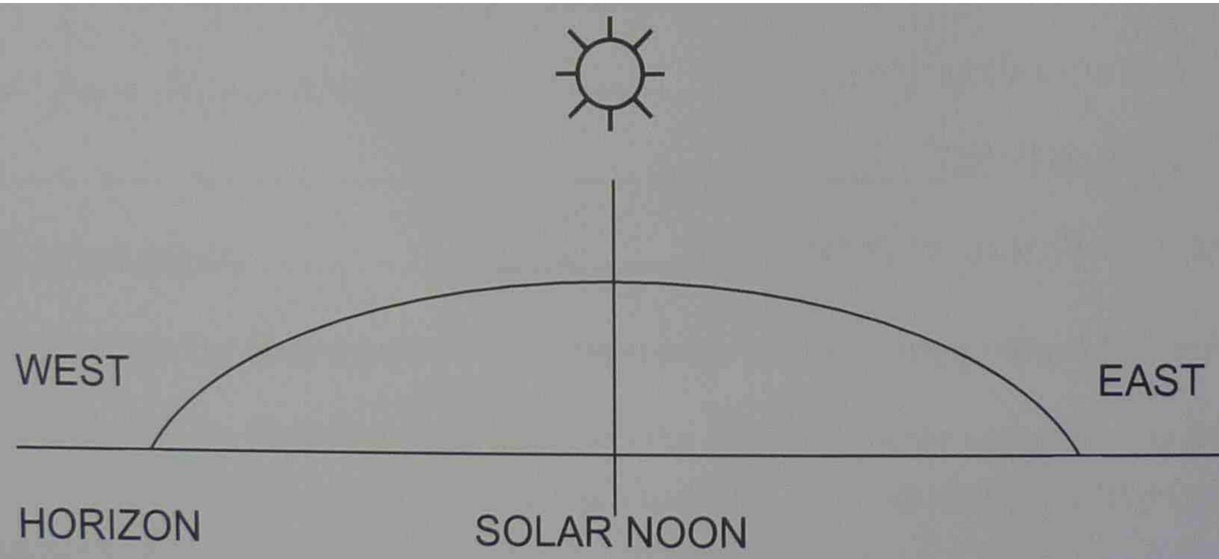
The sun appears to move through the sky. It rises in the east and reaches its highest point it solar noon then continues its arc downwards to the west.

When looking at the horizon the sun appears to make a curved path in the sky. It will appear on the horizon and follow an arc reaching the highest point at **SOLAR NOON**. At this point the position of the sun would be true north (when viewed from a position in the Southern hemisphere).

NOTE the difference between Noon and Solar Noon

The sun's path would then move further to the west and at the same time to be ever decreasing in height until it sets on the horizon in the West .

NOTE that this path is perfectly symmetrical and when the sun is at its highest point this is solar noon or exactly half way through the day.



2.1.1 SOLAR NOON is the exact middle of the day and when the sun is at the highest point in respect to the horizon. At solar noon the suns' position straight ahead will be **true north**. Solar noon is not necessarily midday as indicated by a watch. Time given by watches are local time and represent **time zones** and are not necessarily true time.

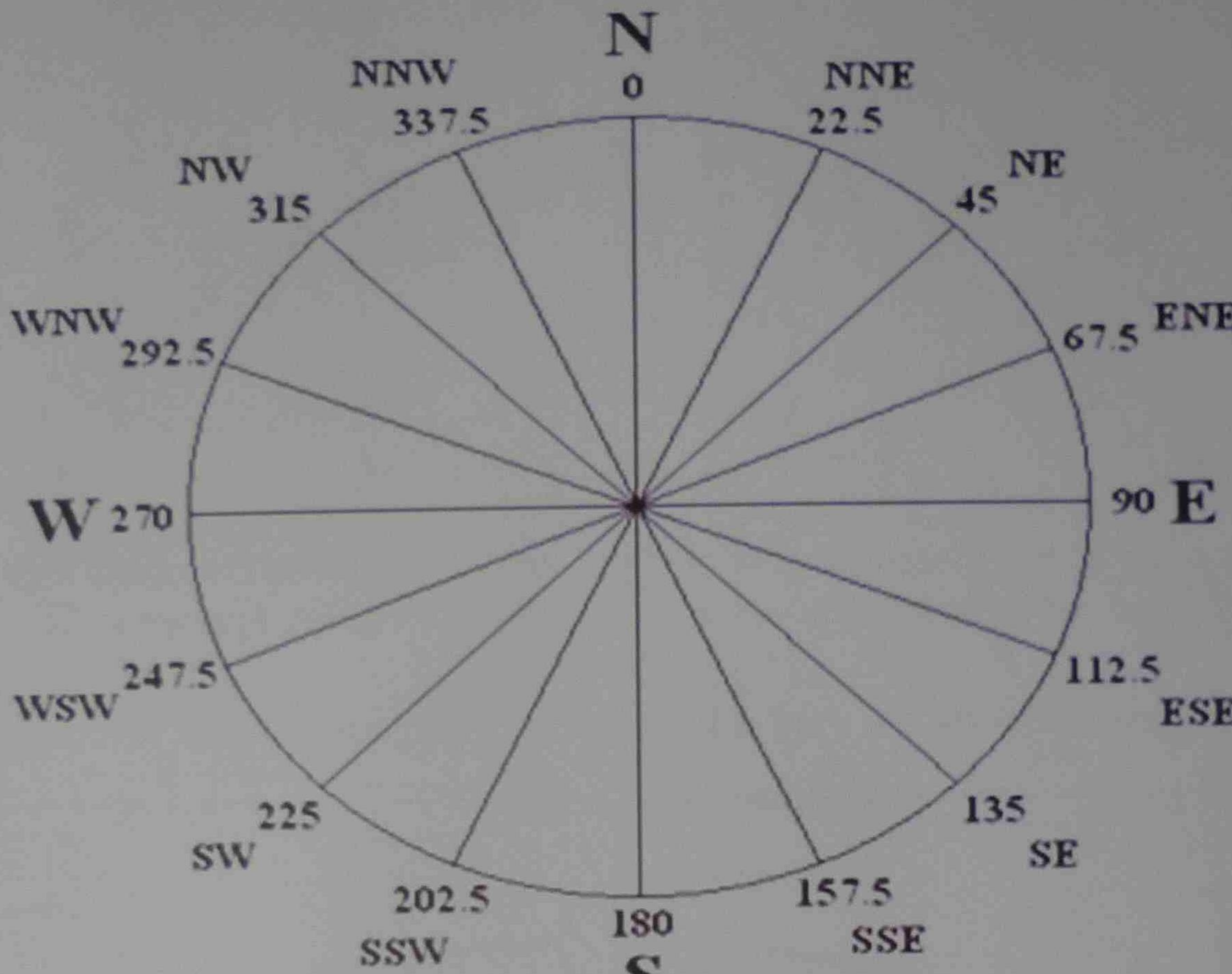
2.1.2 MAGNETIC DEVIATION and that there is a difference between **TRUE NORTH** and **MAGNETIC NORTH.** This deviation varies throughout AUSTRALIA and must be established for the location currently being determined. With the use of a bearing compass determine the direction of MAGNETIC NORTH.

Longitude is also necessary for finding time differences in time zones and from that true north can be found.

2.2 BEARINGS

A directional compass is shown below. It is used to find a direction or bearing .

Compass Rose



Cardinal points are shown as the four main directions of a compass. They are North (N), East (E), South (S) and West (W).

Half-cardinal points are North-east (NE), North-west (NW), South-east (SE) and South-west (SW) as shown on the compass. The above compass rose shows degree measurements from 0° to 360° intervals with:

NORTH is shown as	0° or 360°
EAST is shown as	90°
SOUTH is shown as	180°
WEST is shown as	270°

When using a directional compass note that the magnetic needle always points to the north. Hold the compass so that the point marked south is closest to your body.

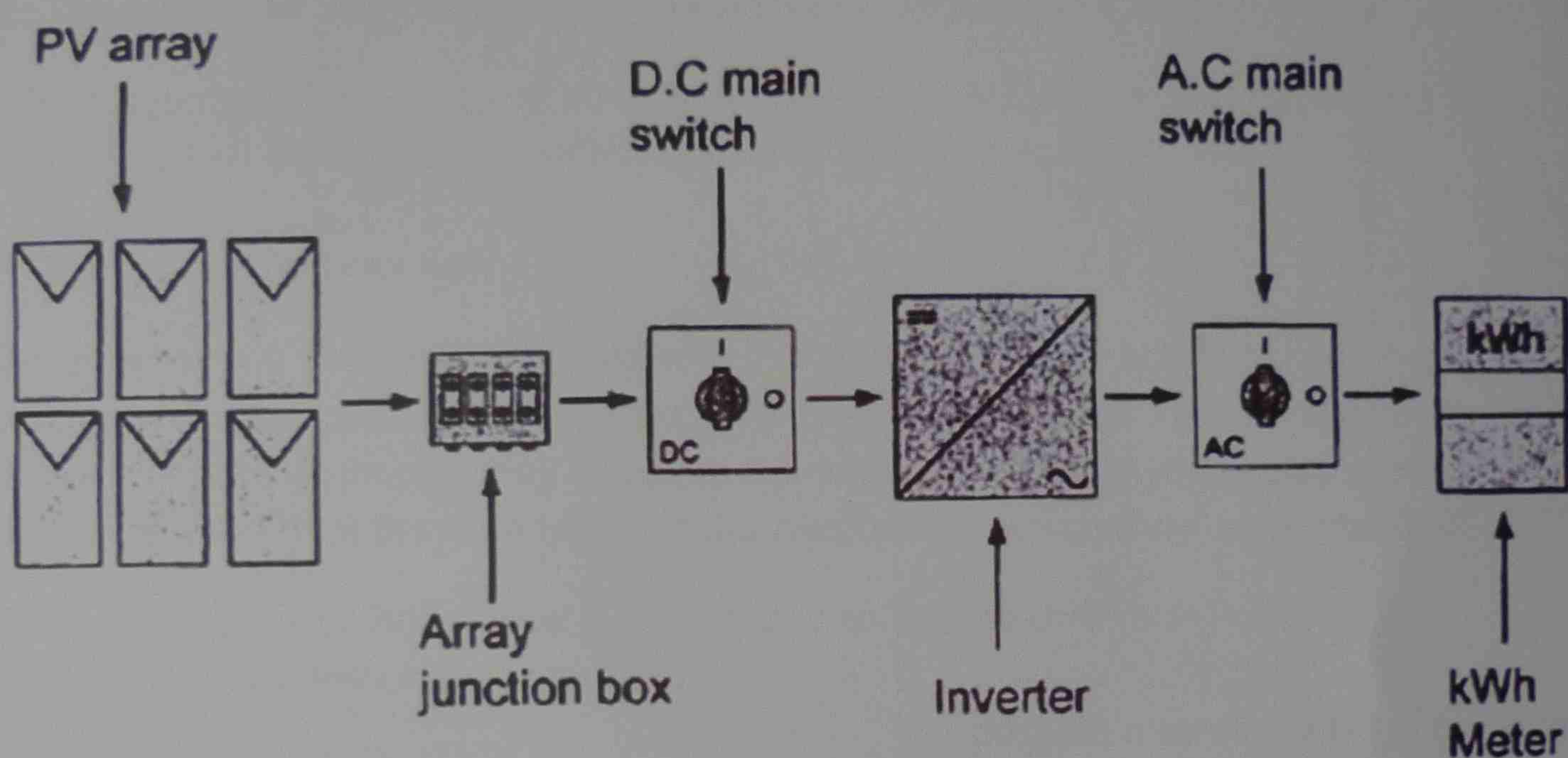
FIGURE 3.1 (in part) WIND REGIONS

If you're a Accredited Installer you MUST have and use a copy of these standards. They can be purchased from
www.standards.com.au

Other relevant standards include:

AS 1768 Lightning Protection
ASNZS 1170.2 Wind Loads
AS 4777 Grid Connections of Energy Systems via Inverters

The diagram below shows in pictorial form a standard domestic grid connected PV system and its major components



CONTENTS

Power in a DC circuit is calculated simply by multiplying voltage times current.

VOLTS x AMPS or

V x I.

EXAMPLE

A solar panel has a output voltage of 30V and a short circuit current of 5.5A. Calculate the power of that module.

30 x 5.5 = 165 Watts

Power in a AC circuit is a little more complex in that the power factor of the circuit load must be taken into account. The power is then calculated by multiplying the product of voltage and current by the power factor.

VOLTS x AMPS x POWER FACTOR or

$$P = V \times I \cos \theta$$

Power factor is expressed as Cos θ but this is used when dealing with sinusoidal wave-form. Power factor is generally expressed as lambda (λ), so the equation becomes

$$P = V \times I \lambda$$

With grid connect systems we are dealing with sine wave so the use of either equation is acceptable.

EXERCISE

A 240V AC supply is supplying a current of 5A to a load with a power factor of 0.8. Calculate the total power taken by the circuit?

____

____

____

____

____

____

1.1.2 PARALLEL CIRCUITS

In parallel circuits the voltage is the same as the voltage in any part of the circuit. In the previous example the open circuit voltage would be 30V.

NOTE it is important that panels with different voltages or current / voltage curves should not be connected together in parallel.

If six panels each with a short circuit current of 5.5A were connected in parallel then the total circuit current would be the sum of the individual panel current.

EXAMPLE

$I_T = I_1 + I_2 + I_3 + I_4 + I_5 + I_6$

$= 5.5 + 5.5 + 5.5 + 5.5 + 5.5 + 5.5$

= **33 A** *ANSWER*

1.1.3 SERIES CIRCUITS

In a series circuit the total voltage is the sum of all the voltages in that circuit

VT = V1 + V2 + V3 etc.

EXAMPLE

A string of six photovoltaic panels are connected in series. Their open circuit voltage is 30V. Find the total circuit voltage.

$V_T = V_1 + V_2 + V_3 + V_4 + V_5 + V_6$

$= 30\ V + 30\ V + 30\ V + 30\ V + 30\ V + 30\ V$

= **180V** *ANSWER*

In a series circuit the total current is limited to the current in any part of the circuit .

EXERCISE

A string of six photovoltaic panels are connected in series. Each panel can supply a current of 5.5A but one of the panels only has a maximum output current of 5.0. What is the total current for that circuit?

____

____

____

____

____

____

1.2 SERIES PARALLEL CIRCUITS

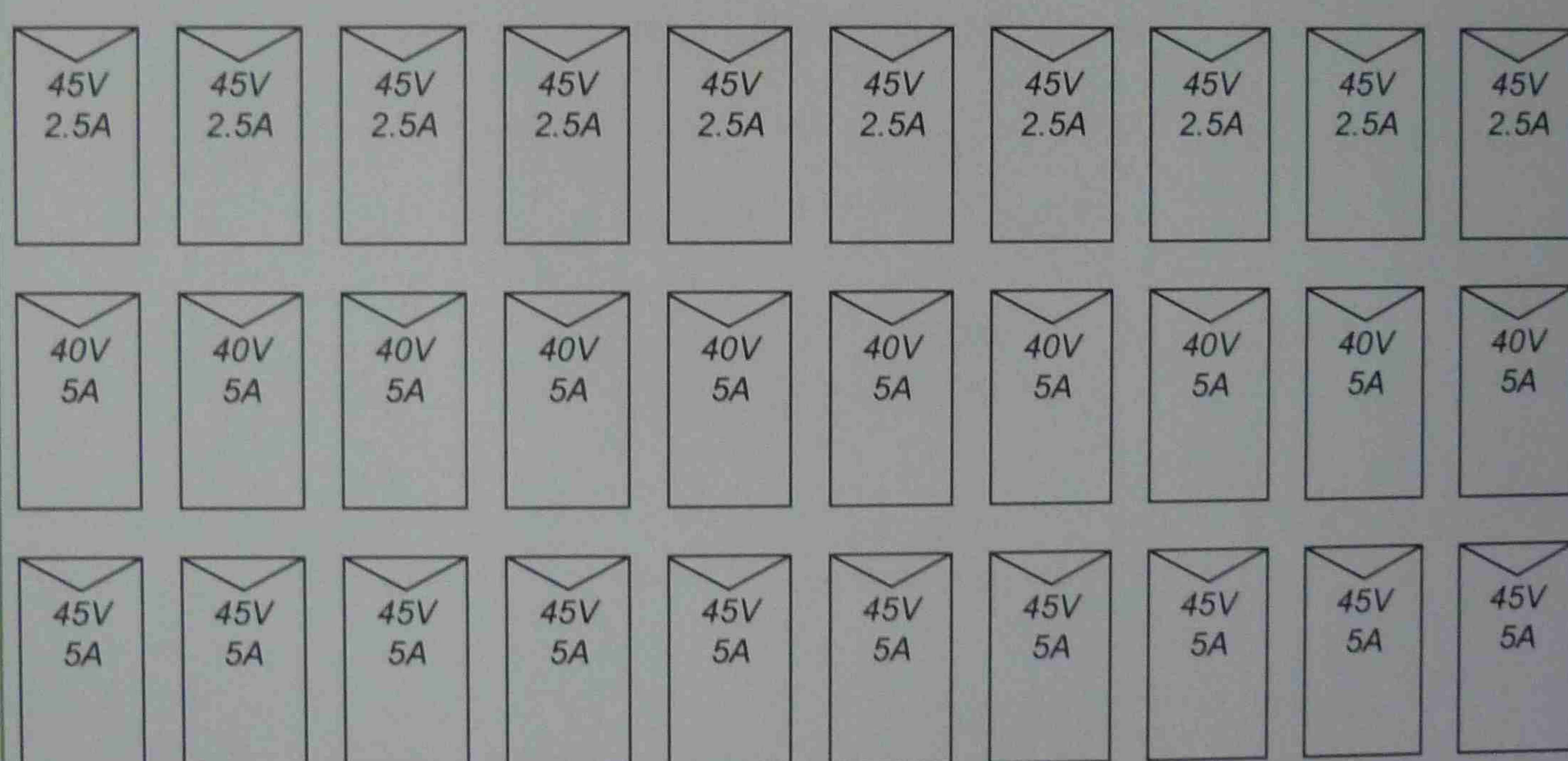
Often it is necessary to combine series and parallel arrangements of panels in order to provide the calculated power output also comply with the voltage requirements of the inverter .

For example, if 10 panels at 200W each were required to provide the power requirements of a 2KW system. If the open circuit voltage of each panel is 45V and the maximum input voltage to the inverter is 280V DC, the panels would need to be connected in a combination of series and parallel.

In this case 5 panels times the voltage would be 225V so this would work even if the voltage increased by 10%. Another series connected 5 panels could then be connected in parallel with the other sting and the output voltage would be still 225V and the power would be 2KW and the circuit current would be double. If the panel current (Isc) is 5A the total current would be 10A.

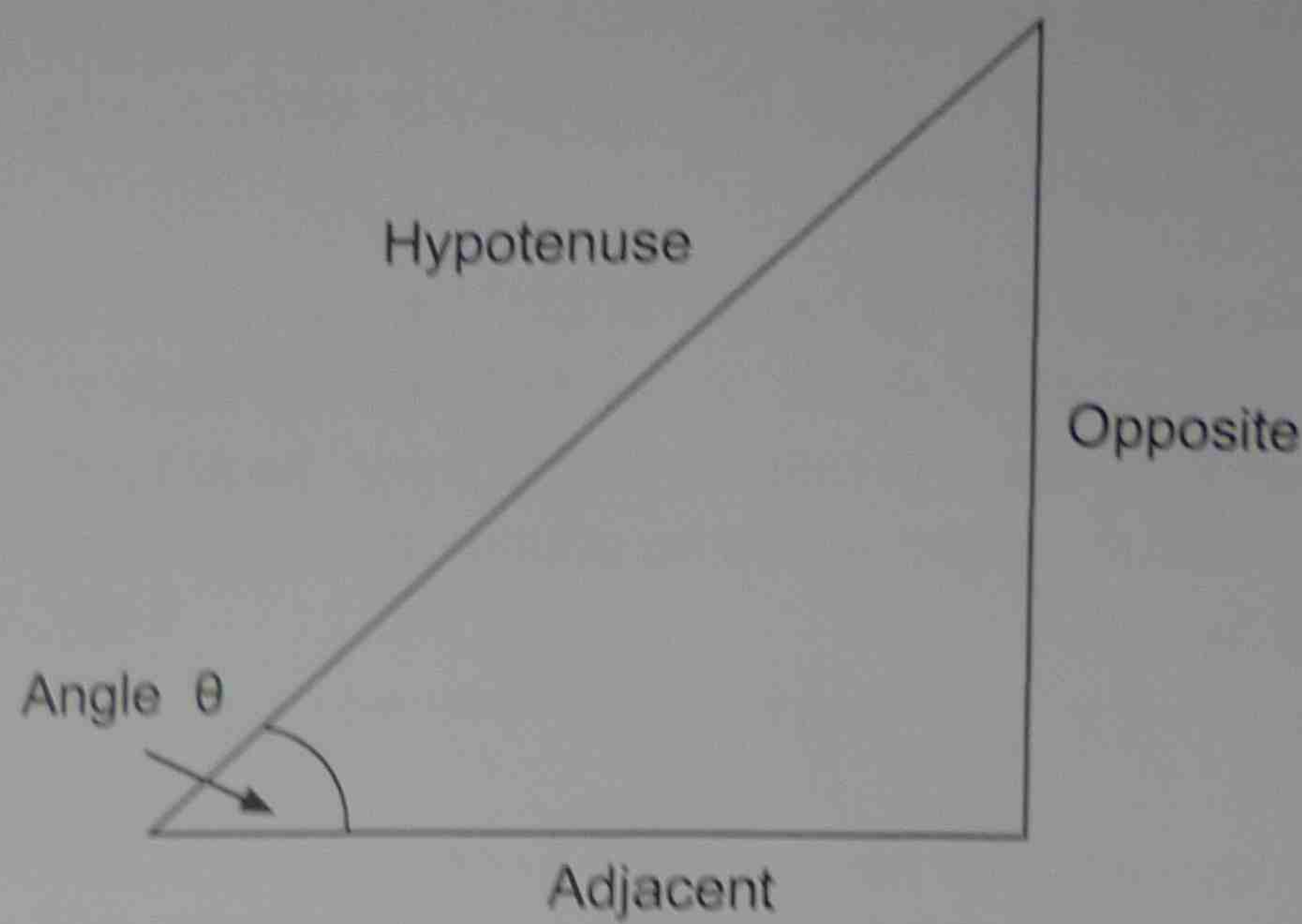
EXERCISE

The following diagram contains ten panels. Each panel is rated at 45V and 5A. Select the row of panels that provide 225V and 10A. Two parrallel strings of 5 panels.



Trigonometry is the study of the ratios of the sides on a right angle triangle. This study can be used not only for determining the combined forces acting in different directions but also for physical measurements such as the height of obstacles and structures.

View the triangle below and observe and record the sides of the triangle



If we know the angle θ then we can calculate the ratios of the sides using the following

$$\text{Sine of angle } \theta = \frac{\text{opposite}}{\text{hypotenuse}}$$

$$\text{Sin } \theta = \frac{\text{opp}}{\text{hyp}}$$

$$\text{Cosine of angle } \theta = \frac{\text{adjacent}}{\text{hypotenuse}}$$

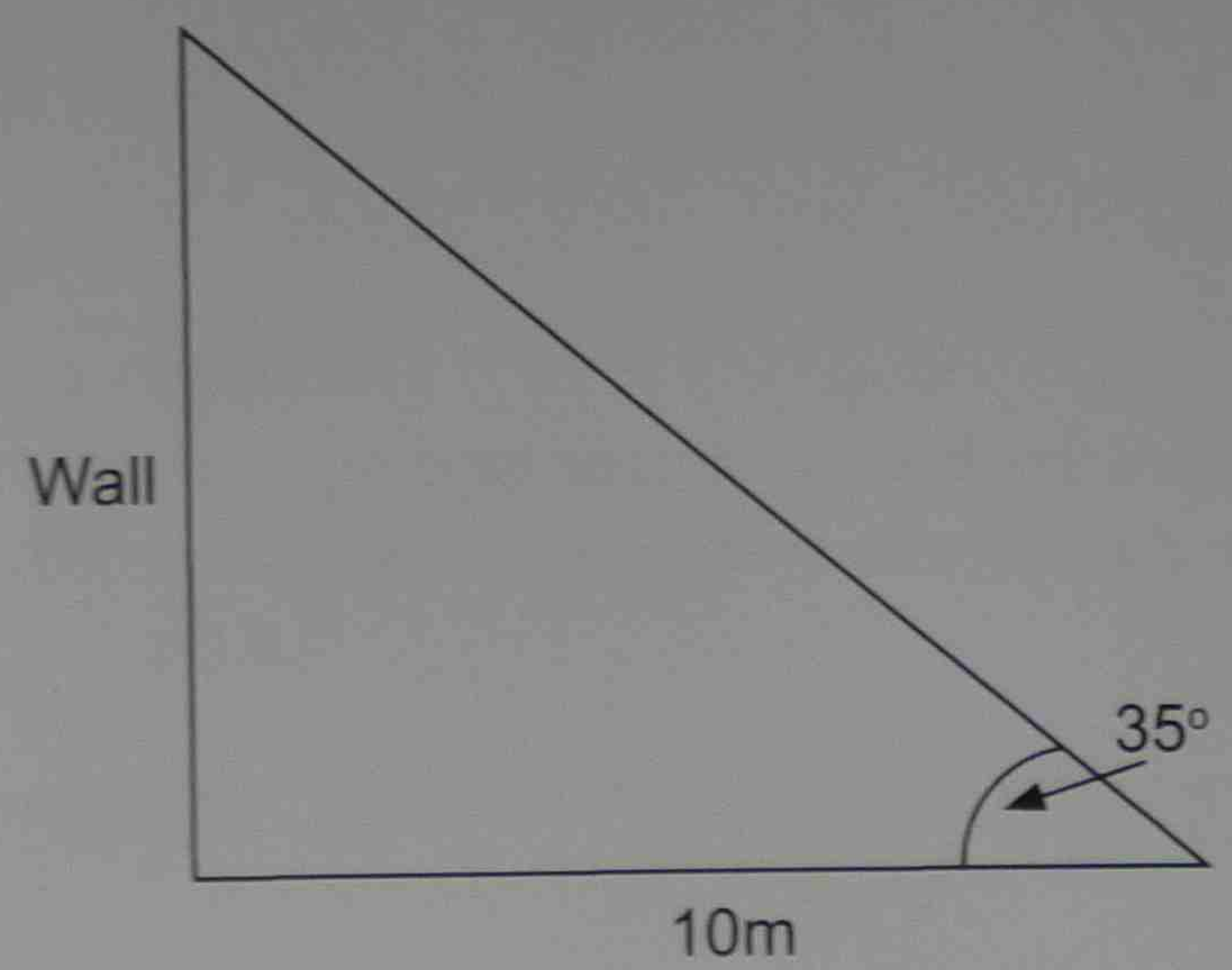
$$\text{Cos } \theta = \frac{\text{adj}}{\text{hyp}}$$

$$\text{Tangent of angle } \theta = \frac{\text{opposite}}{\text{adjacent}}$$

$$\text{Tan } \theta = \frac{\text{opp}}{\text{adj}}$$

EXAMPLE

Find the height of the wall in the following diagram



$$\tan \theta = \frac{opp}{adj}$$

$$\begin{aligned} \text{Opp.} &= \tan \theta \times adj \\ &= 0.700 \times 10 \\ &= 7.00 \text{ m} \end{aligned}$$ *Answer*

When dealing with AC loads it is important to take into consideration out of phase components to determine

True power (P)
Apparent power (S)
Reactive power (Q)

1.4.1 TRUE POWER takes into account the leading and/or lagging components of the circuit. As we are dealing with sinusoidal waveform the true power can be calculated by

$$P = VI \cos \theta$$

EXERCISE

A circuit with a power factor of 0.8 is supplied by a 240V a.c. inverter with a maximum output current of 5A. Calculate the output power.

$$P = 240V \times 5A \times \cos \theta$$

= ___________

1.4.2 APPARENT POWER is measured in volt/amperes and is usually expressed as (VA) Transformers, gen sets etc. are usually rated in VA because the current rating of the output device is the limiting factor for the output of the device.

EXAMPLE

$$S = V \times I$$

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

$$= \frac{1{,}000\ W}{240V}$$

$= 4.167$ *ANSWER*

1.4.3 REACTIVE POWER is calculated by using the line current that flows into the reactive components only. Because reactive power does not consume watts then it is measured in volt/amperes reactive or VAR.

$$Q = V \times I \sin \theta$$

Power factor is the ratio of true power to apparent power. If apparent power was multiplied by that ratio the result would be true power.

$$Pf\ (\lambda) = \cos \theta = \frac{R}{Z}$$

Also

$$Pf\ (\lambda) = \cos \theta = \frac{P}{S}$$

EXAMPLE

An inverter rated at 1100 W is to be connected to a 240V load. Assuming the power factor is 0.8. Calculate the maximum current of the load.

$$P = VI \cos\theta$$

So

$$I = \frac{P}{(v \times \cos\theta)}$$

$$= \frac{1100}{(240 \times 0.8)}$$

$$= 5.73\text{ A} \quad \textit{Answer}$$

1.5 SAMPLE CALCULATIONS

1.5.1 PERCENTAGES

Often amounts are expressed as a percentage of the total amount .as voltage may be expressed as a percentage of the total volts .In such a case the calculation would be –

$$\% = \frac{\text{amount}}{(\text{total amount})} \times \frac{100}{1}$$

EXAMPLE

The voltage drop in the cables of a 240 v circuit was measured to be 15v .Calculate the percent voltage drop ?

$$Vd\ \% = \frac{15}{240} \times \frac{100}{1}$$

$$Vd = 6.25\ \%$$

When dealing with the efficiency of a electrical apparatus the efficiency is given and the required output is known the required input can be calculated.

EXAMPLE

A power supply is 95% efficient and the output is 1250W. Calculate the input required. If the power supply represents 95% of the input, dividing it by 95 will give 1% of the input.

So

$$P_{in} = \frac{1250}{95}$$

$$P_{in} = 13.1578$$

This answer would give 1% of the input. Now if it was multiplied by 100 then the amount would equal 100%.

P_{in} = 13.1578 x 100

P in = 1315.78W *ANSWER*

OR we could simply divide 1250 by 0.95

P in = 1315.78W *ANSWER*

If we needed to add a percentage to the total amount then we simply multiply the amount by a decimal point in front of the percentage amount.

EXAMPLE

The voltage of a 240v circuit increased by 5%

V increased = V (1 + 0.05)

= 252 v *ANSWER*

The voltage of a circuit has increased by 50%

V increased = V (1 + 0.50)

= 360 v *ANSWER*

The answer may also be calculated by adding 5% to 240V and 50% to 240V.

240v x 0.05 = 12 v

240 v + 12v = 252 v *ANSWER*

And

240v x 0.50 = 120 v

240v + 120v = 360 v *ANSWER*

1.5.2 COMPOUNDING

If a number was to be increased by a certain rate or percentage then the number would be multiplied by that that rate sample (A). If the number was then to be increased each period by that rate it the number would then be compounded by the number of periods sample (B).

(A) Number x (1 + r)

(B) Number x $(1 + r)^n$

EXAMPLE

If electricity was charged at a rate (R) of 15 cents per unit and it was due to rise at a rate of 10% per year for the next five years how much would electricity (Rf) be charged for in five years time ?

Rf = $R (1 + r)^n$

Rf = $15c (1 + 0.1)^5$

1.6 PRACTICAL EXERCISE

Go to the Clean Energy Council website and down load

a) A list of approved grid connect inverters.

b) A list of approved panels.

Select a poly crystalline panel of about 100 W and obtain a brochure and specifications for that panel.

Select a 1.5KW inverter from that list and obtain a brochure that contains the panels specifications.

Attach a copy of this information to your answer sheet.

For the inverter write the following:-

Maximum input voltage________________________________

Minimum input voltage________________________________

Maximum power rating________________________________

For the panel write the following:-

Power maximum power point________________________________

Short circuit current rating (Isc)________________________________

Open circuit voltage (Voc)________________________________

Temperature Co efficient of power________________________________

2.1 SOLAR GEOMETRY

As the source of energy is dependent on the sun and the installation of solar equipment is dependent on the position of the sun it is important to understand the position of the sun and the importance it has in designing the photovoltaic grid connect system.

In this section you should learn the apparent motion of the sun and be able to determine the suns position in respect to the horizon for any point of latitude and longitude.

The sun appears to move through the sky. It rises in the east and reaches its highest point it solar noon then continues its arc downwards to the west.

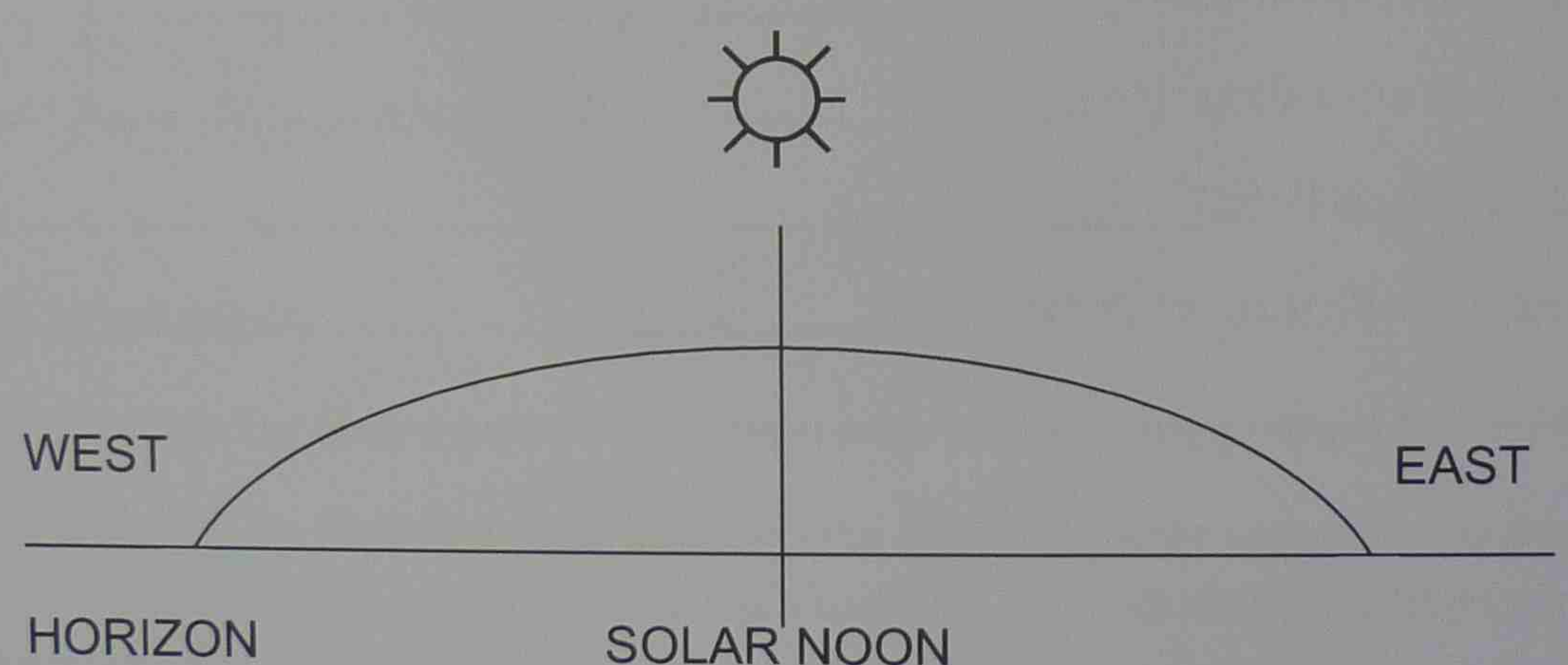
When looking at the horizon the sun appears to make a curved path in the sky. It will appear on the horizon and follow an arc reaching the highest point at **SOLAR NOON**. At this point the position of the sun would be true north (when viewed from a position in the Southern hemisphere).

NOTE the difference between Noon and Solar Noon

The sun's path would then move further to the west and at the same time to be ever decreasing in height until it sets on the horizon in the West .

NOTE that this path is perfectly symmetrical and when the sun is at its highest point this is solar noon or exactly half way through the day.

APPARENT MOTION OF THE SUN



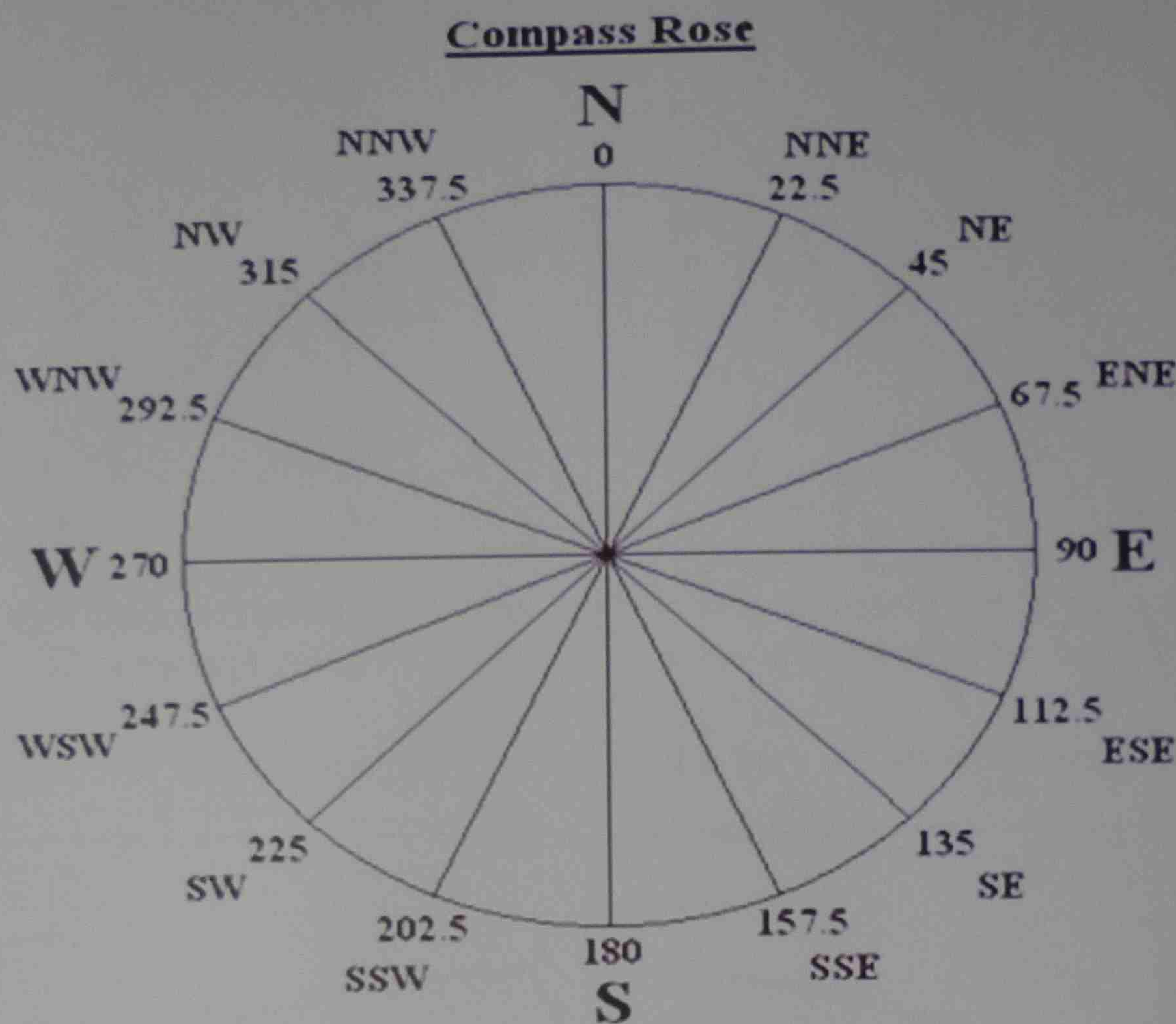
2.1.1 SOLAR NOON is the exact middle of the day and when the sun is at the highest point in respect to the horizon. At solar noon the suns' position straight ahead will be **true north**. Solar noon is not necessarily midday as indicated by a watch. Time given by watches are local time and represent **time zones** and are not necessarily true time.

2.1.2 MAGNETIC DEVIATION and that there is a difference between **TRUE NORTH** and **MAGNETIC NORTH.** This deviation varies throughout AUSTRALIA and must be established for the location currently being determined. With the use of a bearing compass determine the direction of MAGNETIC NORTH.

Longitude is also necessary for finding time differences in time zones and from that true north can be found.

2.2 BEARINGS

A directional compass is shown below. It is used to find a direction or bearing .



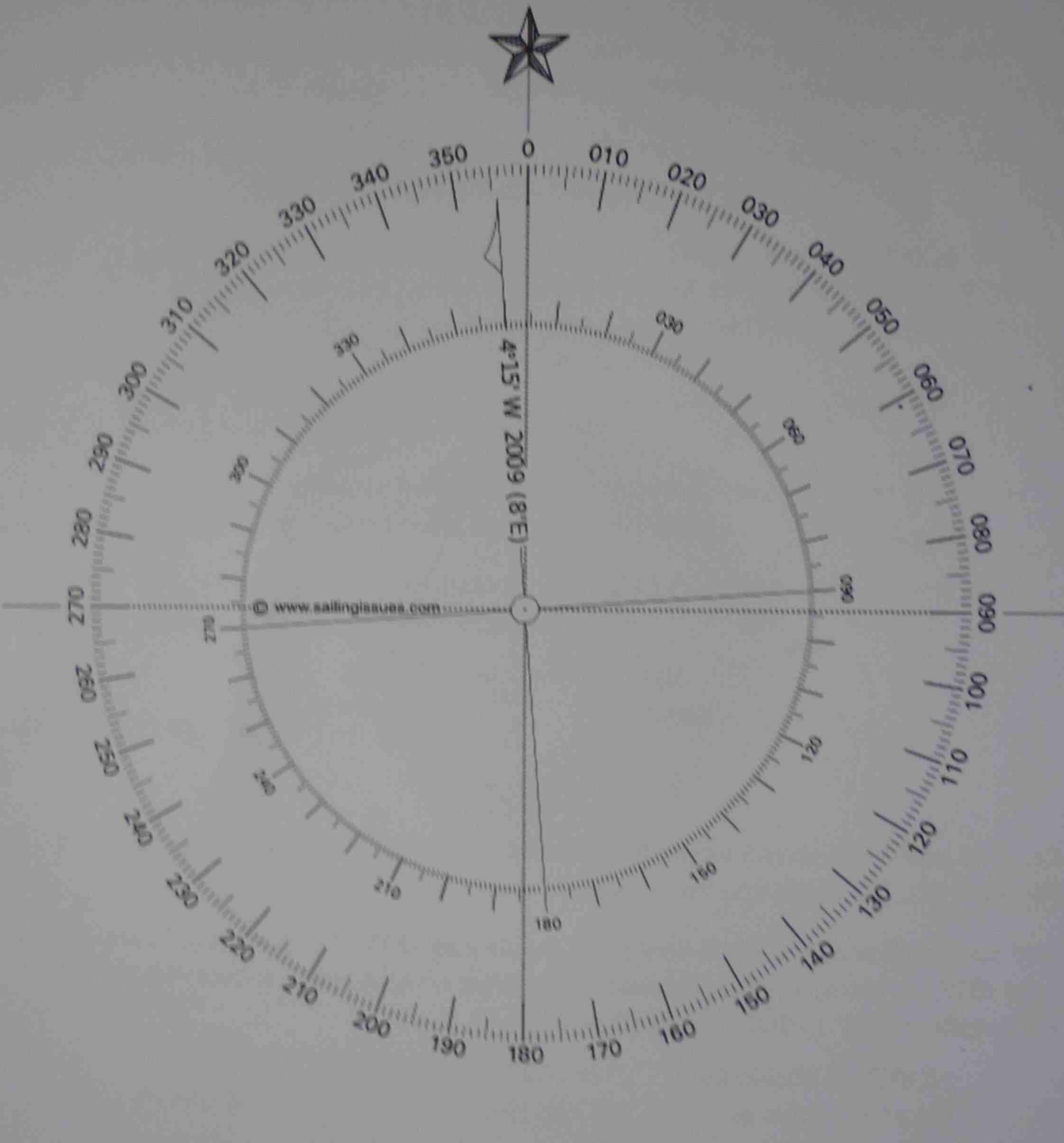
Cardinal points are shown as the four main directions of a compass. They are North (N), East (E), South (S) and West (W).

Half-cardinal points are North-east (NE), North-west (NW), South-east (SE) and South-west (SW) as shown on the compass. The above compass rose shows degree measurements from 0° to 360° intervals with:

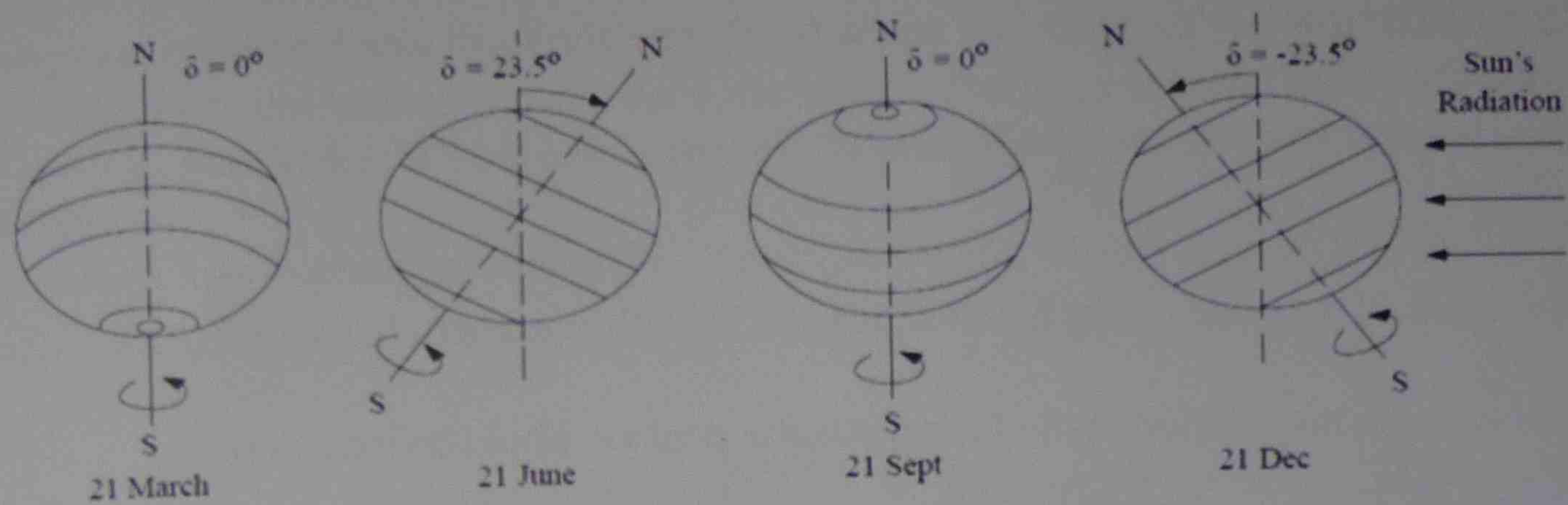
NORTH is shown as	0° or 360°
EAST is shown as	90°
SOUTH is shown as	180°
WEST is shown as	270°

When using a directional compass note that the magnetic needle always points to the north. Hold the compass so that the point marked south is closest to your body.

EXERCISE
In the diagram below the rose shows a magnetic deviation of 4°E draw a line that indicates true north for Sydney which has 13° difference.

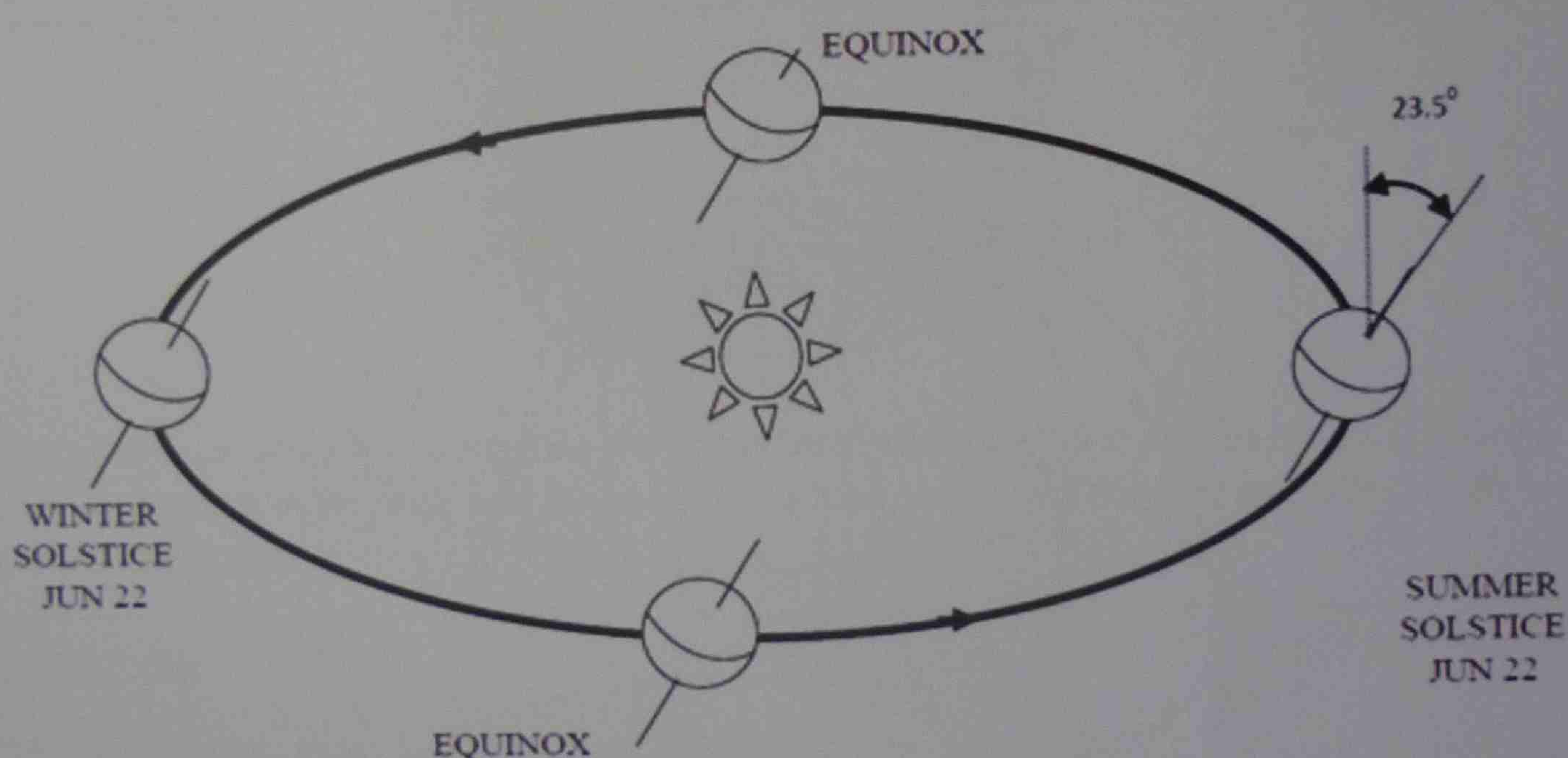


As the earth revolves around the sun each year, the inclination of the earth's axis remains fixed in space at an angle of 23.5 degrees away from the normal to the plane of rotation. The angle between the sun's direction and the equatorial plane is called the declination angle and will vary between 0 and 23.5 degrees with the seasons.



As the Earth tilts from Summer to Winter these tropics represent the maximum tilt and determine Summer and Winter. The maximum angle of the Earths' tilt is 23.5°

These dates, and the motion of the Earth about the Sun, are shown in the diagram below.



2.3 LONGITUDE and LATITUDE

Any position on the earth can be positioned by coordinates called **longitude** and **latitude.**

2.3.1 LATITUDE can be described as the position on the earth with regards to the poles. These are called lines of latitude and are lines that run parallel with the equator. In the southern hemisphere the lines of latitude are called **SOUTH LATITUDE**.

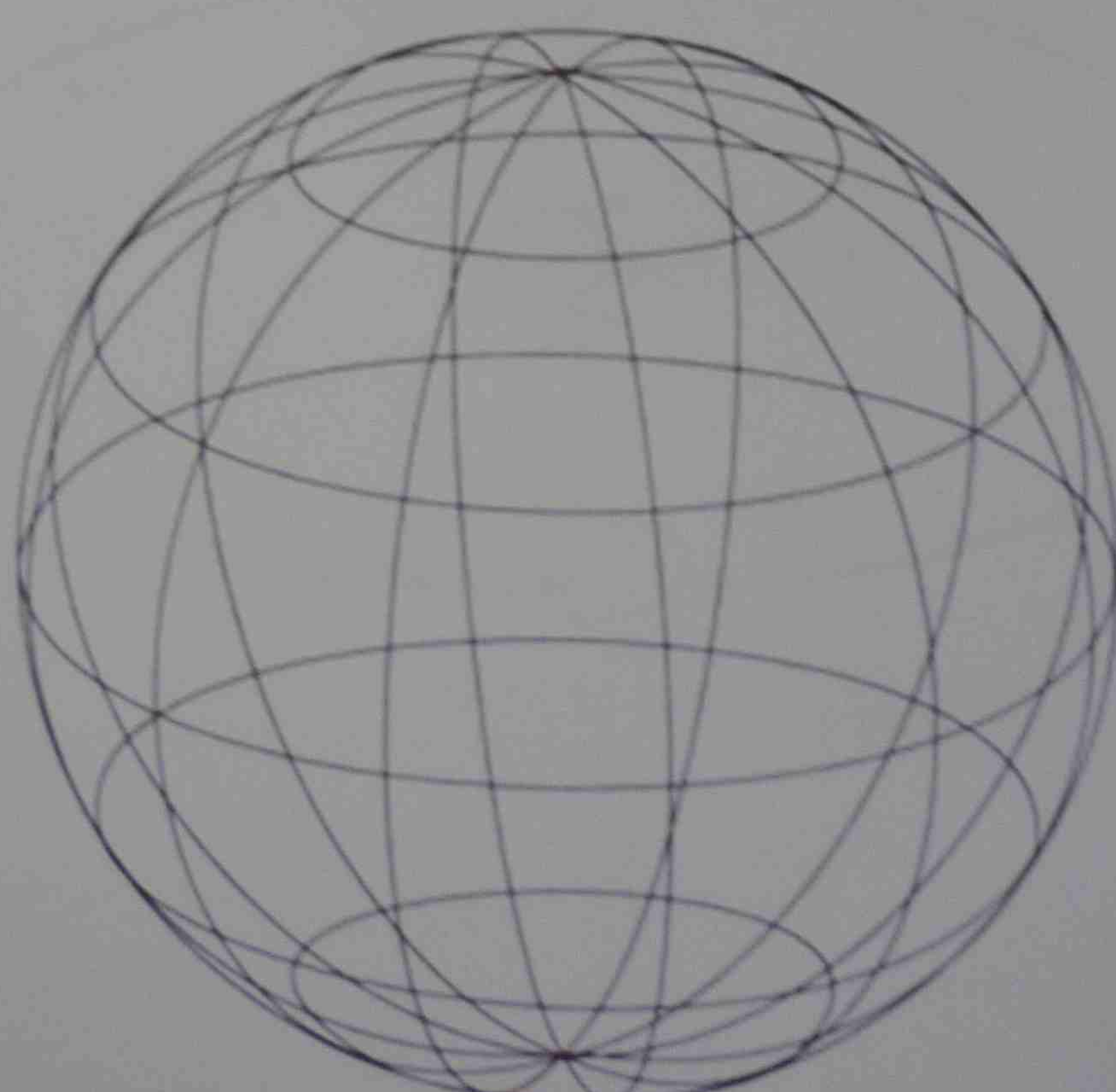
Shown as eg.

-34° or 34° SL both indicating that this position is on the southern half of the globe.

If we were on the northern half of the globe the position would be indicated as
34° or 34° NL

2.3.2 LONGITUDE are the lines running front h north pole to the south pole and the actual time of day can be calculated using the time at Greenwich and the number of degrees in a circle (EARTH).

EXERCISE
Using the globe below indicate lines of latitude and longitude.

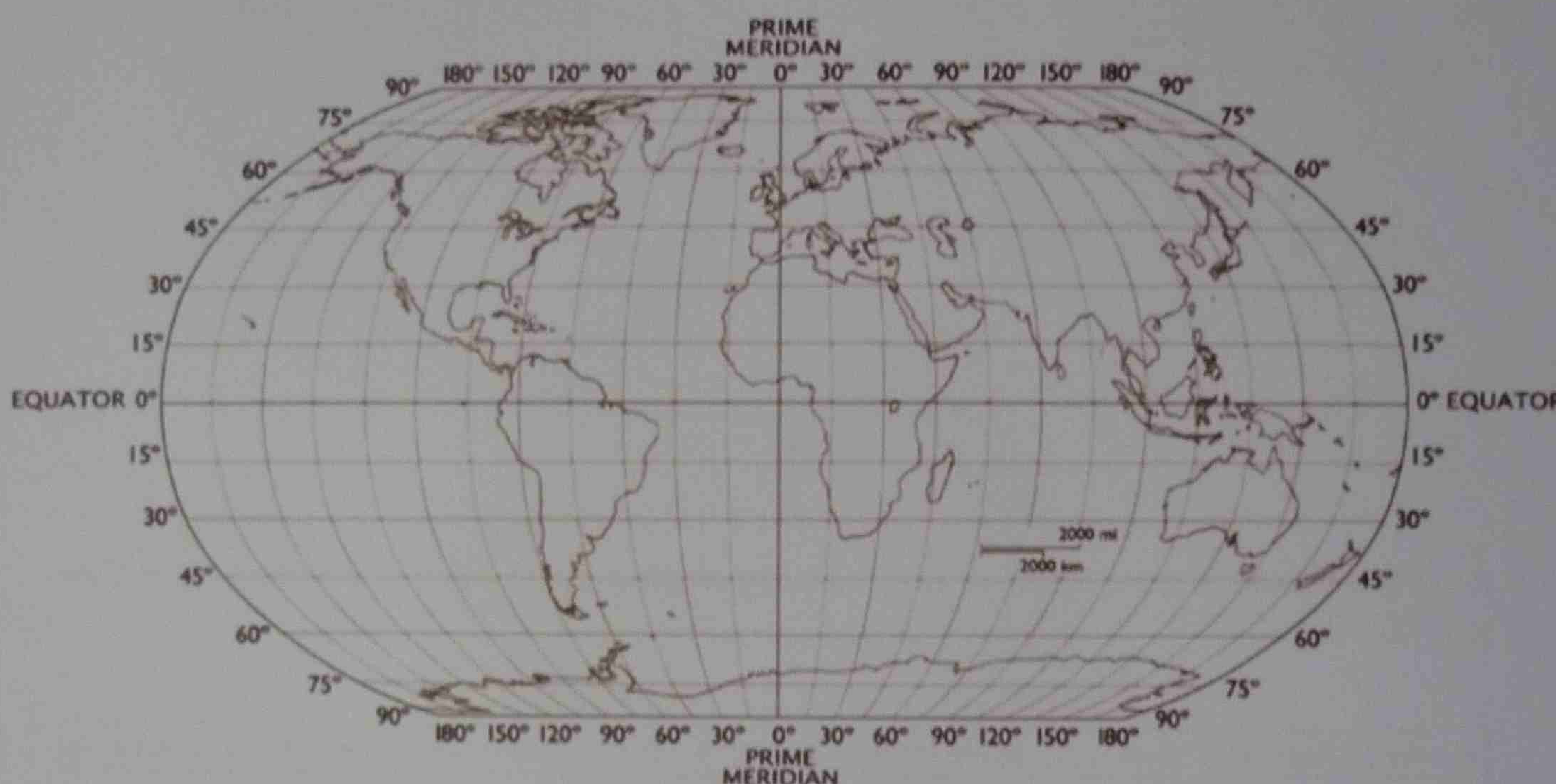


The following diagram is a world map with lines of longitude and latitude. Note the Prime Meridian which is a line through Greenwich marked as 0°.

The lines of longitude are marked (east longitude and west longitude). Those to the right of the Greenwich Meridian are east longitude. This means that Australia is east longitude and America to the left is west longitude.

EXERCISE

Draw two lines intersecting through Sydney representing latitude and longitude.



The earth is a circle and therefore there are 360° and that there are 24 hours in a day and 60 minutes in an hour and 60 seconds to the minute. So there are 4mins per degree of longitude

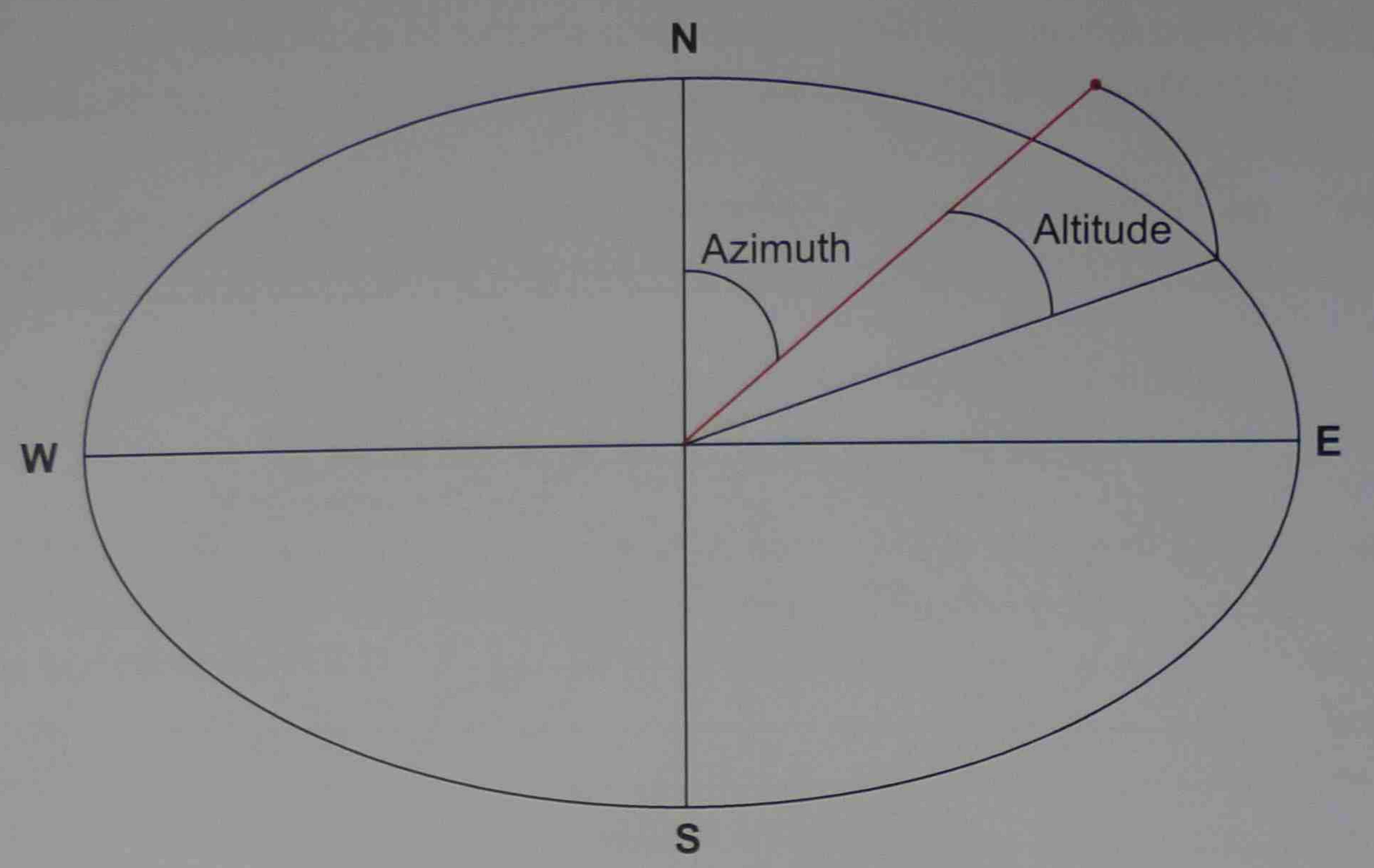
EXERCISE

360/ 24x60 minutes = 4 minutes per degree of latitude.

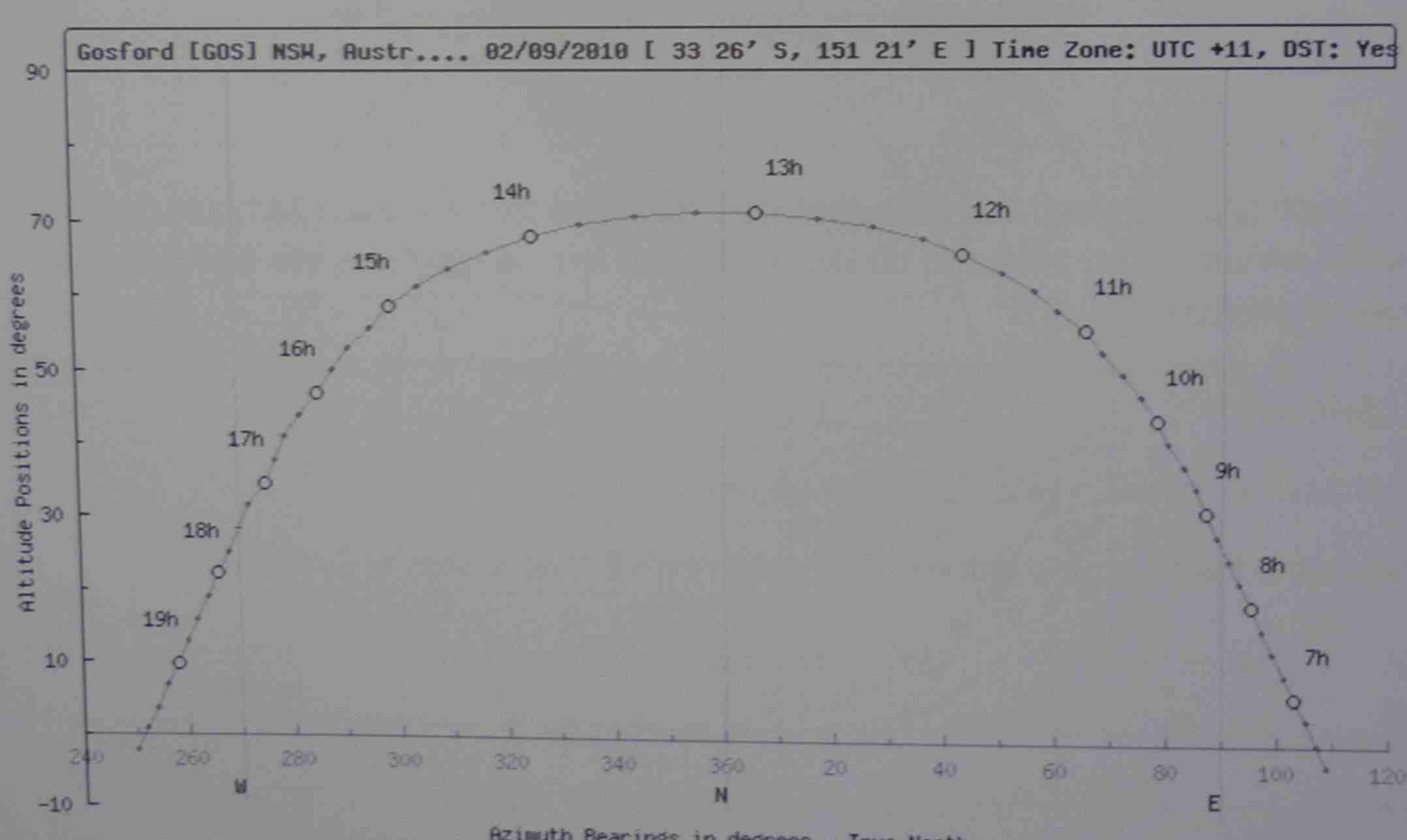
Determine the longitude of the sun at solar noon if it were 3am at Greenwich .

ANGLE.

The angle east or west to the sun from true north is called **AZIMUTH ANGLE.**



The diagram below shows bearing and altitude angles for the Sun's position over Gosford N.S.W.



The difference between **BEARING** and **AZIMUTH** is that a compass shows bearing angle and can be between 0° and 360°. The Azimuth angle is the angle from true north to true south and is angle from 0° to 180°.

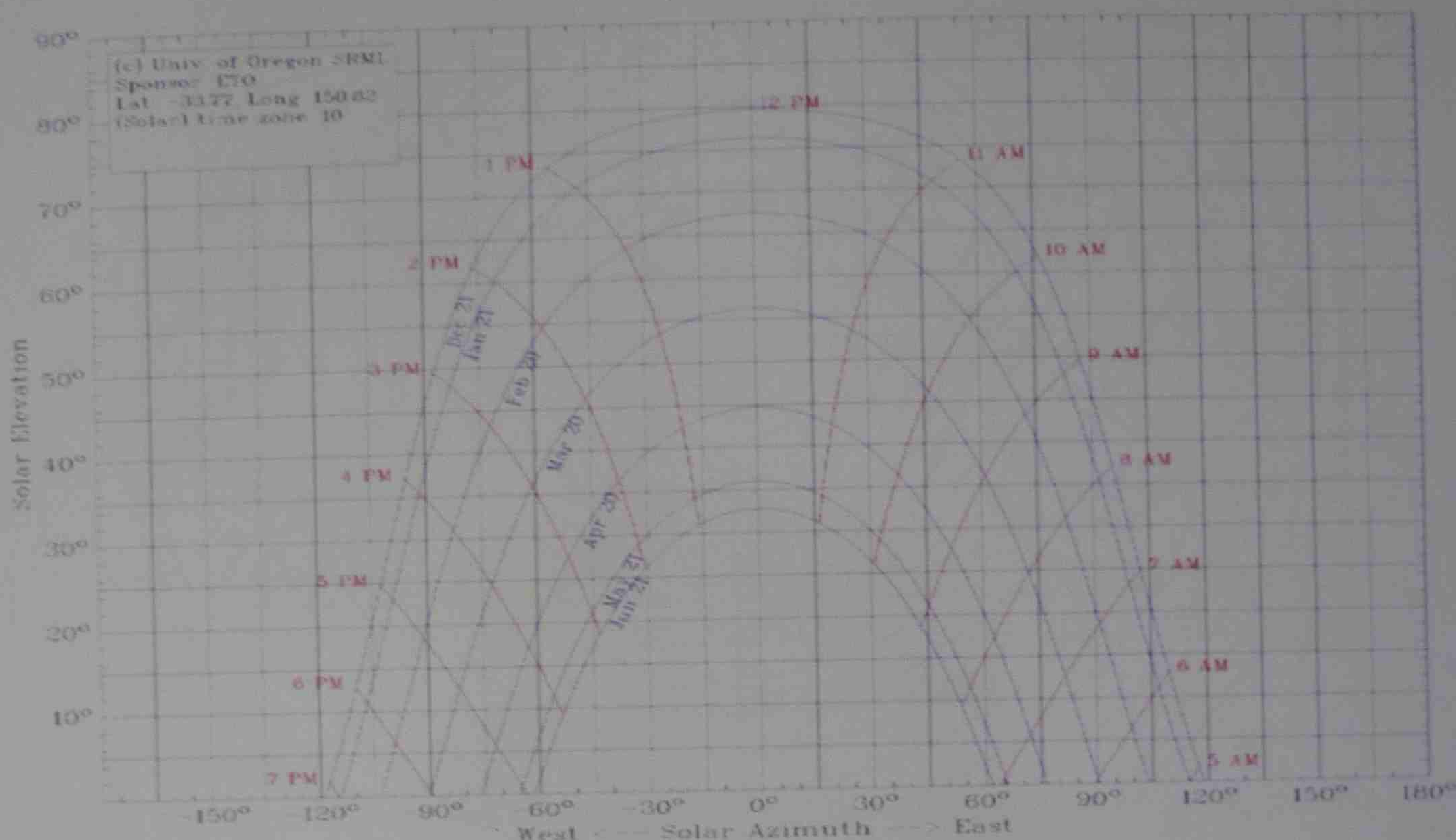
EXERCISE

Using the sunpath diagram below determine the position of the sun at 9.30am March 20.

Time ______________

Azimuth ______________

Altitude ______________



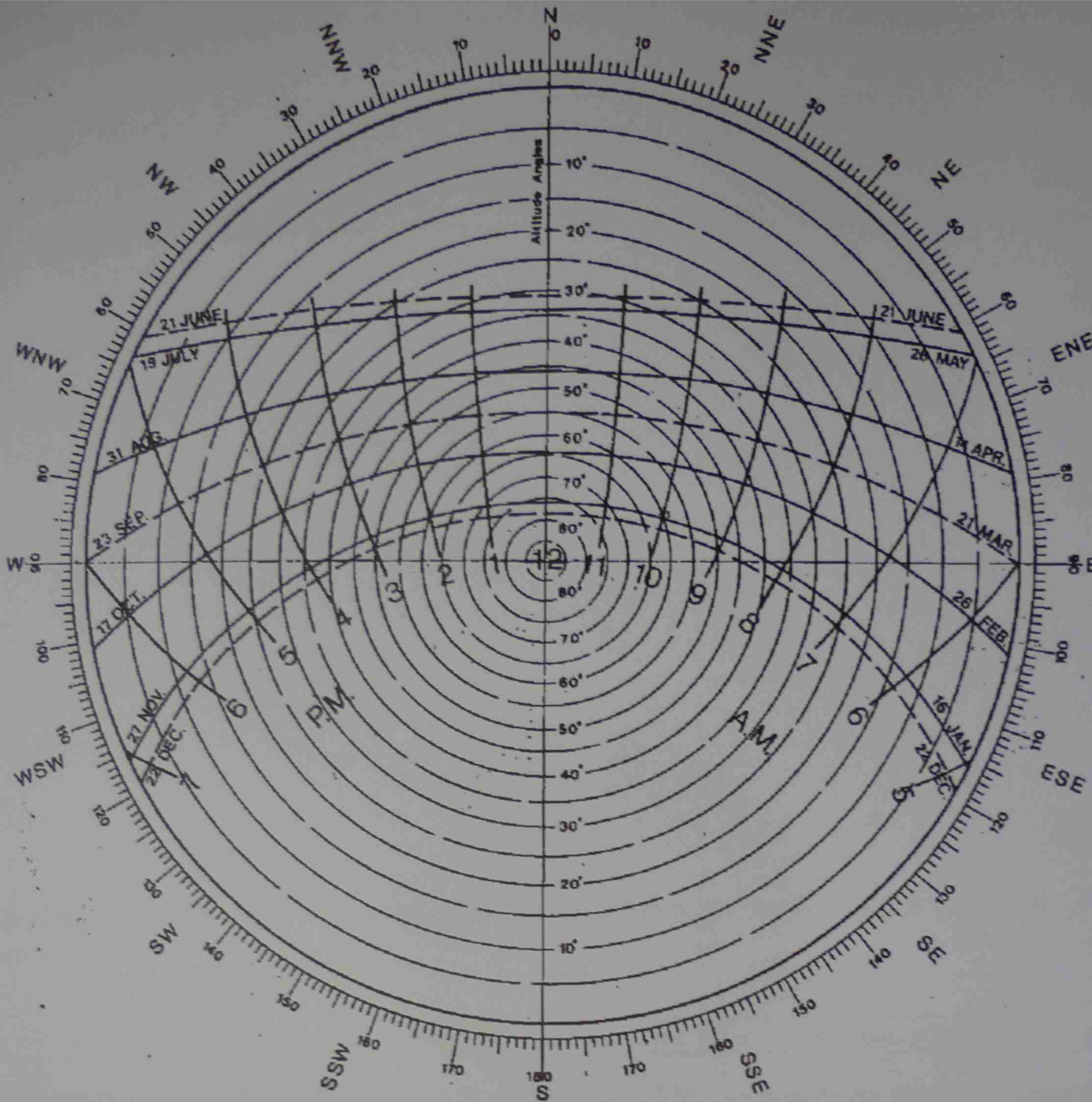
Sun path charts from University of Oregon Solar Radiation Monitoring Laboratory calculator pages

http://solardat.uoregon.edu/SunChartProgram.html

and

http://solardat.uoregon.edu/PolarSunChartProgram.html

Although the angle of latitude does influence the angle of tilt the solar panels will be mounted at, the latitude angle is not the angle of TILT (explained later).



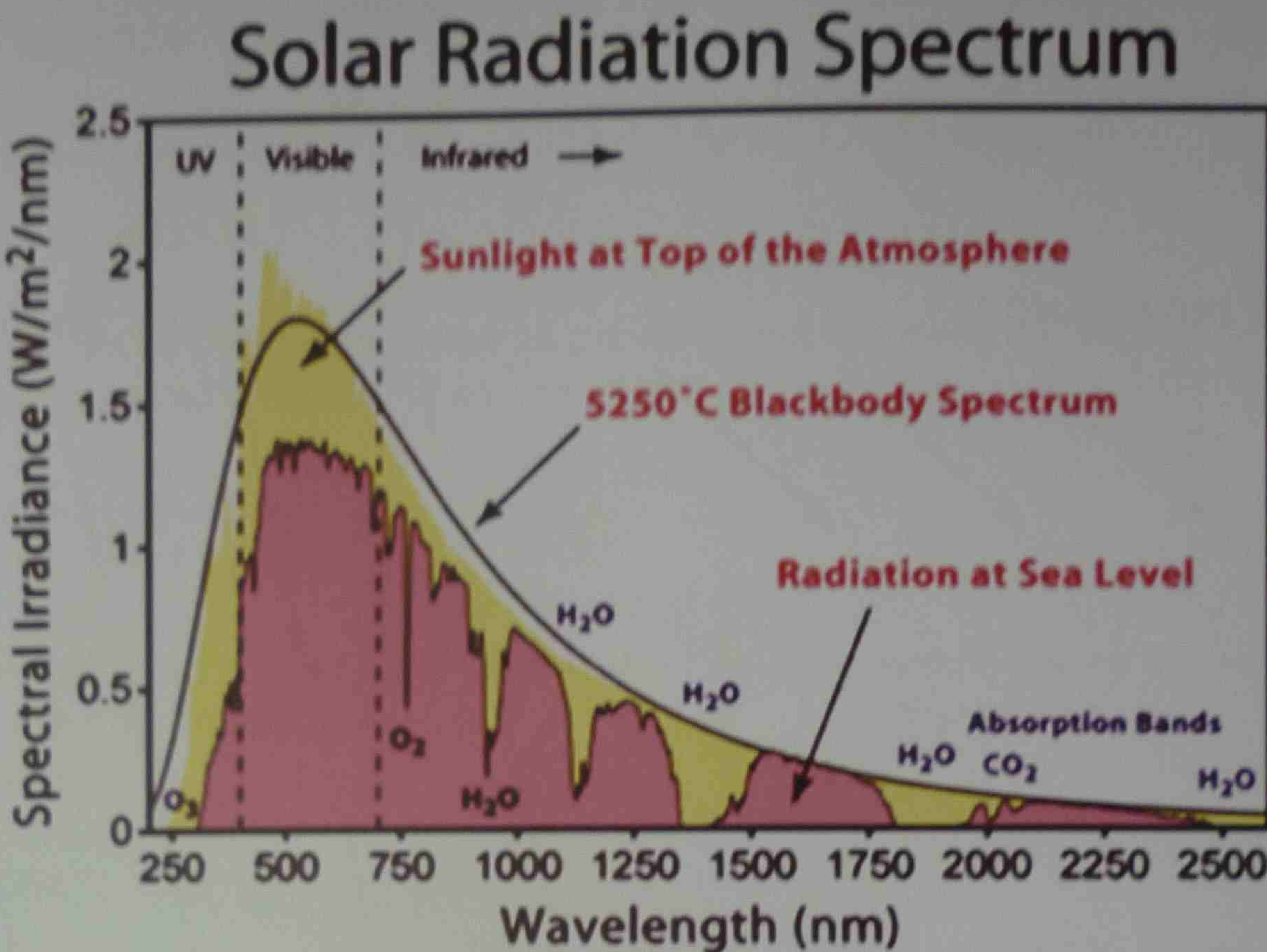
Latitude 35° south

EXERCISE

Using the SOLAR PATH DIAGRAM above, determine the Sun's position 4.30pm on the 19th July.

2.4 SOLAR RESOURCES

The energy derived from the solar panels is directly proportional to the amount of energy radiated from the sun and the type of panel being used.



Shading and local climate will also have a affect the energy yield from the panels.

The amount of energy from the sunthe sun falling on a flat plain is called **IRRADIANCE** symbol (G). The amount of irradiance at any one time coming from the sun can be either measured or available data can be sourced from web sites hosted by organisations such as the Australian Bureau of Meteorology.

For fault find and evaluating the performance of a solar panel the IRRADIANCE can be measured using an instrument called a **PYRANOMETER**.

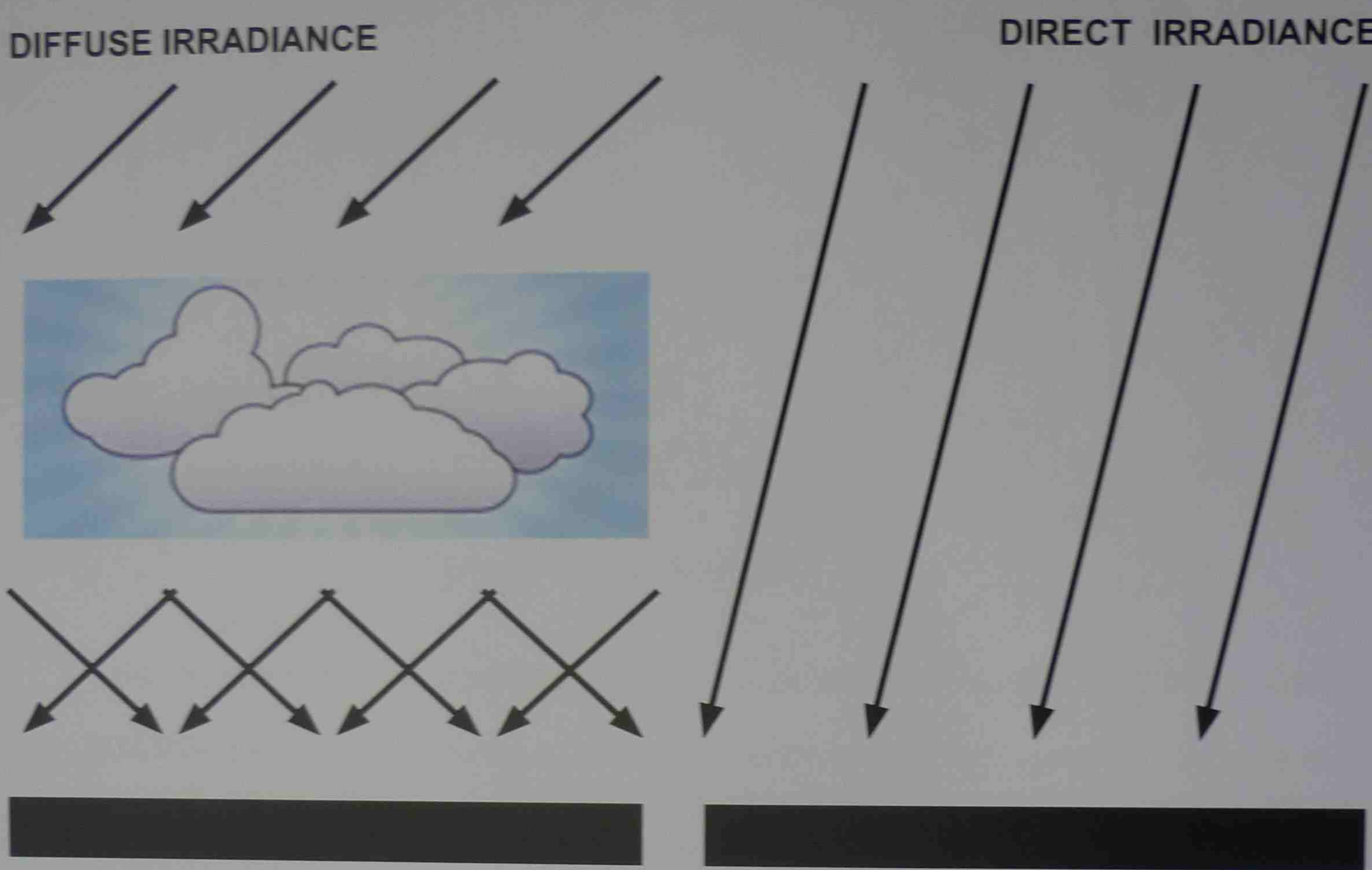
This picture shows a SolData SP80 pyranometer. This type of instrument is used for measuring global radiation over a period of time. The output is measured in mV/1000W/m2. When using this device it can be found that each instrument is calibrated individually. The purpose of this instrument is to measure and record radiation over long periods of time and is used in conjunction with a recording instrument.

This picture shows a SolData 105HP rail portable hand held pyranometer. For convenience it can be held by hand or mounted on a DIN rail assembly. This instrument provides an output in mV/1000W/m2 and a digital readout in Wm2. This instrument is very useful when fault finding, as it is always necessary to know what the value of irradiance falling on the panels at the time of determining the electrical output of the photovoltaic array.

through cloud structures and also that which may be reflected from other surfaces.

2.4.2 DIRECT IRRADIANCE is the irradiance falling on a surface in a direct path from the sun without passing through any medium such as clouds.

The total irradiance is the sum of the direct irradiance and diffuse irradiance .



To measure the irradiance an instrument called a **PYRANOMETER** is used. These instruments will give readings in W/m^2 if a hand held unit such as the Erickson 4890.0 was used.

Instruments such as the Sol Data proved a $mV/KW/m^2$ output. In such a case the mV will have to be calculated back to W/m^2 as all of these types of instruments are calibrated individually.

Hand held portable instruments such as the Erickson 4890 can provide an output either in mV/m^2 or W/m^2.

EXAMPLE

This particular device is calibrated to 161mV. 1000 W /m2 and if the reading on a millivolt meter was 100mV then the irradiance would be

100/161 = 621 W/m.

So a panel with a surface of 1.5m would be expected to give an output of

621 X 1.5 = 931 W.

This would not be the case however as panels do not efficiency that high. In fact most reasonably have an efficiency of around 15%.

So expected output would be
931 X 0.15 = 139.75 W.

You can calculate the power derived from the irradiance by determining the area of the collector and the irradiance.

$P = G \times A$

EXERCISE

A surface has an the dimensions of 1.5m x 2.0m and has an irradiance of 850 W/m2 falling on it. Calculate the power.

$P = G \times A$

P = ______________

P = ______________

EXERCISE

If there is a collector plate with an area of 1.50m2 has an irradiance of 850W/m2 falling on it calculate the total irradiance

____

____

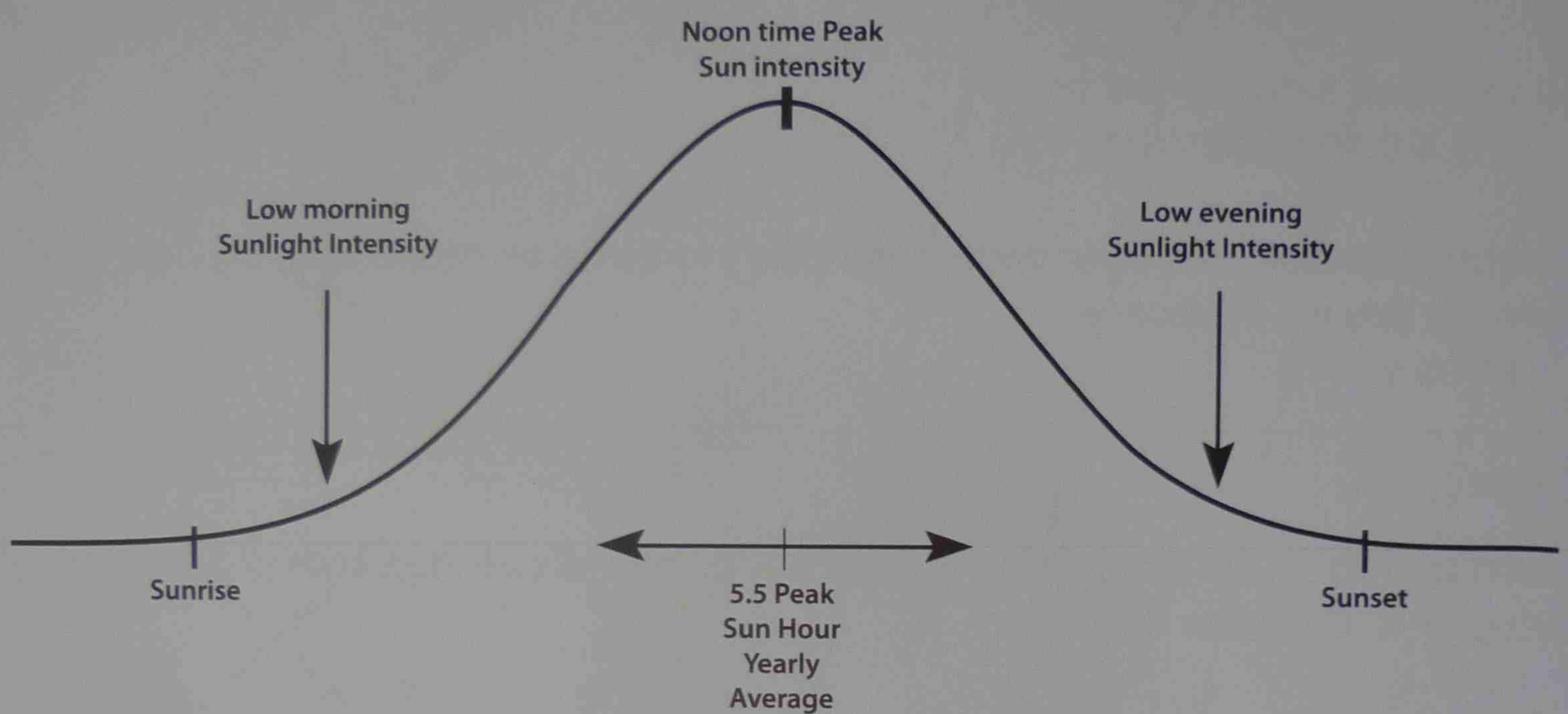
2.4.3 IRRADIATION symbol (H) is the amount of irradiance over time falling on a collector

$H = G \times t$

this information more useful when calculation expected Watt/hours or KWh it is necessary to convert MJ/m^2 to KWh/m^2. This is usually given in MJ/m^2 by organisations such as The Australian bureau of Meteorology in MJ/m^2 because this information is used by many other disciplines such as Architecture, Air conditioning etc.

This information may then be re converted to kWh/m^2, KWh is a more convenient term for those interested in electrical output as it is the function of the solar panels to convert the suns' energy into electrical energy sun will therefore be the factor in estimating how many Panels will be required to give a required output in KWh.

Daily Sun Profile



IMPORTANT NOTE

For grid connect applications it is the average annual daily data that is used for calculating average daily output. For Standalone systems it is important to use the average daily output in the month of lowest irradiance.

In the case of fault finding however it is important to know the Irradiance at the time of analysing the fault.

NOTE (If you don't know what is going in to the panels then there is no way of knowing what the output of the panels should be.)

In the case for Williamtown this would be June
As one Joule equals one watt for one second then one hour is 60 mins x 60 secs. = 3,600

$$\text{So kWh} = \frac{MJ}{3.6}$$

ENERGY

E = Energy in MJ/m^2

A = Area in m2

t = Time in hours

(Energy) E = G x A x t

EXERCISE

If there is a collector plate with an area of 1.5 m^2 has an irradiance of 850W/m^2 falling on it calculate the

A) Total irradiance

B) Total energy over 5 hours

EXERCISE

A surface with the same area as the previous exercise has been exposed to the previous irradiation for 4.5 hours. Calculate the irradiance.

H= G x t

incidence (highest output from solar panels is when the angle of incidence is at right angles).

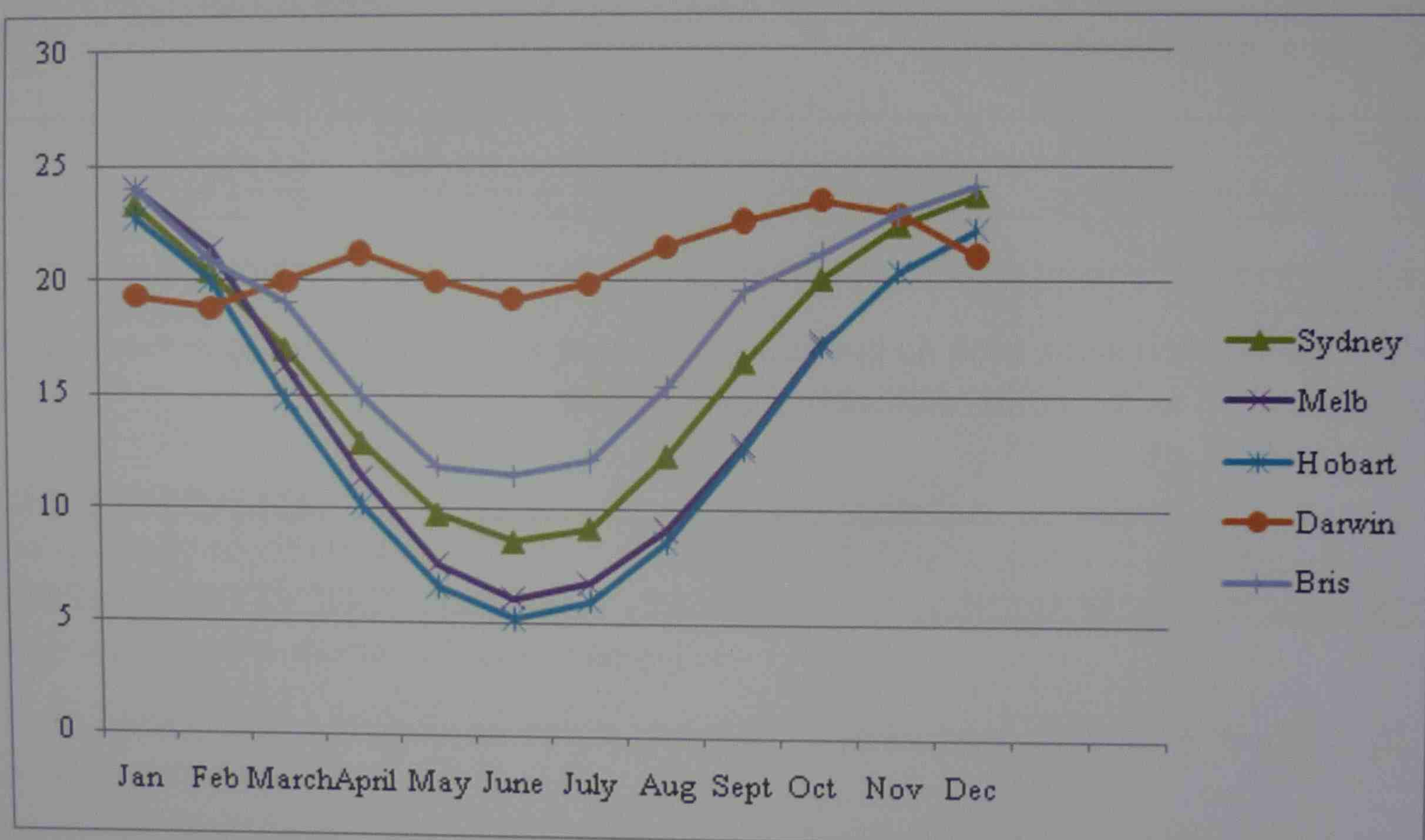
This variation in proportion with angle is called the **COSINE RULE (COS θ).**

NOTE That in the chart for Williamtown it can be seen that for different inclinations the mean monthly irradiation figures are different.

This data can be given in W/m^2 or in MJ/m^2. This information is usually given in tabular form as average daily Wh/m^2 for a month or in average W/m^2 for a year.

Using the generic diagram below (use only for indicative calculations only as this set of graphs may not be accurate that differences in LATITUDE and season vary the IRRA-DATION.

Graph Showing Daily Variation In Irradiation Due To Latitude And Month W/M^2



Notice on the diagram above that as the cities are located in lower latitudes then so to is the average daily irradiance. As Darwin is almost on the equator there are two peak values of irradiance because the sun will appear to move across this latitude twice in on year.

The term PEAK SUN (1,000 W/m^2) (Area under the curve at 1,000W/m^2).

The term PEAK SUN HOURS (1KWh/m^2).

The term SUNSHINE HOURS (total hours of bright sunshine).

On a clear day in Australia that at SOLAR NOON the sun's intensity will reach...

PEAK SUN HOURS

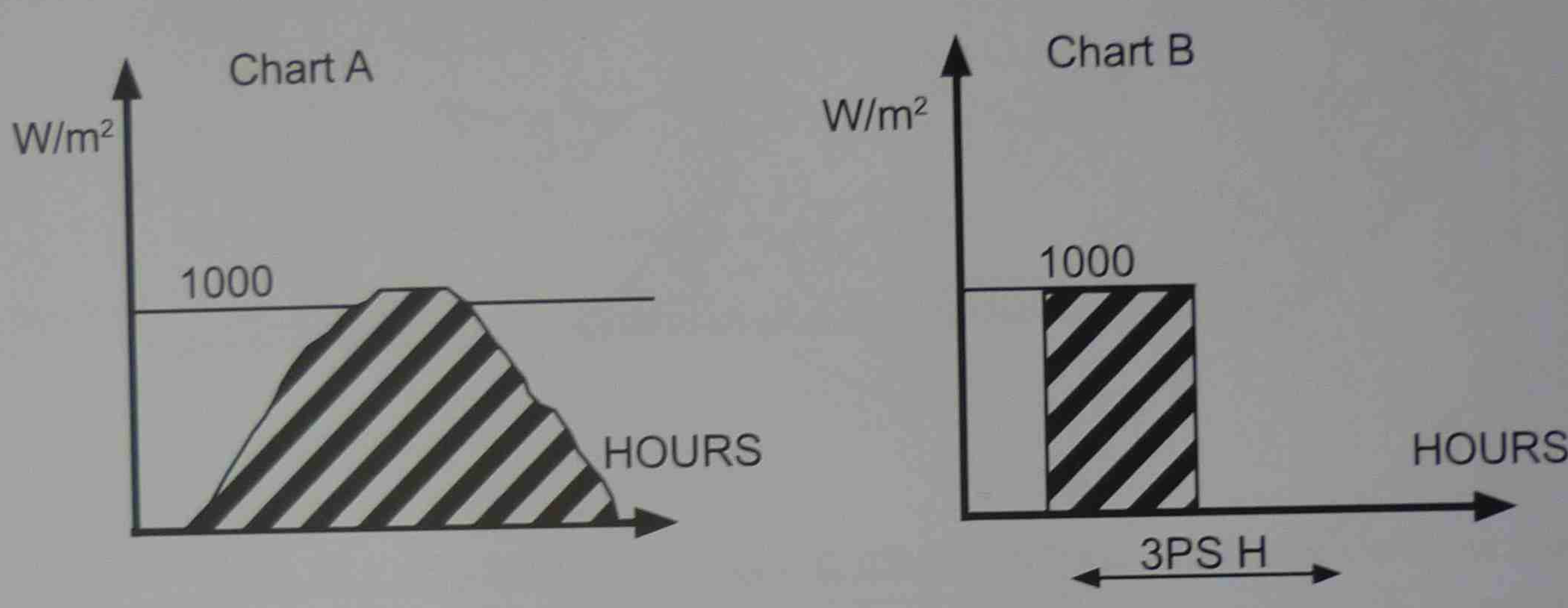
PEAK SUN: One peak sun is the equivalent of (1,000 W/m^2).

PEAK SUN HOURS: Is the equivalent of one peak sun for one hour (1KWh/m2). In the diagram on previous page the variation over one day can be summarised to the equivalent of 100W/m2 for just a few hours.

SUNSHINE HOURS: (total hours of bright sunshine).

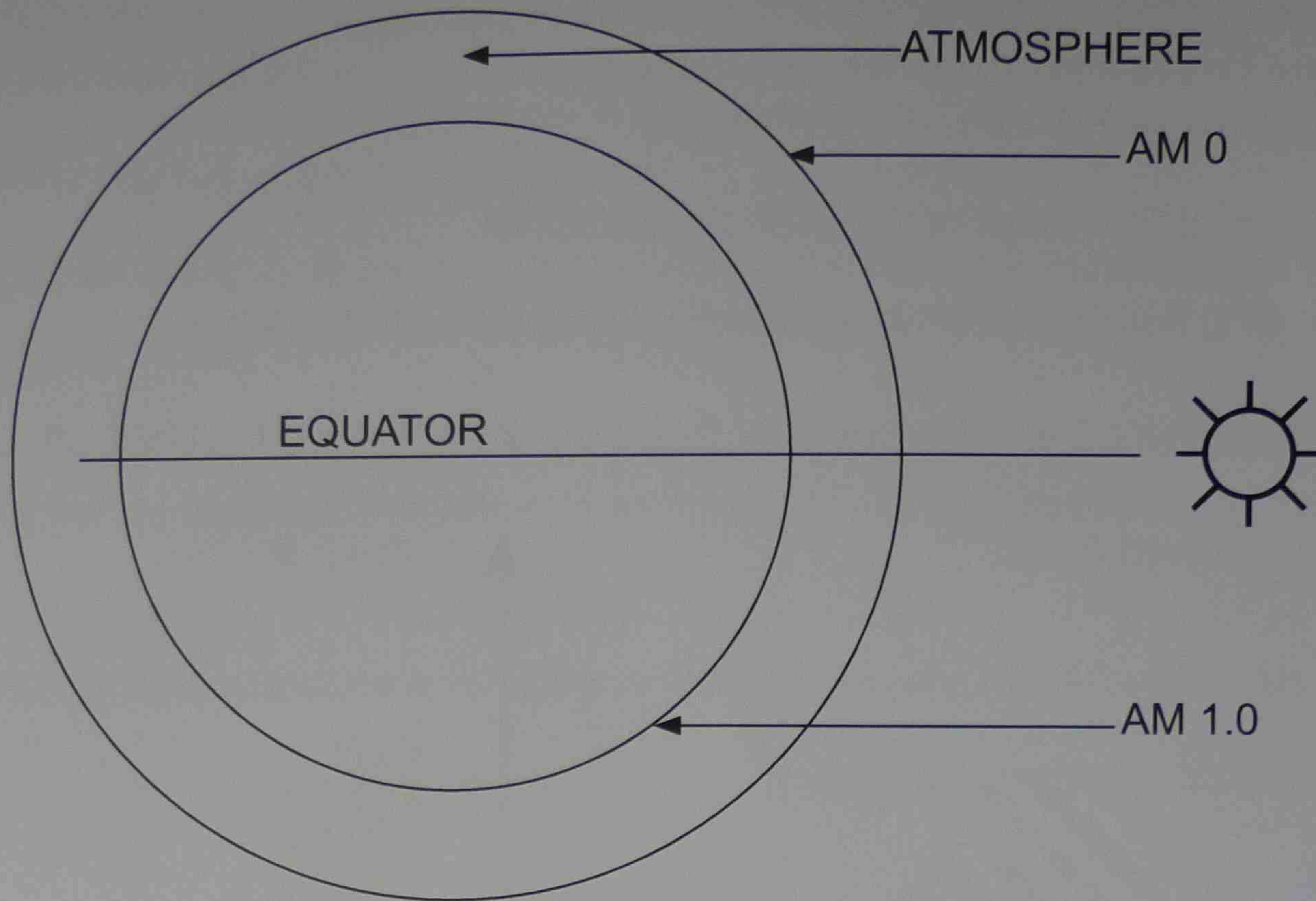
Graph showing daily variation in irradiation due to time of day W/m2

GRAPH SHOWING DAILY VARIATION IN IRRADIATION DUE TO TIME OF DAY W/m^2



In the diagrams above it can be seen that in chart A the irradiance varies throughout the day and in chart B the equivalent value if the area within the curve were calculated into a solid block with a maximum value of 1,000 W/m2.

sun is overhead AIR MASS 0 is just outside the Earth's atmosphere.



Air Mass will also affect the energy spectrum but it is not necessary for the context of this course to determine the exact amount of change but it is necessary to know that as part of a standardised testing procedure photovoltaic panels are tested at AM 1.5

Shading and local climate will also have an affect the energy yield from the panels.

With the aid of a solar path finder (CONERGY) explain how that the solar path can be tracked on the chart shown.

For **GRID CONNECT** calculations, the actual irradiance at that instance is of little use other than determining expected output at a particular time.

For Grid Connect it is important to look at – Average irradiation over a one year period but when determining the peak output of the system in order to get the loading on the cables and the inverter maximum irradiance is used.

NOTE If this the case then irradiance measured will be much lower on cloudy days because of the amount of diffuse irradiation.

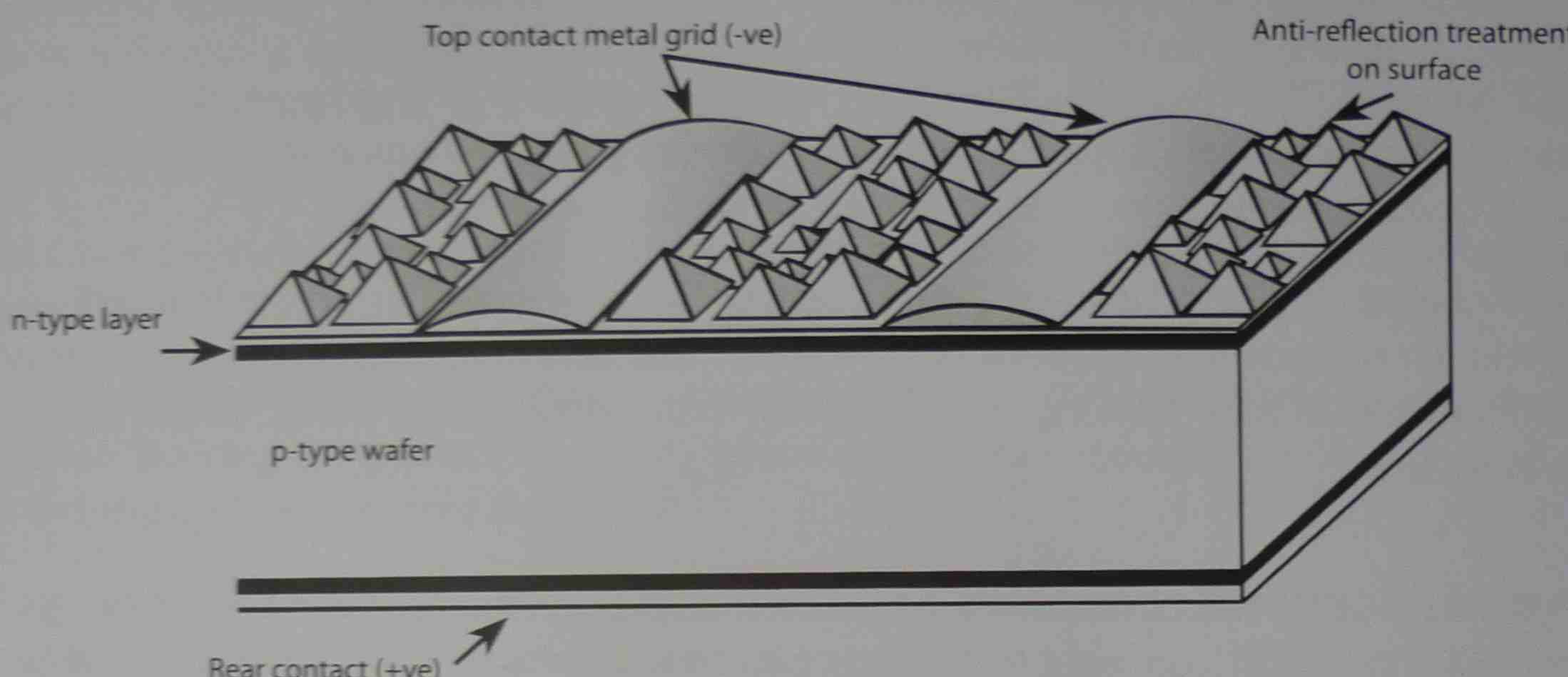
IRRADIATION (symbol **H**) is the amount of irradiance over time falling on a collector.

3.1 PHOTOVOLTAIC POWER SOURCES

This section should be read in conjunction with AS/NZS 5033:2005. Installations of Photovoltaic (PV) arrays.

Installations of (PV) arrays must comply with the requirements of AS/NZS 3000 and may only be varied by the adoption of the requirements of AS/NZS 5033:2005.

3.1.1 PHOTOVOLTAIC CELLS are basically silicon semiconductor device in the configuration of a P-N junction diode.This device captures irradiance or light in the visible part of the energy spectrum usually in wavelengths between 400 nm and 600 nm.



It is the function of this device to convert the suns' energy into electrical energy .The conversion of the suns' energy into electrical energy is called the panel efficiency .The higher the electrical output to the area of the panel then the higher the panel efficiency . To achieve a designed output of voltage and current many cells are connected together and mounted in a frame to form a photovoltaic panel.

It is important to note that the output of a solar cell is variable according to the cell temperature and the irradiance falling on it .Calculation of both current and voltage under different conditions is necessary for a reliable grid connected system.

Output current varies with irradiance.
Output voltage varies with temperature.

EXAMPLE

This particular device is calibrated to 161mV. 1000W /m^2 and if the reading on a millivolt meter was 100 mV then the irradiance would be **100/161= 621 W/m**

So a panel with a surface of 1.5m would be expected to give an out put of
621 x 1.5 = 931 W

This would not be the case however as panels do not have efficiency that high. In fact most reasonably have an efficiency of around 15%

It is also important to refer to manufacturers data for other factors that may cause de-rating of the panel such as ambient temperature (see diagram page 31).

More than one panel will be necessary to provide enough power input to make enough power to justify the expenditure of a grid connect installation .More than one panel electrically connected together is called an array.

Often panels are connected in parallel to provide the currents required for the system demand .In such cases these are often below 120V dc. This is then classified as an extra low voltage system. Systems above 120V dc. Are classified as a low voltage system and require licensed electricians for their electrical wiring installation.(refer AS/NZS 3000).

3.1.2 MONO-CRYSTALLINE - this silicon crystal structure is formed by melting semi-conductor grade silicon, and causing a single crystal growth around a small crystal Mono-Crystalline has a good response in the red to orange band gap.

Mono-crystalline silicon cells are the most expensive but they are also the most efficient under most conditions. Because of their smaller size in comparison to out put they are often used in solar tracking systems which further improve the overall efficiency of the solar array.

3.1.3 POLY-CRYSTALLINE - this produces a multiple-grained structure by controlling the cooling rate of silicon material that has been melted in a crucible. Crystalline silicon has a good response in the band near infra-red band gap.

Poly-crystalline cells are less expensive than mono-crystalline but have a much larger surface area for the same output. This type of panel are often seen in potable systems where positioning in the best possible location is not always possible because of better shade tolerance.

3.1.4 AMORPHOUS silicon are often considered as the least efficient but are very robust in construction and are often adhered to flexible sheeting. Amorphous panels are also very good in more extreme temperatures and light conditions. Often out performing mono and poly crystalline panels under some conditions.

These are often available in adhesive strips suitable for sticking direct to metal roofing material alleviating the need for mechanical structures etc. Amorphous silicon (thin film) have a good response in the visible band gap similar to that of the human eye.

New enhancements to crystalline cells include buried grid cells, triple-junction cells and "Slivercr" cells, which provide higher efficiency or lower production costs.

3.2 CONSTRUCTION

SOLAR PANEL or PV MODULE is made up by connecting number of cells (generally 36) make up a "PV module", also known as a solar panel. PV modules can be interconnected to form arrays of different voltage and current capacities.

Photovoltaic systems produce DC electricity, so power conditioning equipment such as inverters are required to produce AC for normal household appliances. Power output is very dependent on the solar radiation hitting the PV cells, so modules must be installed to face as close to true north as possible and minimise shading to ensure maximum possible energy output.

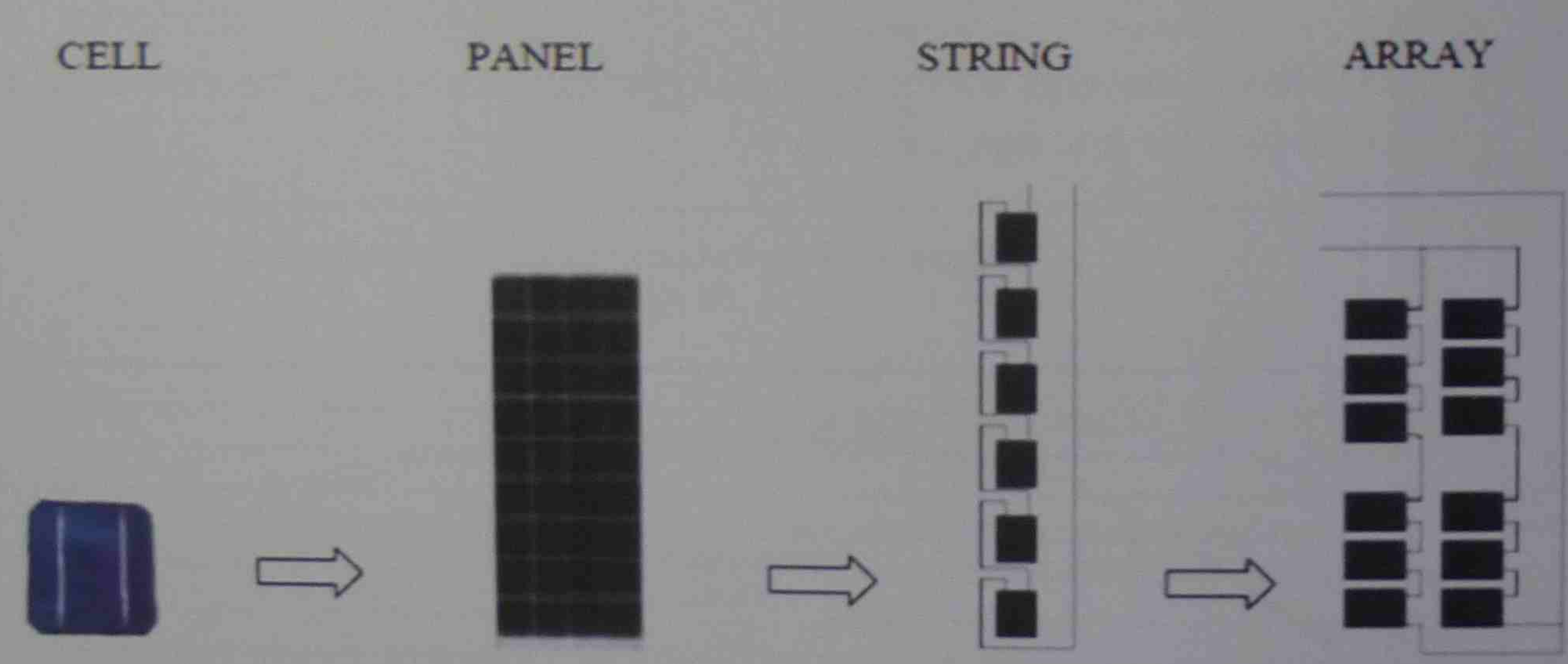
Tracking systems can sometimes be used to allow the modules to point toward the sun and provide extra energy output. Photovoltaic systems are an ideal match to many summer electrical loads, producing maximum power when demand is also highest, so they are being increasingly used in grid-connected systems as distributed generators.

In off-grid systems, some form of energy storage will be required for night or periods of low sunlight. This is usually in the form of battery storage.

While panels are the most commonly installed format for PV cells, there is large potential for "Building-integrated PV" (BiPV), where photovoltaic modules are incorporated into building fabrics or roof tiles.

Concentrating systems allow small high-efficiency modules to be used, though extra cooling and specialised mounting construction are required.

The diagram below shows the combination of photovoltaic cell connected together to provide a photovoltaic panel and then a PV string connected to make a photovoltaic array.



That typical cell efficiency will vary according to the available irradiance and that if efficiency of panels is used for sizing calculations actual sunshine hours should be used.

Mono-crystalline	12% to 19%
Poly-crystalline	12% to 15%
Amorphous	5% to 9%

These will vary according to:-
Temp
Irradiance

Photovoltaic panels will produce maximum efficiency when the irradiance is direct or at right angles to the panel. The following chart shows how the output will vary when both azimuth and altitude angles are changed.

Output Ratio at Different Angles Latitude 35° South							
	Azimuth						
Tilt	**0**	**15**	**30**	**45**	**60**	**75**	**90**
10	97.5%	97.5%	97%	96.2%	95.2%	94%	92.5%
15	99%	99%	98.1%	97.1%	95.6%	93.8%	91.7%
20	99.8%	99.8%	98.7%	97.4%	95.4%	93%	90.3%
25	100%	100%	98.8%	97.2%	94.8%	91.9%	88.7%
30	99.6%	99.6%	98.2%	96.4%	93.8%	90.5%	86.7%
35	98.6%	98.5%	97.1%	95.1%	92.3%	88.7%	84.5%
40	97%	97%	95.4%	93.5%	90.3%	86.5%	81.9%
45	94.8%	94.8%	93.3%	91.2%	88%	84%	79.2%

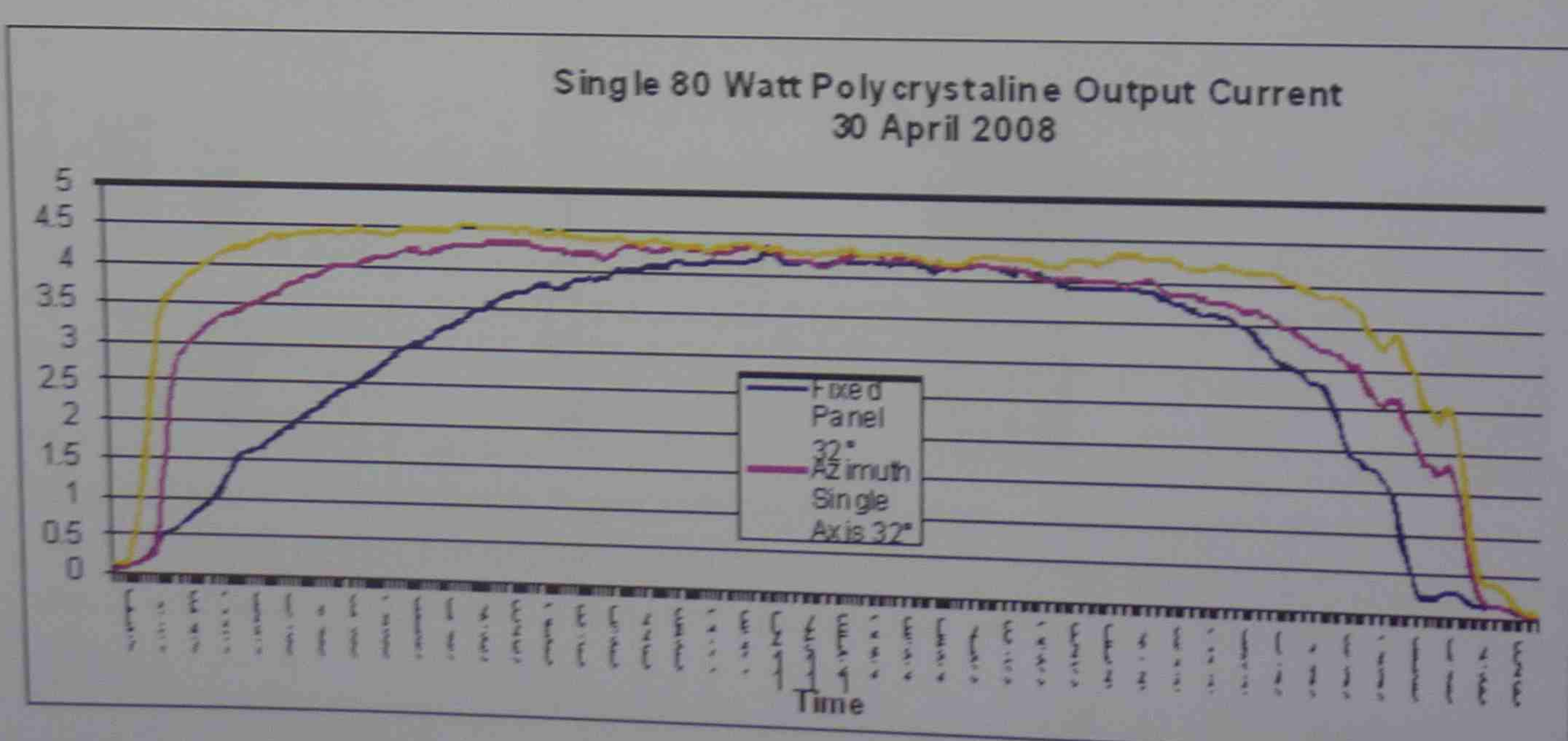
3.2.1 TRACKING SYSTEMS

To maximise the output of a photovoltaic system, the reduction in output caused by the cosine rule can be minimised by using an automatic system that tracks with the position of the sun.

Single Axis trackers usually track on the azimuth angle as given a choice between azimuth and tilt it is the azimuth angle which will be the greatest as it has a variation between 90 0 and 0 0 .

Dual Axis trackers will track both azimuth and altitude angle which just about eliminates the reduced output caused by the cosine rule.

The diagram below represents comparison a logged output showing the difference in fixed system, single axis and dual axis.



Below is a data sheet of a typical panel type. Read each data sheet and record the information provided on the sheet. This type of information will also be used later in SIZING THE SYSTEM section.

NU-S0E3E – MAXIMUM POWER

ELECTRICAL CHARACTERISTICS

Cell	48 Monocrystalline (155.55mm)² Sharp silicon solar cells
No. of Cells and Connections	48 in series
Open Circuit Voltage (Voc)	30.0V
Maximum Power Voltage (Vpm)	23.7V
Short Circuit Current (Isc)	8.37A
Maximum Power Current (Ipm)	7.60A
Maximum Power (Pm)[1]	Min. 171W Typical 180W
Encapsulated Solar Cell Efficiency (ηc)	15.5%
Module Efficiency (ηm)	13.7%
Maximum System Voltage	DC 1000V
Series Fuse Rating	15A
Type of Output Terminal	Lead Wire with MC Connector

Specifications are subject to change without notice
(STC) Standard Test Conditions: 25°C, 1 kW/m², AM 1.5

MECHANICAL CHARACTERISTICS

Dimensions	1318 x 994 x 46mm
Weight	16.0kg

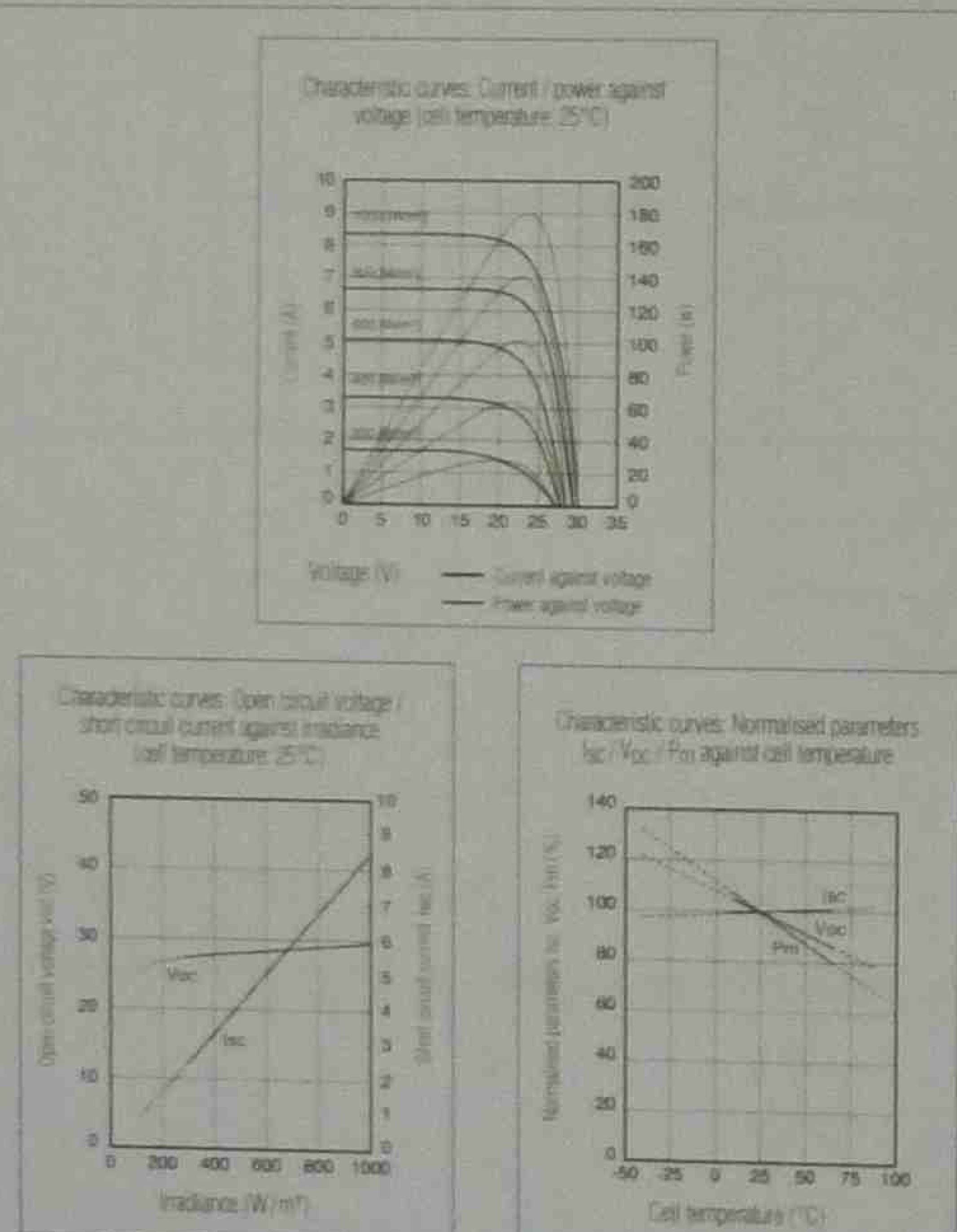
TEMPERATURE COEFFICIENT

Temp. Coefficient of Pmax	-0.485	% / °C
Temp. Coefficient of Voc	-0.104	V / °C
Temp. Coefficient of Isc	0.053	% / °C

ABSOLUTE MAXIMUM RATINGS

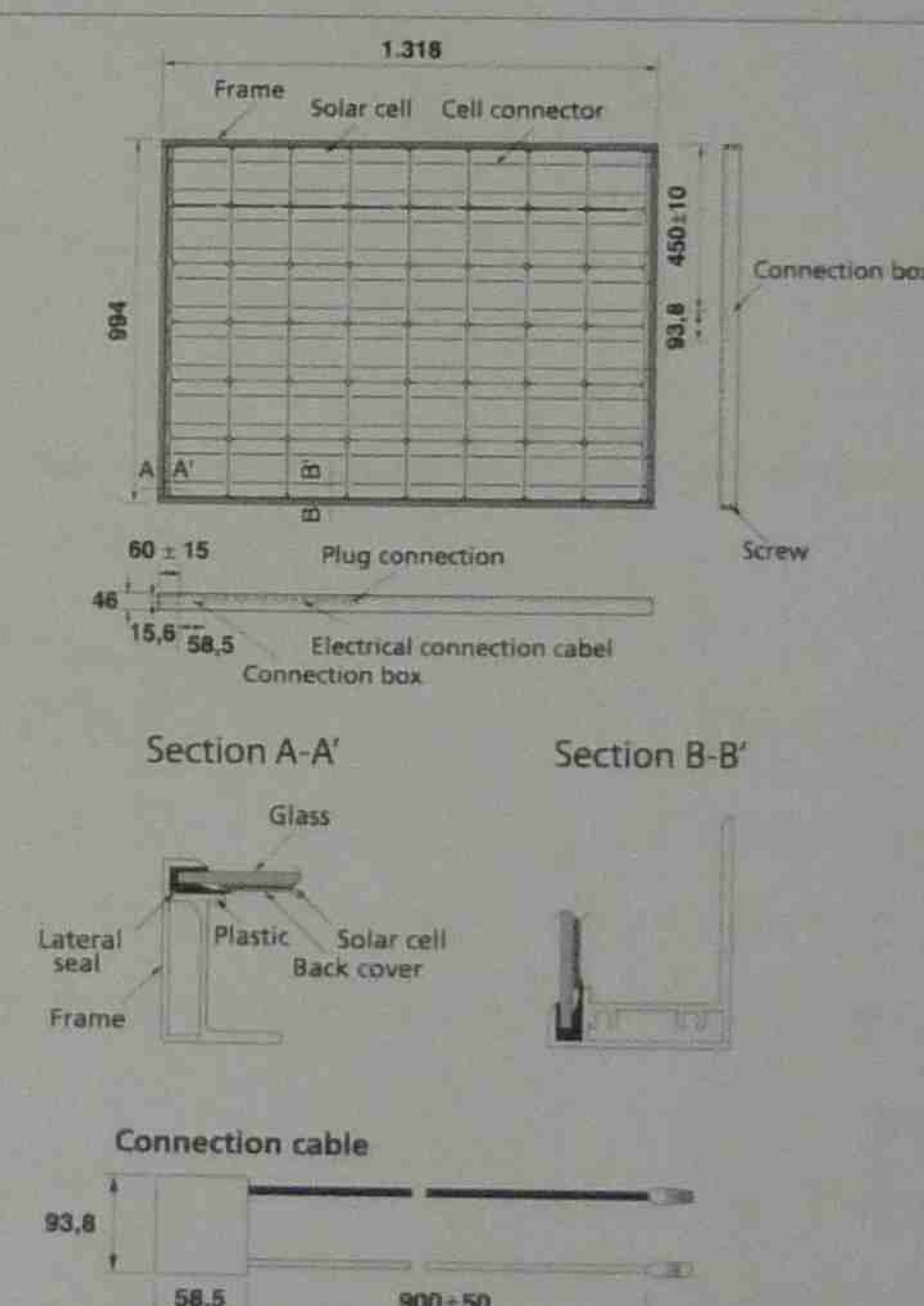
Parameters	Rating	Unit
Operating Temperature	-40 to +90	°C
Storage Temperature	-40 to +90	°C
Dielectric Voltage Withstood	3000 max.	V DC

IV CURVES

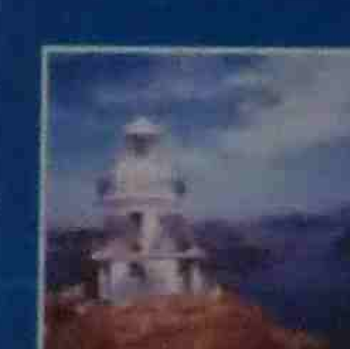


Specifications are subject to change without notice

DIMENSIONS



Specifications are subject to change without notice



In the absence of confirmation by device specifications sheets, Sharp takes no responsibility for any defects that may occur in equipment using any Sharp devices shown in catalogues, data books, etc. Contact Sharp in order to obtain the latest device specification sheets before using any Sharp device.

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SHARP Solar

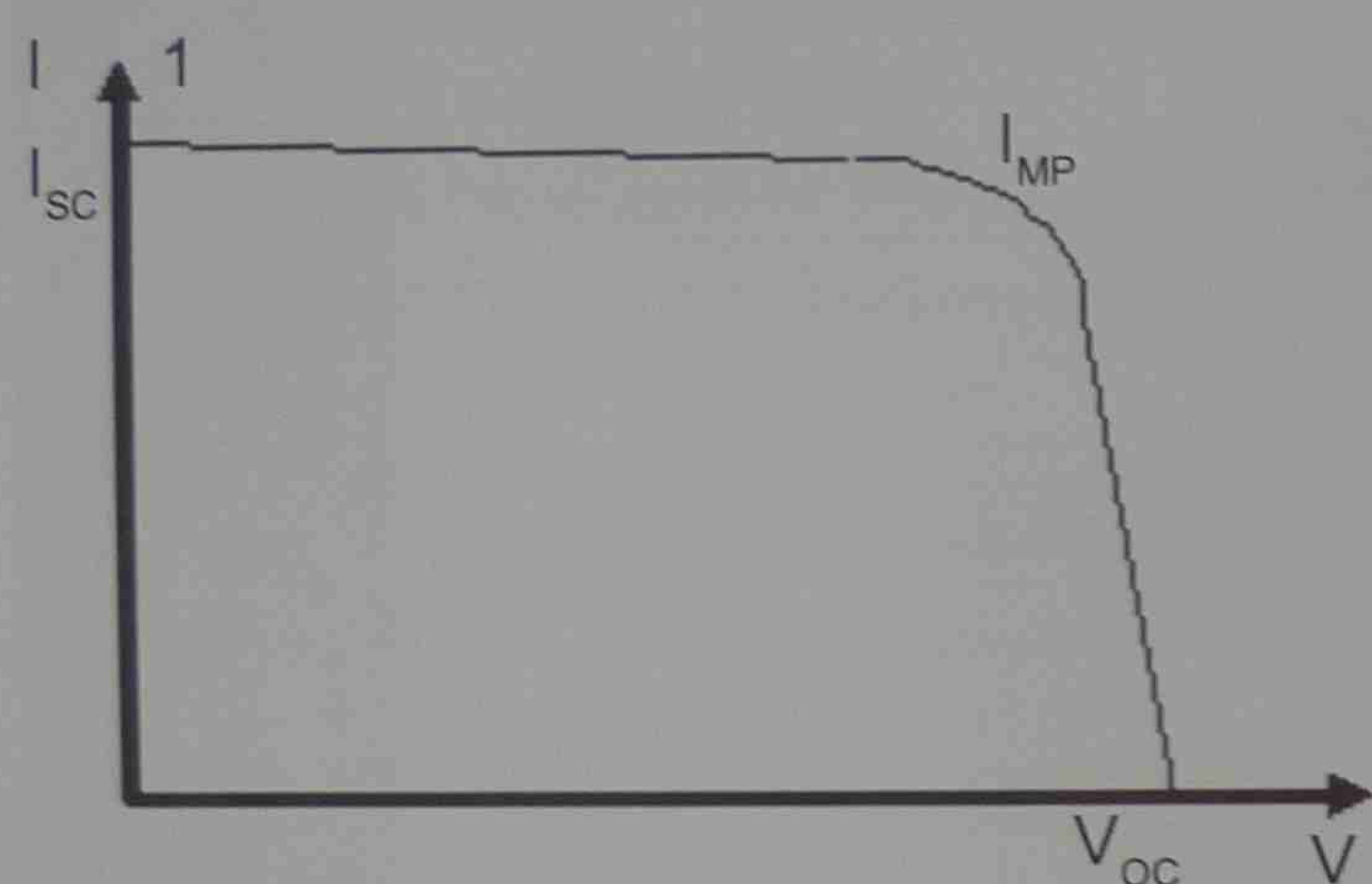
3.3 IV CURVES

The output characteristics of a photovoltaic panel can be best described as the relationship between voltage and current. In the following diagram it can be seen that as the current drawn from the PV panel is in creased the voltage varies little and therefore as the current increases so too does the power output of the panel increases as shown in I.V. CURVE **A**.

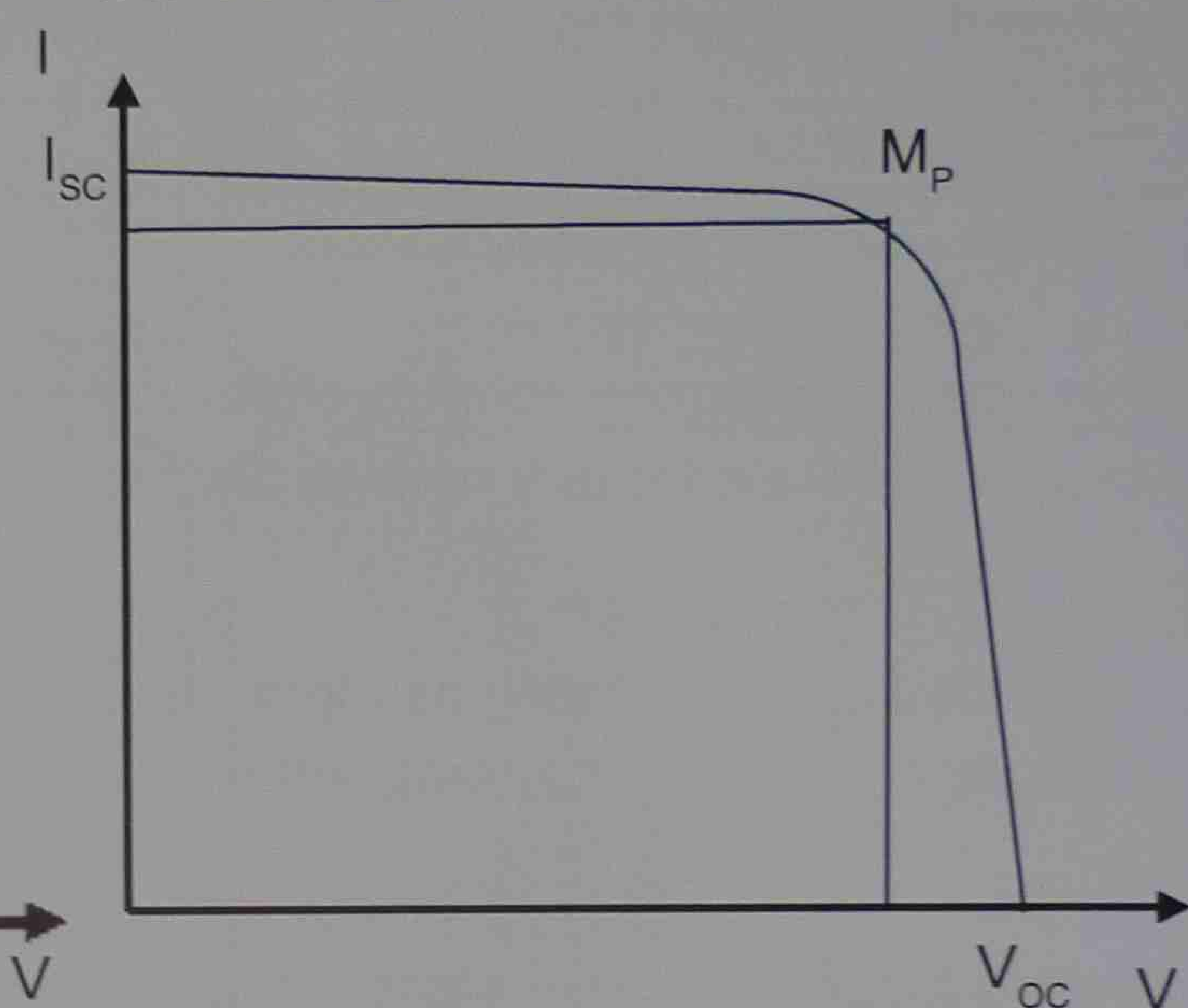
In I.V. CURVE **B** it can be seen by the dotted lines that when current is increased past Mpp the voltage falls sharply and the output power is significantly reduced.

The maximum power point is important when designing a grid connect system. If the current required by the inverter is more than the current at the maximum power point then the systems output will be reduced to that available at Mpp. The maximum power point normally occurs at 85% to 95 % of Isc.

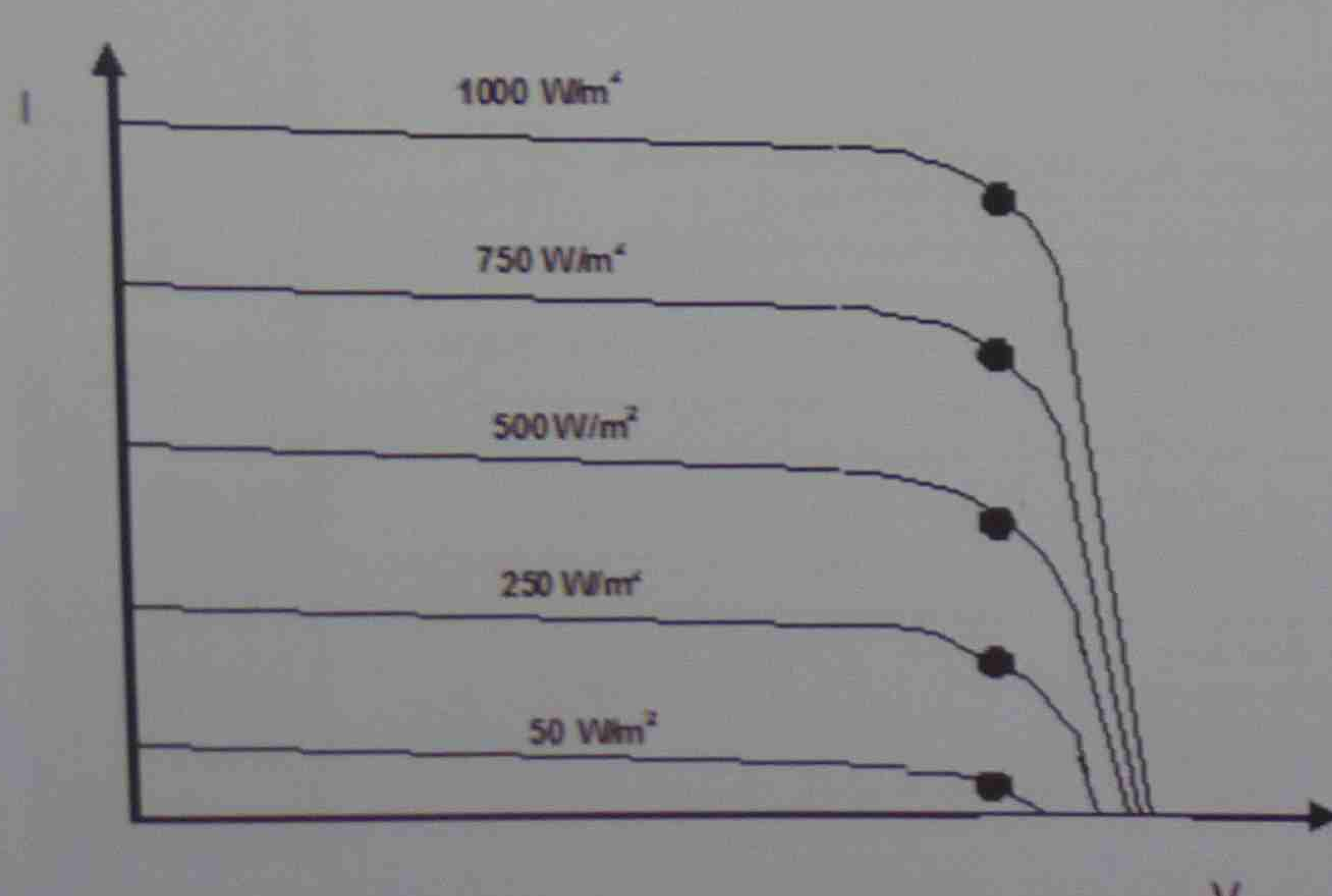
I.V. CURVE **A**



I.V. CURVE **B**



IRRADIANCE will also affect the I.V. CURVE. In the diagram below it can be seen that the current available from the panels varies with the irradiance as does the maximum power point. It can therefore be said that output current and power are practically in proportion to irradiance. The output from the panels varies throughout the day with the irradiation curve.



The following diagram is of a Sharp 180W polycrystalline panel which shows variation in IV curve and power curves which vary with temperature.

TMVF07508

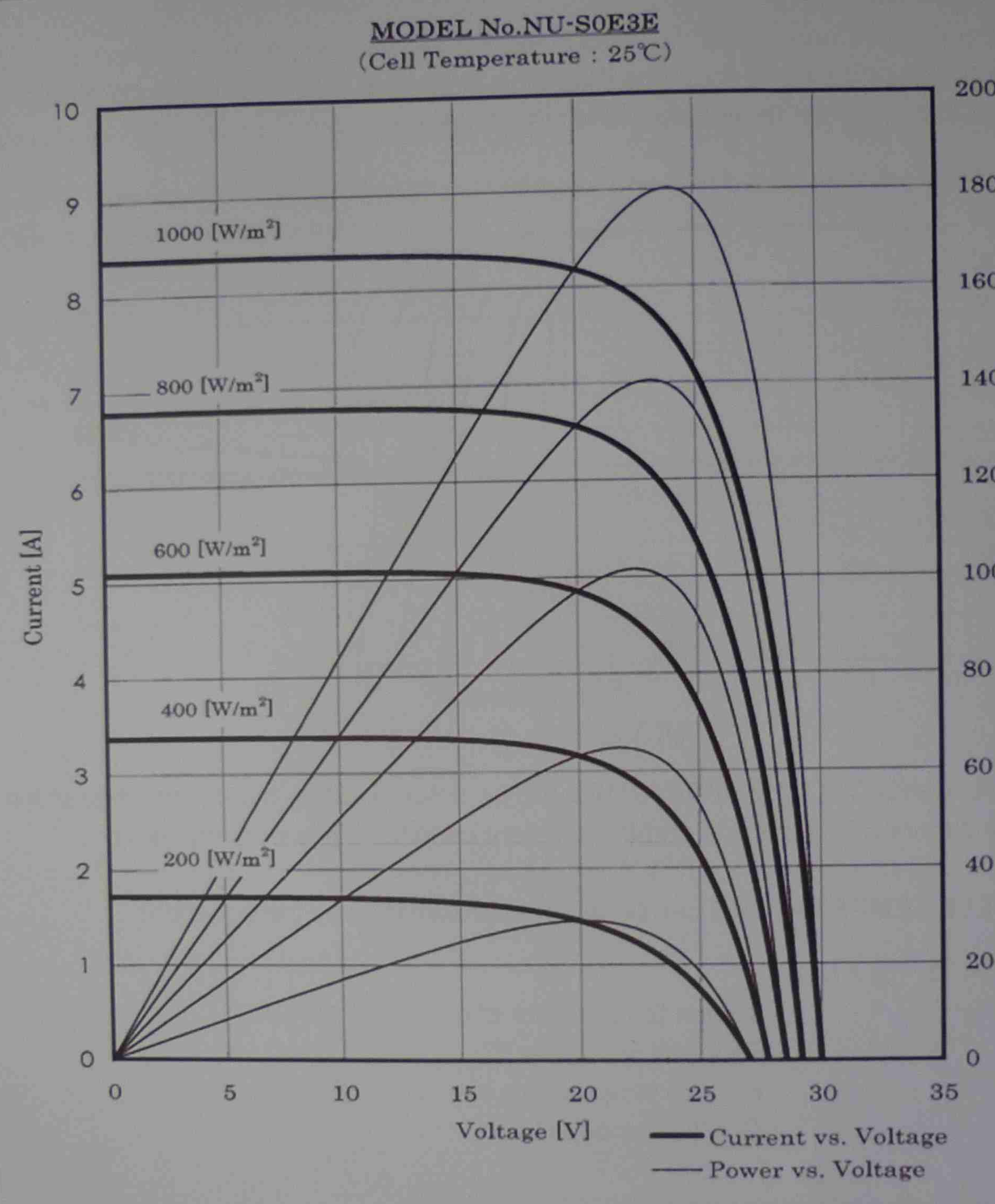
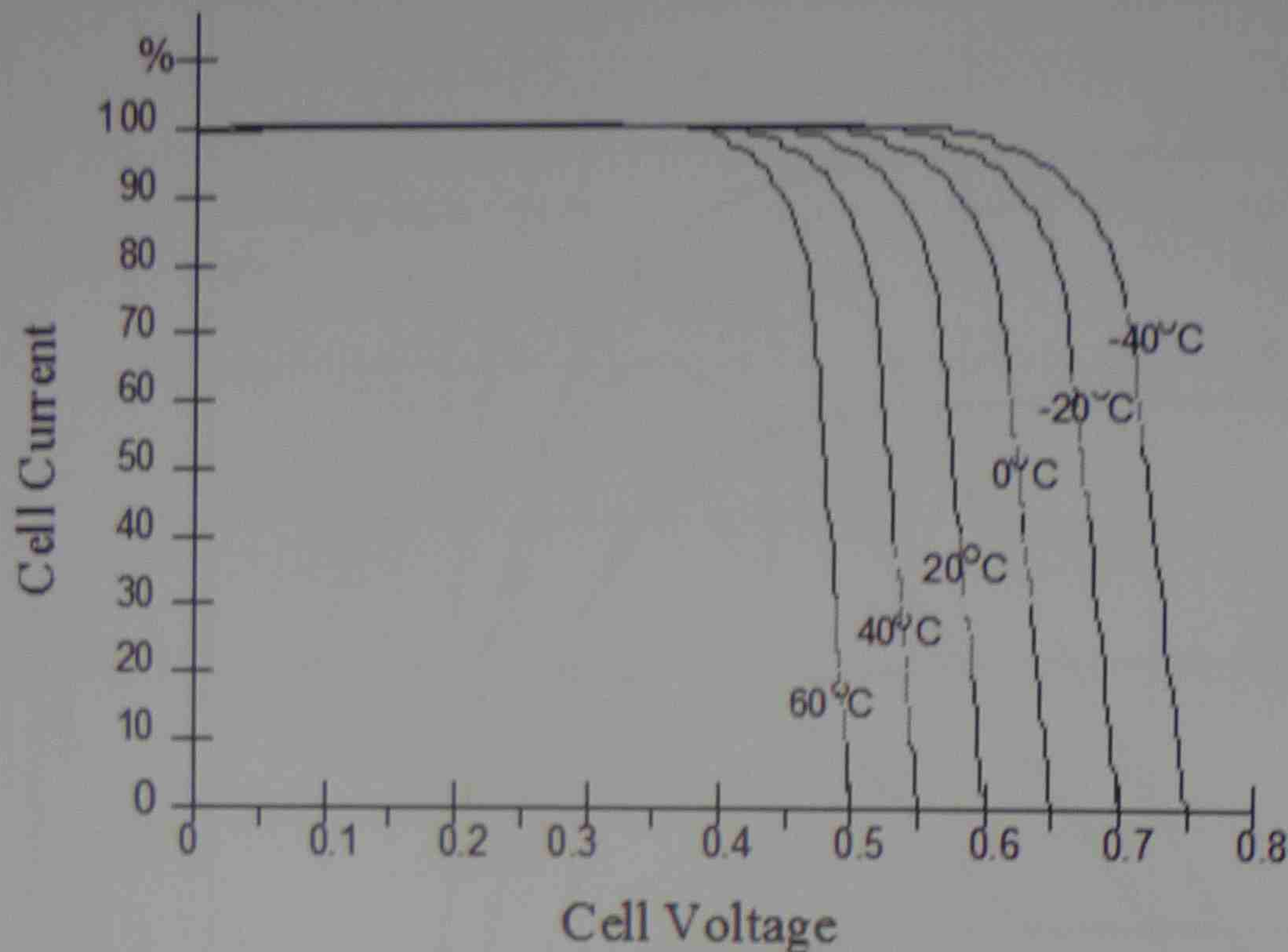


Fig. I -2 Current , Power , vs. Voltage Characteristics

Modules rise in temp due to the power created by the panel and ambient temperature it is operating in. Temperature rise will also be affected by mounting method and the panel construction.

If the panel is unbalanced it means that the energy from the sun and the power produced is the same as the heat loss from the panel.



CALCULATING CELL TEMPERATURE will be determined by the construction of the panel and its derating to temp and the ambient conditions it is working under.

3.4.1 CELL TEMPERATURE can be given approximately by the equation:

Tcell = Ta + **k** x **G**

Where Tcell = temperature of cell in the module °C
Ta = Ambient temp °C
K = cell temperature coefficient °C
G = irradiance in W/m^2

Normal operating cell temperature (NOCT).
This is the temp specified by the manufacturer under the following test conditions.

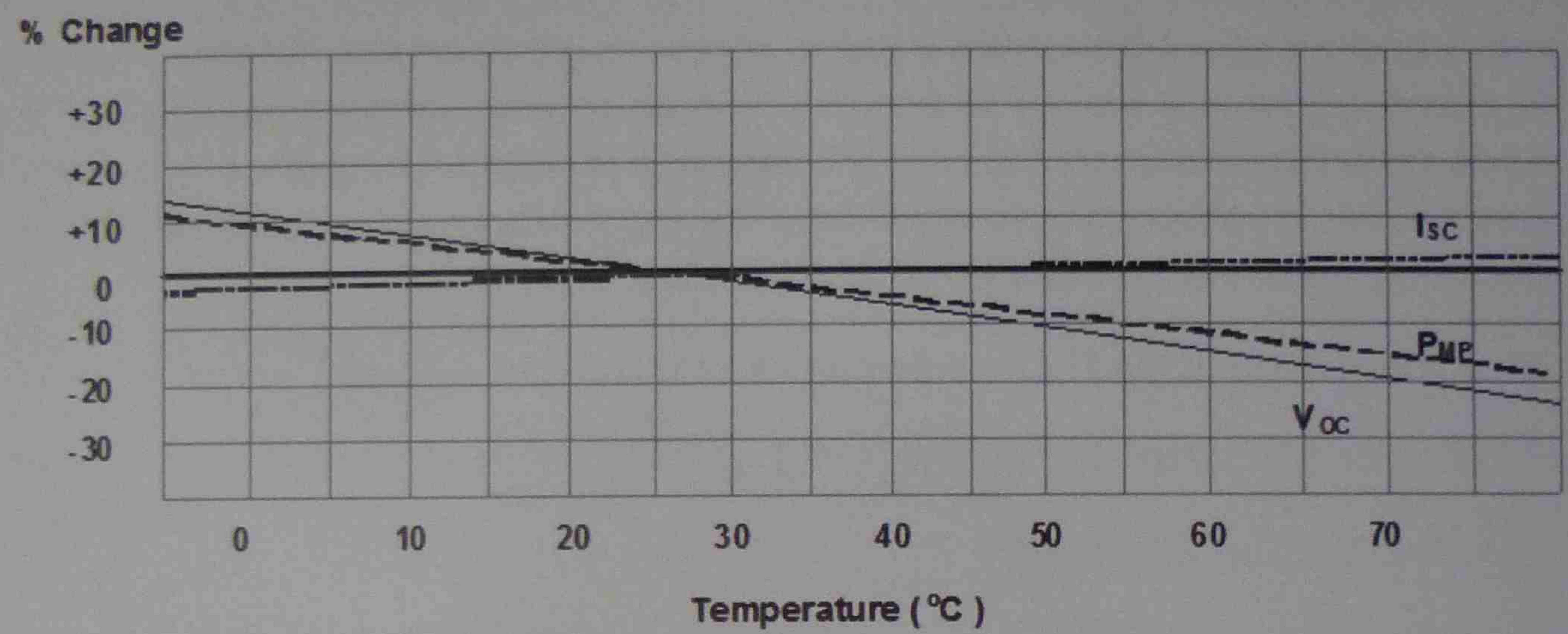
Irradiance	800w/m2
Ambient temperature	20°C
Wind speed	1 m/s
No load	
Free flowing air around module	

Cell temperature may be calculated by:

$$T_{cell} = TA \left(\frac{NOCT - 20}{800} \times G\right)$$

Below is a typical performance verses temperature graph of a silicon. Note that the short circuit changes very little with changes in temperature and is so small that it is often ignored when calculating performance value with change in temperature.

The most significant change is the output voltage. Note that because of the change in voltage the power changes with it.



3.4.2 TEMPERATURE COEFFICIENTS is the temp specified by the manufacturer the following test conditions are the rates at which the cell performance changes with changes in temp.

Both voltage and power have a negative temperature coefficient and current has a positive temperature coefficient.

Derating for temp depends upon how much the output varies with temp. This will also vary with different manufactures so whilst Amorphous Silicon panels vary little with temp - 0.5 % could be used for mono-crystalline and poly-crystalline if the manufacturers specifications are unknown. Manufacturing techniques and performance are dynamic and may change year to year. Check the temp coefficients on the data sheet you have.

The output rating of a photovoltaic cell is measured at its most efficient and in the specifications this temp is usually to a standard of 25 degrees centigrade (25° C). The actual operating temperature of the cells will raise well above that because of the operating currents and the effects of ambient temp. The array will now have to be derated for manufacturing tolerances, temp and dirt accumulation.

AS4509.2 stipulates that the PV module can be calculated as follows:

The cell derating factor can now be calculated by

$$F_{temp} = 1 - (Y \times Top - Tcell\ eff)$$

For a polycrystalline array operating at 60°C with a standard specification of 25°C

$$\begin{aligned} ftemp &= 1 - (0.5 \times 35) \\ &= 1 - 17.5 \\ &= 16.5\% \end{aligned}$$

Panels may also be derated for dirt accumulation and manufacturer's tolerance.
NOTE: the derating factor for dirt may be dependent on environmental conditions such as dust from brakes and tyres when close to a major highway or normal industrial fallout patterns.

Pderated = Pstandard x *f*manufacturing tolerance x *f*dirt x *f*temp derating

Pd = Pstd x *f*tol x *f*dirt x *f*temp

So a 10kW PV array would be derated thus, if the derating for dirt is 0.95 and manufacturer's tolerance derating is 0.95 and using the temp derating from above.

Pderated = 10,000 x 0.95 dirt x 0.95 tol x 0.835 temp
= 7,535 W

System required to provide 10kW
= 10,000W / 7,535W
= 1.327 multiplying factor

P_{array} = 1.237 x 10,000W

3.5 VOLTAGE CHANGES

Due to temperature is a very important consideration when designing a system as the PV system is connected directly to and inverter which has defined maximum and minimum input voltage requirements (this will be applied later in sizing the system).

Manufacturers may specify the coefficients in either percent voltage (%/°C) change or in millivolt per degree change (mV/°C).

EXAMPLE

Voltage change as a %

A panel had an open circuit voltage of 45V (Voc), the temperature coefficient was 0.5%/°C and the panel temperature was 0°C first thing in the morning. What would the open circuit voltage (Voc) be?

V temp = Voc [1 – 0.005 (T−TSTC)]
= 45 [1 – 0.005 (0−25)]
= 45 [1 – 0.005 x −25]
= 45 x 1.125
= 50.625V

EXERCISE

Part 1

A panel had an open circuit voltage of 35V (Voc), the temperature coefficient was 0.5%/°C and the panel temperature was -5°C first thing in the morning. What would the open circuit voltage (Voc) be?

____

____

____

____

Part 2

If that panel was still operating after midday and the panel temp rose to 60°C, what would the panel voltage be?

____

____

____

____

A panel had an open circuit voltage of 45V (Voc), the temperature coefficient was 150mV/°C and the panel temperature was 0°C first thing in the morning.
What would the open circuit voltage (Voc) be?

So 150mV/°C is 0.15V/°C

Vtemp = Voc + [0.15 *(T - TSTC)*]
= 45 + [0.15 (0 - 25)]
= 45 + [0.15 x - 25]
= 45 + 3.75
= 48.75V

EXERCISE

Part 1
A panel had an open circuit voltage of 35V (Voc), the temperature coefficient was 16mV/°C and the panel temperature was -5°C first thing in the morning.
What would the open circuit voltage (Voc) be?

____

____

____

____

Part 2
If that panel was still operating after midday and the panel temp rose to 60°C. What would the panel voltage be?

____

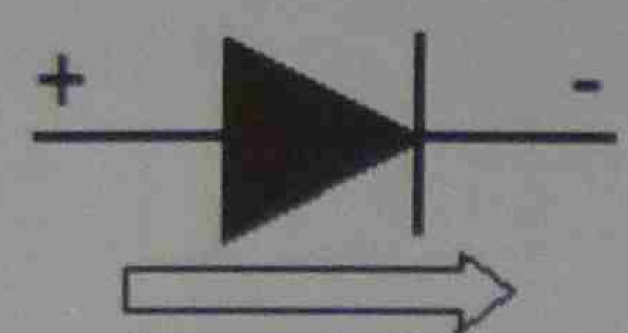
____

____

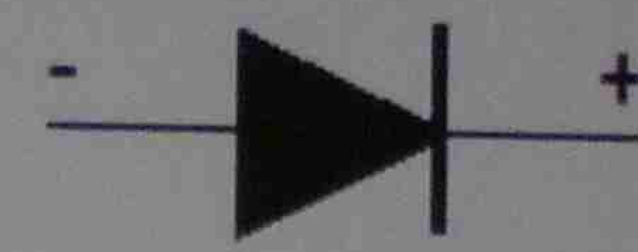
____

3.6 FUNCTIONAL DIODES

It is suggested that bypass and blocking diodes are supplied as an integrated part of the module supplied by the manufacturer. If however, diodes are to be added by the installer then it is best to consult the panel supplier for recommended types. In such a case such diodes should be encased so that there are no live parts exposed and that they are protected from the environmental elements.



A diode in the conducting state
(forward bias)



A diode in the non-conducting state
(reverse bias)

3.6.1 BYPASS DIODES are usually used to prevent a module from becoming open circuited in the event of a cell failure or partial shading of one module. The event of such failure can cause reverse biasing and subsequent overheating.

3.6.2 BLOCKING DIODES are used to prevent reverse bias being applied by other generating sources and or battery systems when the array is not generating voltage (night hours) or more often when a number of panels in one string are shaded. If by-pass diodes were used this string would have a much lower voltage and therefore be subject to reverse current from other strings in connected in parallel.

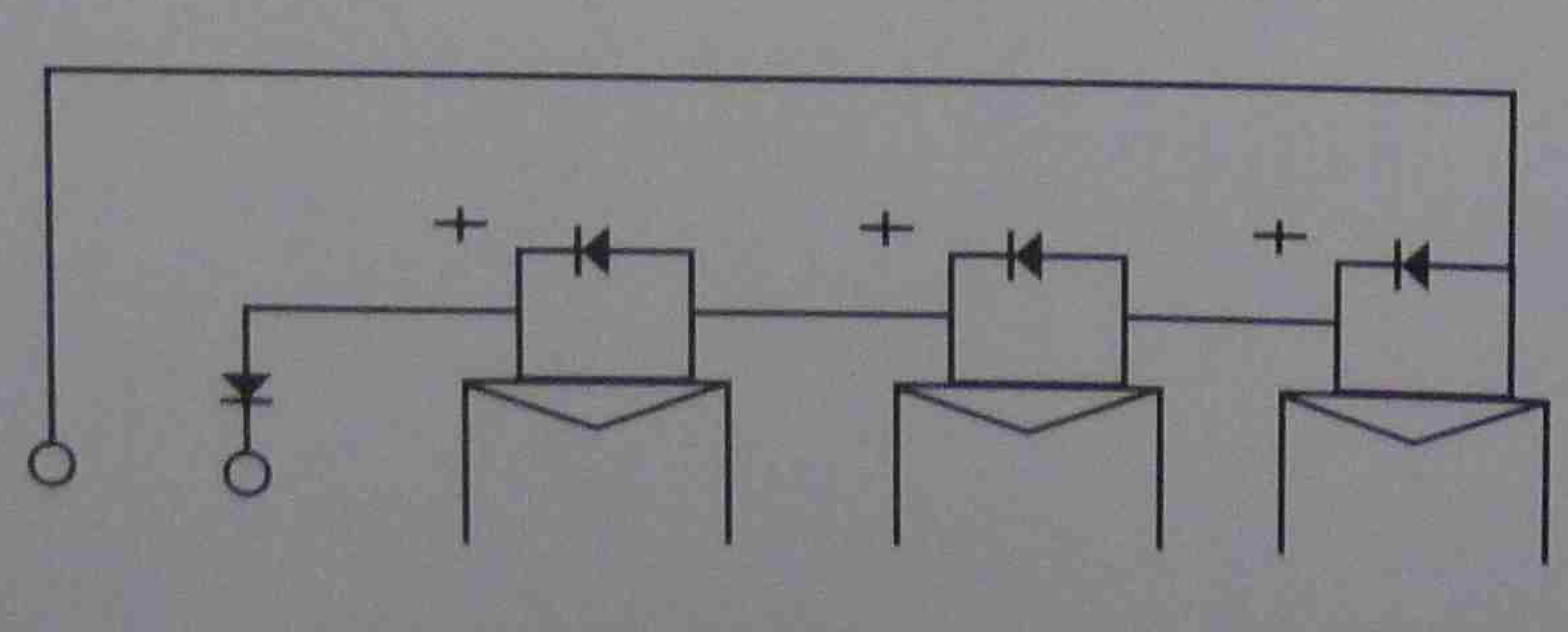
Blocking diodes also prevent feedback from stings that have higher voltages than others in the array.

The rating of the diodes should comply with AS5033:2005.

Have a peak inverse voltage (PIV) rating of 2 x Voc^{MOD}

Rated at 1.25 x ISC MOD for PV strings
Rated at 1.25 x ISC S-ARRAY
Rated at 1.25 x ISC ARRAY

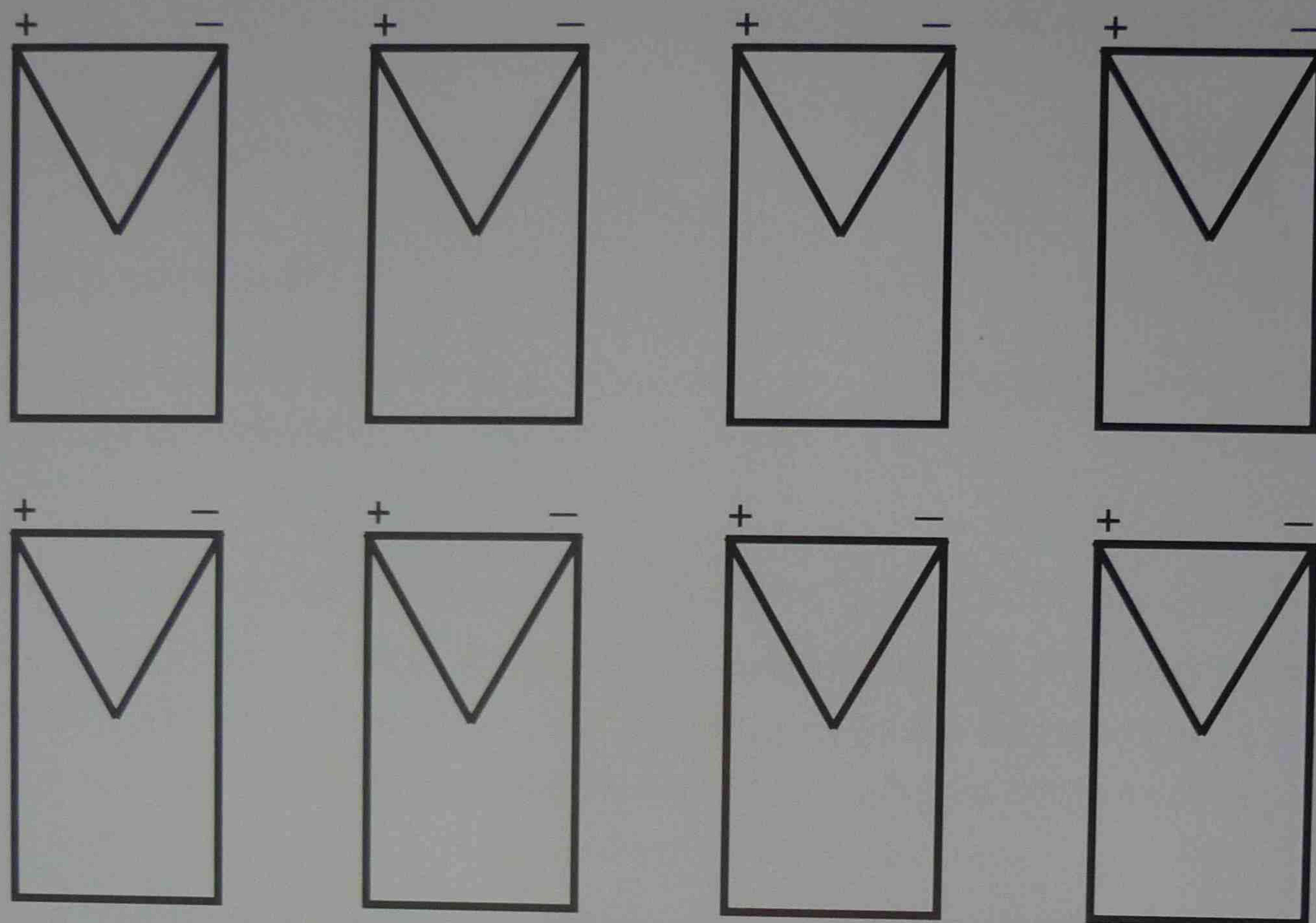
In the diagram below three panels are connected in series and by-pass diodes are fitted across each panel and series with the positive output lead a blocking diode is fitted.



EXERCISE

n the following diagram connect the following panels into 2 strings and then ad

. By-pass diodes one for each panel
. Blocking diodes



3.7 GRID INTERACTIVE INVERTERS

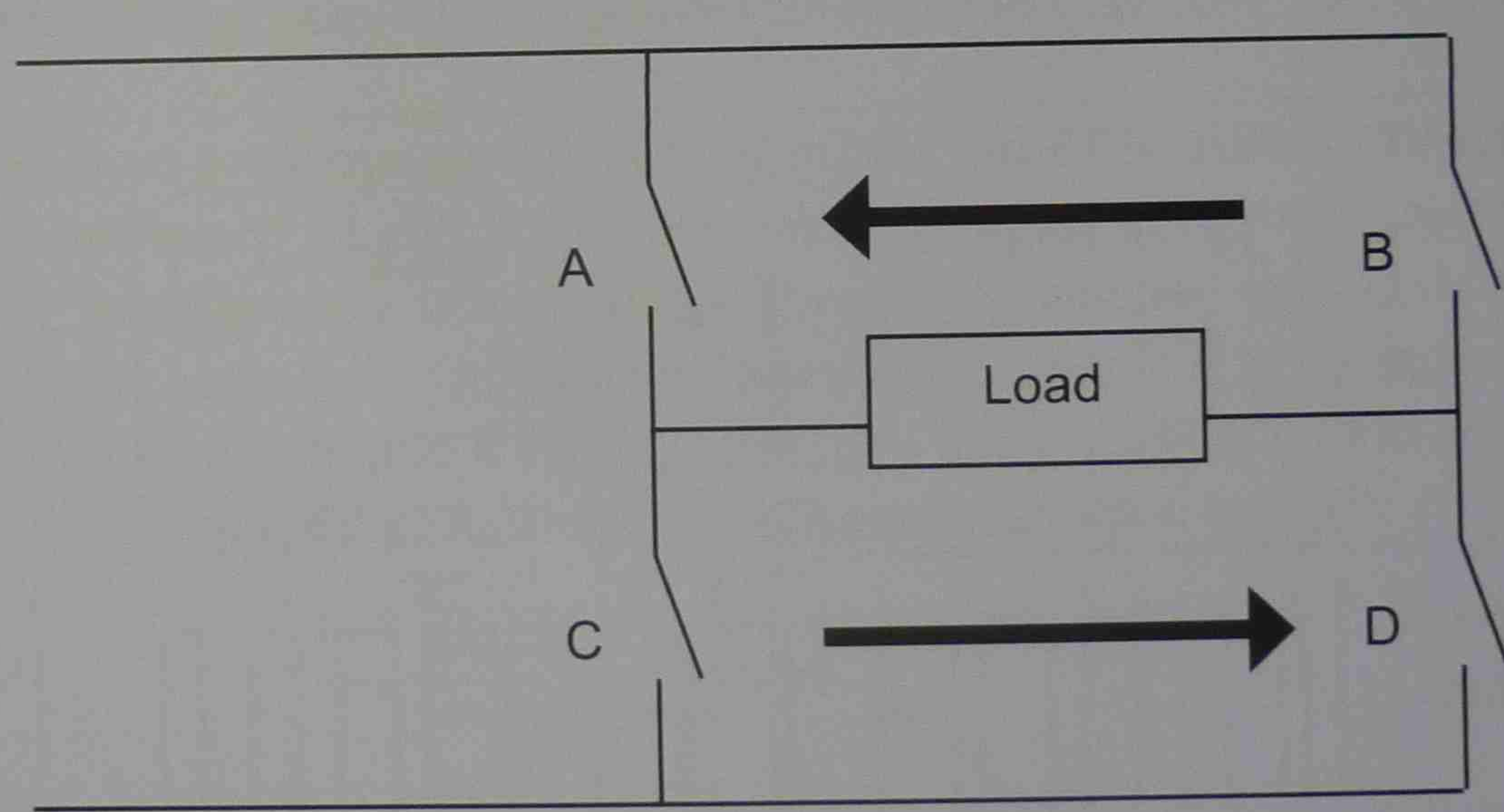
The basic purpose for power inverters is to convert the DC supply from the array to a useable AC power source. To provide isolation the switching and control circuits is done in the DC section of the inverter and the AC output is connected directly to output transformer windings. A simplified version of inverter operation is shown below.

In this diagram it can be seen that if switches A and D were closed then current would pass through the load in the direction shown by the arrows.

If switches B and C were closed then current would pass through the load in the opposite direction.

In the case of an inverter the load would be a toroidal transformer which steps up the voltage through transformer action. This toroidal transformer provides an isolation rating of many thousands of volts between the DC and AC sections of the inverter.

This isolation means that the AC output is floating and earthing is the case of the inverter itself. This means that the earth for the AC must be run from the case to the MEN earthing of the installation.



Inverters are available in many different forms of operation.

Square wave or modified square wave.
Sine wave inverters.

These are the simplest form of inverters and are popular because of their simplicity and low cost. They produce a square wave which is often unsuitable for most loads. They also suffer from poor output regulation and harmonic distortion especially the 3rd harmonic which can cause overheating of load devices. Most devices are designed for a 230V rms input which in the case of a pure sine wave has a peak voltage of (Vp) 339V.

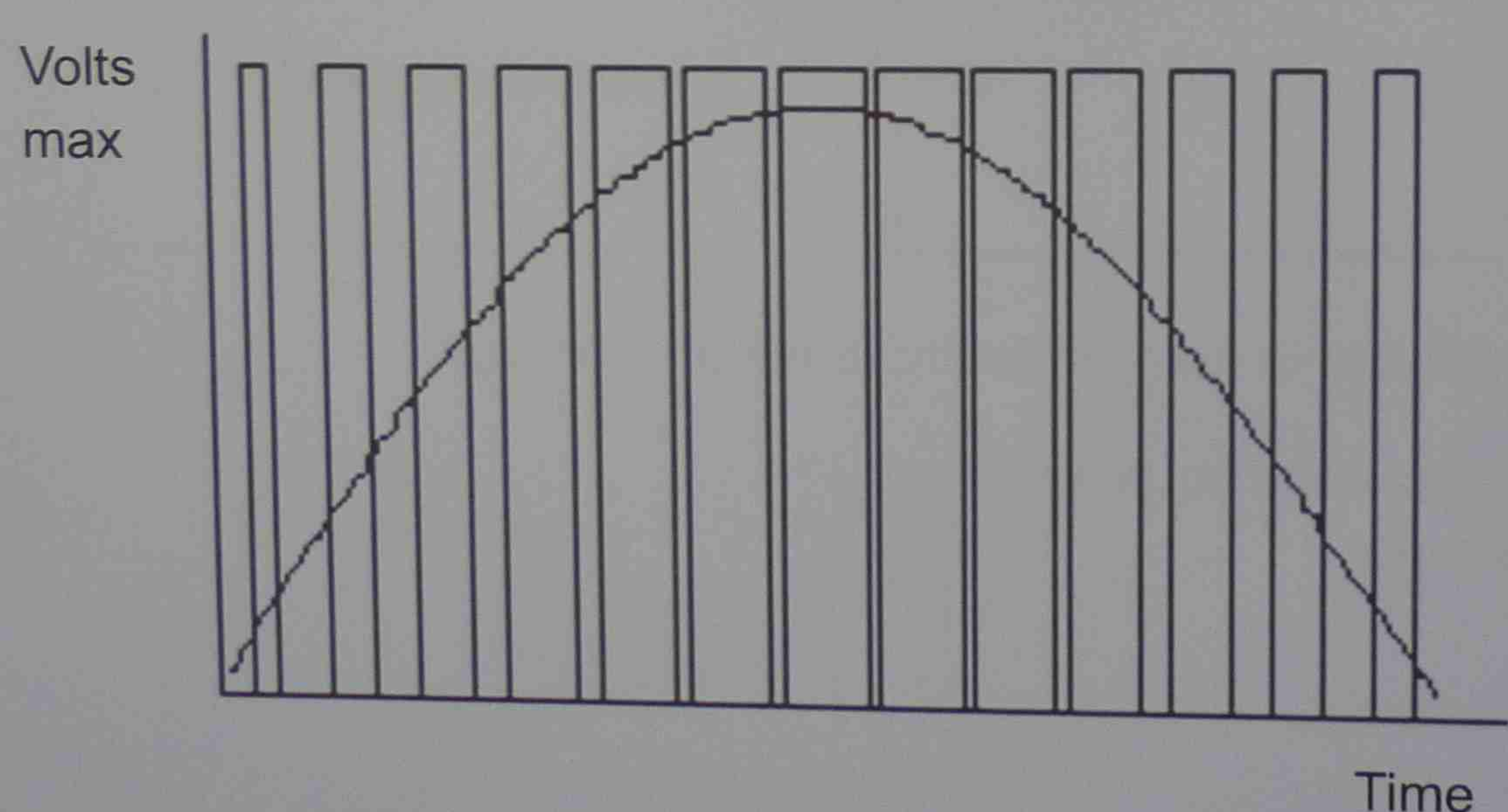
The square wave inverter has a peak value equivalent to the required output voltage. As the output is supplied by a transformer the internal voltage drop of the transformer increases with load which then changes output voltages According to load values.

These types of inverters are suitable only for supplying loads of fixed value such as fluorescent lamps or other loads such as heating etc. Where the actual voltage and wave form are not as important.

3.7.2 MODIFIED SQUARE WAVE INVERTERS have a peak voltage higher than the rms value required and adjust their output by varying the on/off time of the output pulses. This is called pulse width modulation (PWM). If the load increases then the output pulse width is automati cally altered to provide the same rms value. Extra load on the DC voltage input may also vary because of voltage drop caused by the system cabling.

3.7.3 SINE WAVE INVERTERS are similar to modified square wave inverters in that they have an output which is varied by pulse width modulation. These inverters are far more expensive but are necessary for loads that require sine wave input. The input pulses are generated at a high frequency and the duty cycle is varied which simulates a sine wave. This output is filtered and then supplied via a output transformer.

Typical output of sinewave inverter before filtering



Inverter efficiency must be taken into Account when designing the complete system. The output efficiency will vary as does the load. The diagrams below are taken from the Latronics inverter manual and show inverter efficiency with load and also output waveforms of both a sine wave inverter and a square wave inverter.

Smaller inverters may rely upon heat sinks and ambient temperat...

Grid connect inverters are designed for the purpose of supplying both low voltage supply systems and low voltage installations. In this case low voltage supply systems is defined as a 50 Hz system with a nominal line to neutral voltage of 230V AC and a line to line voltage of 400V AC in a three phase system with tolerances of +10% and −6% at nominal frequency.

In general grid connect inverters shall either have a grid protection system fitted to it or have one incorporated in its design. This device should comply with the electrical safety requirements of AS/NZS 3100 and also comply with any other standard that may affect the design construction or testing of the device.

Rating of inverters is in apparent power or Volt / Amps (VA) and not true power (W). As energy audits are conducted to give true power requirements then it is important to consider the power factor or the system load. Often this is not possible because of the mixture of various loads so a rule of thumb power factor of 0.8 can be used.

This model of AURORA is transformer-less, that means that there is no galvanic isolation between input and output. This allows an increase in the inverter efficiency. AURORA, on the other hand, is equipped with all the protection needed to operate safely and to comply with existing safety regulations even without an isolation transformer, as described in the paragraph regarding protective devices.

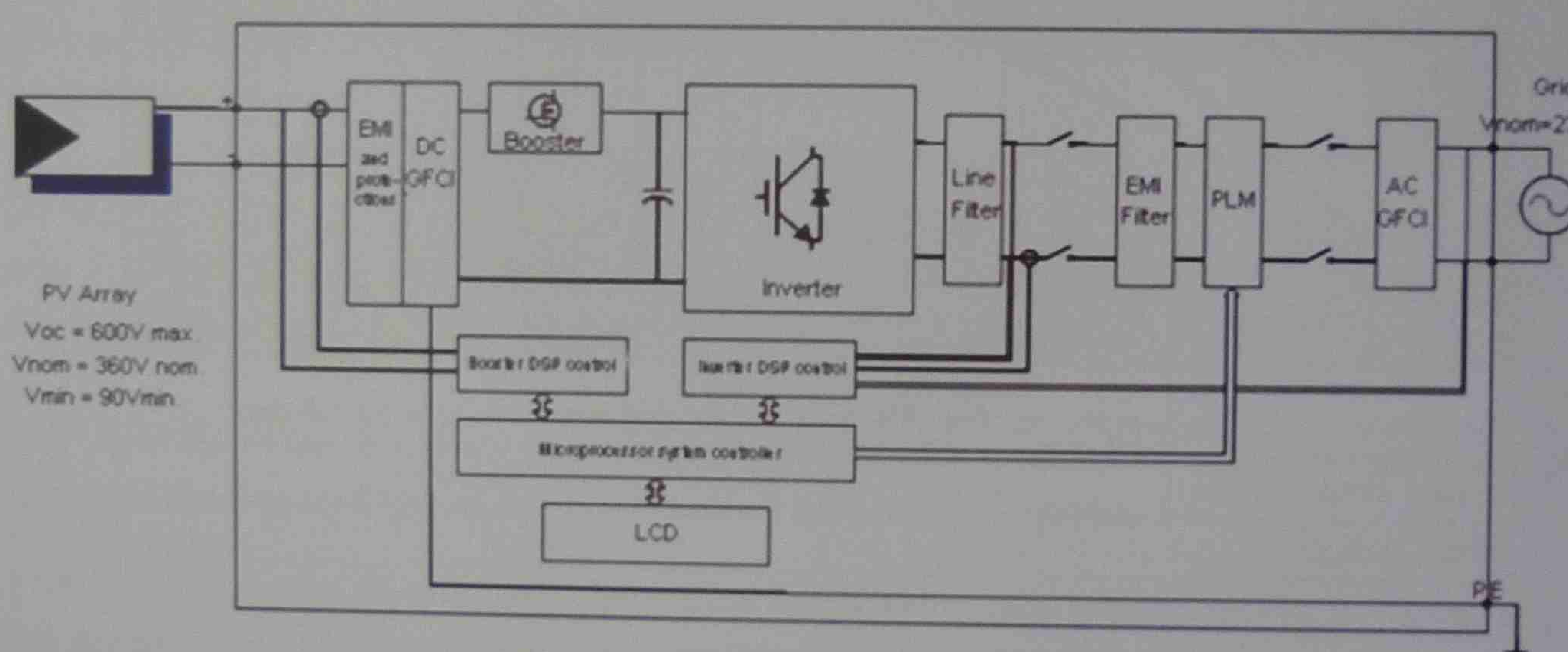


Fig.4 AURORA block diagram

In the case of a 10KW, 230V system with an assumed power factor of 0.8 the VA or kVA would be:

$$P = VI\lambda$$

$$S = \frac{10{,}000}{0.80} = 12{,}500 \text{ VA}$$

Or = 12.5 **kVa**

It is also important to know the current for the purpose of cable sizing and circuit protection rating.

$$I = \frac{12{,}500}{230\text{ V}}$$

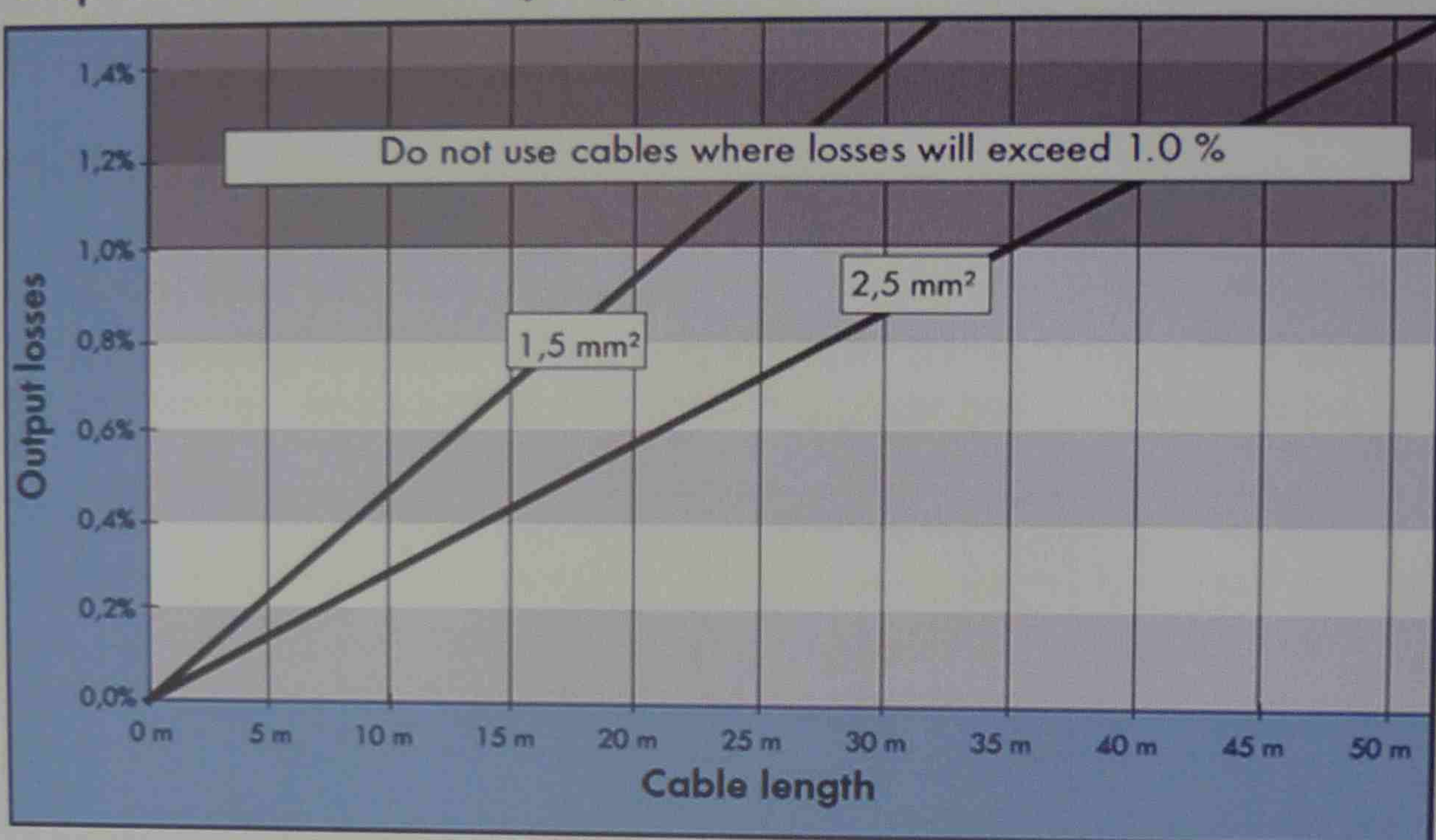
3.7.4 INVERTER OUTPUT

As can be seen from the calculations above the inverter output should be rated in KVA and that the output of the inverter varies with both line voltage and power factor of the load.

Most inverters will fail to connect to the grid if the AC cable has a impedances greater than 1.5 ohms. Later in sizing the system we calculate the cable sizes to ensure the losses are less than 1%.

The following graph from the sunny Boy SB 1100 manual goes far enough to give information on cable length verses cable cross sectional area.

Output Losses of the Sunny Boy SB 1100



The maximum cable lengths for the different cable cross-sections are as follows:

Cable cross-section	1.5 mm²	2.5 mm²
Max. length	21 m	35 m

Assume a overall cable length of 30m x 2.5mm2 cable is being run (15m of 2.5mm2 twin). Using the graph above a line is drawn vertically from the 30m cable length point.

A line is drawn horizontally from the point where it intersects the 2.5mm2 line. On the vertical axis it shows that the output losses due to cable would be close enough to 0.88%.

NOTE: The diagram above may not be accurate and the original graph from the SMA technical data should be referred to.

EXERCISE

A grid interactive inverter is to supply 1700 watts. Calculate the output required by the inverter if the line voltage is 235V and the power factor of the load is 0.9

3.7.5 GRID CONNECT INVERTER REQUIREMENTS

This section should be read in conjunction with the following standards.
AS 4777.1 Installation requirements
AS 4777.2 Inverter requirements
AS 4777.3 Grid protection requirements

ANTI-ISLANDING is achieved by monitoring the grid supply and where the inverter will disconnect the supply from the grid in the event of the grid being switched off for any purpose.

LIGHTING PROJECTION shall be provided by the inverter being able to withstand an energy impulse of 0.5J @ 5kV with a 1.2/50 waveform. Such a requirement would be met if approved inverters are used.

HARMONICS are limited to be no more than 5% total harmonic distortion (THD) to the 50th harmonic. Harmonic current limits for each harmonic are contained in AS 4777.2 2005 table and table 2. The harmonic limit of test voltage are contained in AS 4777.2 2005 table B1.

DATA LOGGING and/or communication equipment shall comply with the requirements contained in AS/NZS 60950.1 AS 4777.2 also makes note of insulation creep age and clearance distances.

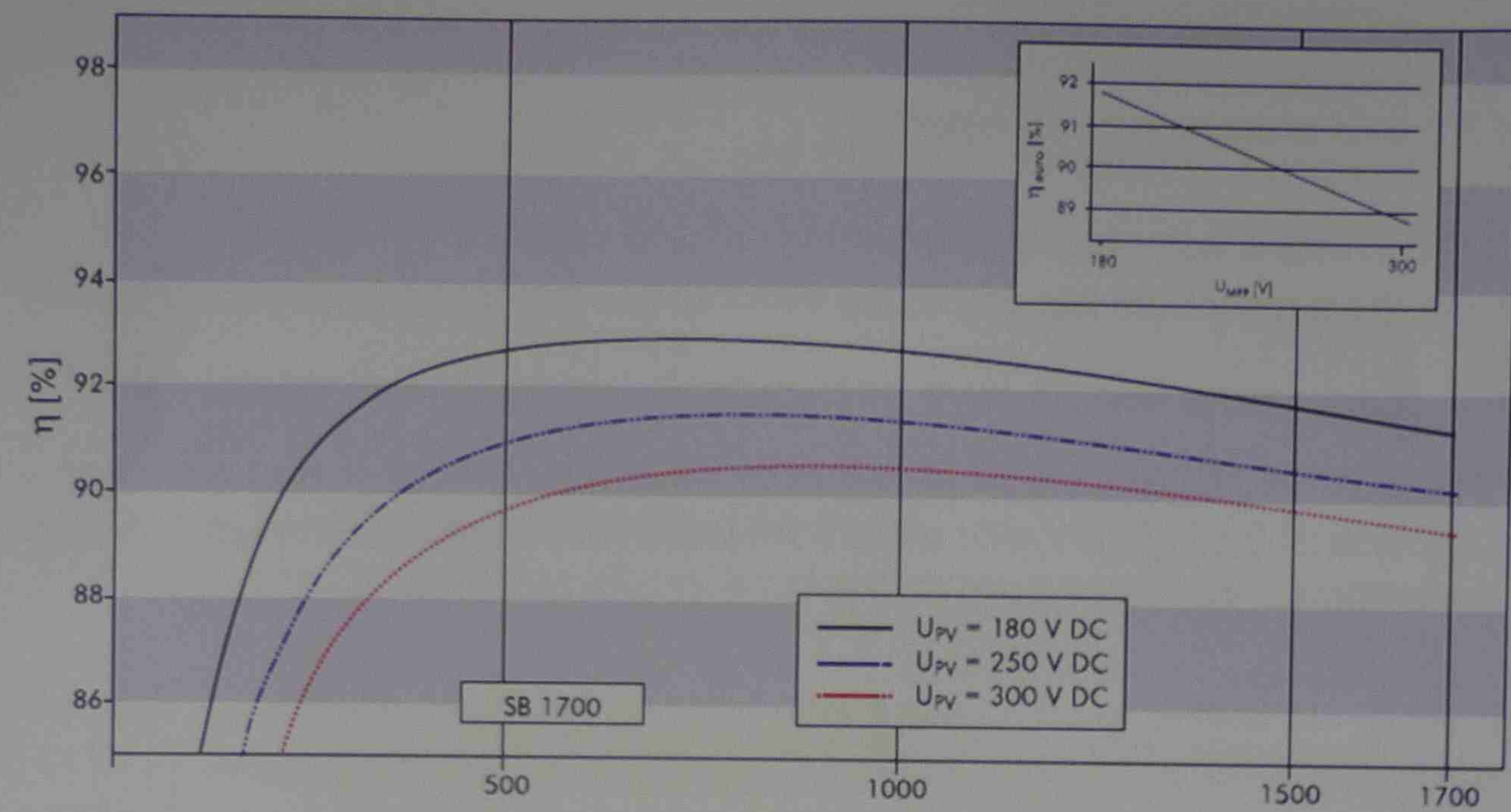
SYNCHRONISATION must be a standard feature included in all grid interactive inverters. The inverter senses line waveform and frequency and supplies output suitable for the grid it is connected to.

EFFICIENCY The efficiency of an inverter is variable and it depends on the input voltage and the percentage of its rated output that it is connected to.

The efficiency of a inverter will vary according to the load connected to it. When selecting an inverter it is not good practice to load it to its fully capacity. If so a larger inverter should be used and therefore greater efficiency can be achieved.

The below diagram is the efficiency of an SMA inverter.

Efficiency curve



NOTE: there are three DC voltage curves shown. There is also a variable load rated up to 1700 Watts.

NOTE: On this diagram a line has been drawn to show a load of around 1,200W at a voltage of 250Vdc.

From this it can be seen that the efficiency of the inverter at a load of 1,200W and an input voltage of 250Vdc the efficiency will be a about 91.5%.

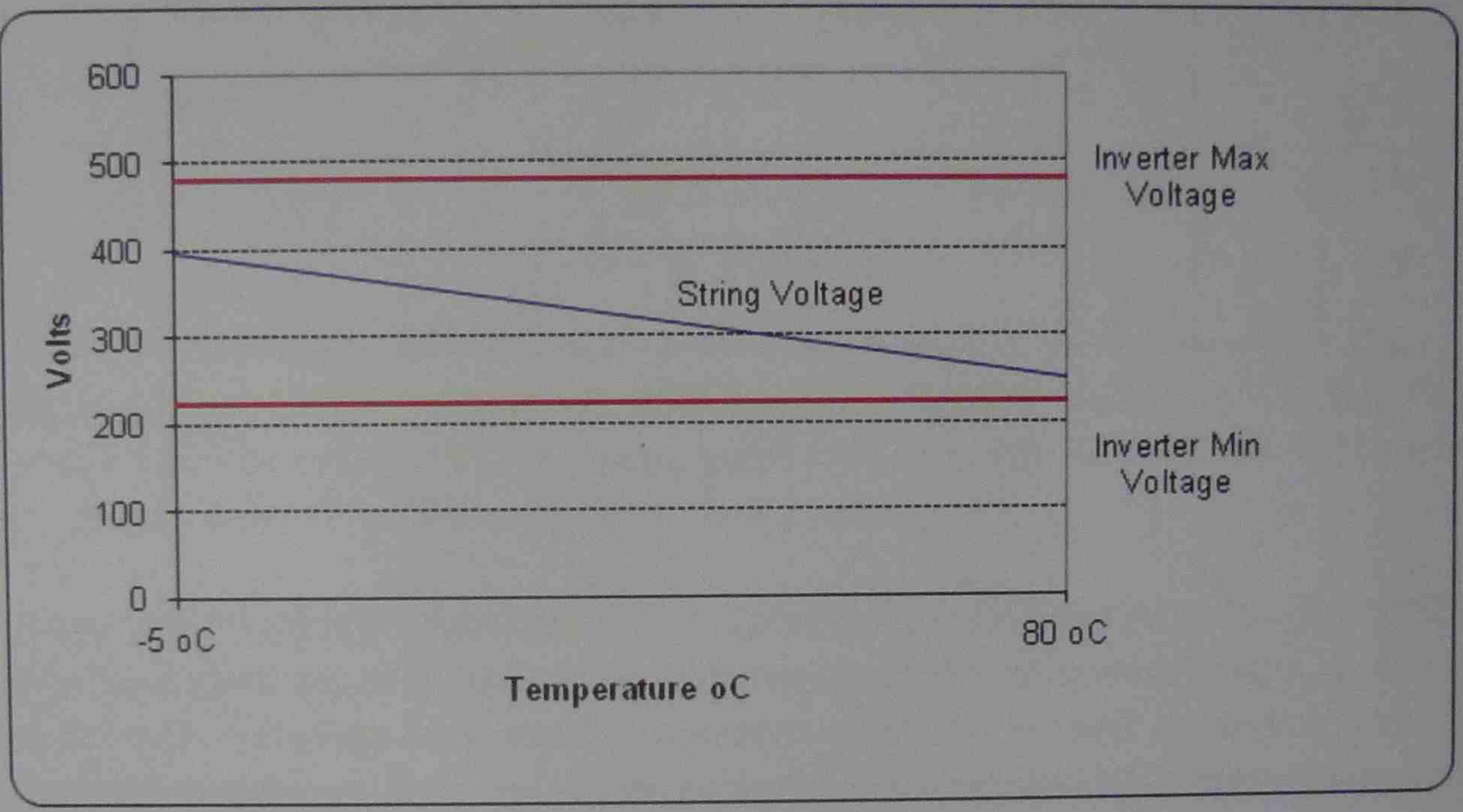
It is important to determine the inverter efficiency for calculating the input power required to provide calculated output. As the inverter efficiency decreases then the output from the panels will have to be increased to allow for it.

INVERTER INPUT REQUIREMENTS Inverters have a maximum d.c. voltage limit. If this limit is exceeded then serious damage to the inverter may result. When sizing a system it necessary to calculate the maximum voltage that will be applied (early morning when the temperature is coldest).

Inverters also have a minimum voltage under which they will operate. When sizing a system it is necessary to calculate the system voltage at the highest temperature does not fall below that value (just after noon when the panels will be at their highest temp).

NOTE: When doing the calculations for system sizing it will be necessary to calculate maximum and minimum voltages applied to the input of the inverter.

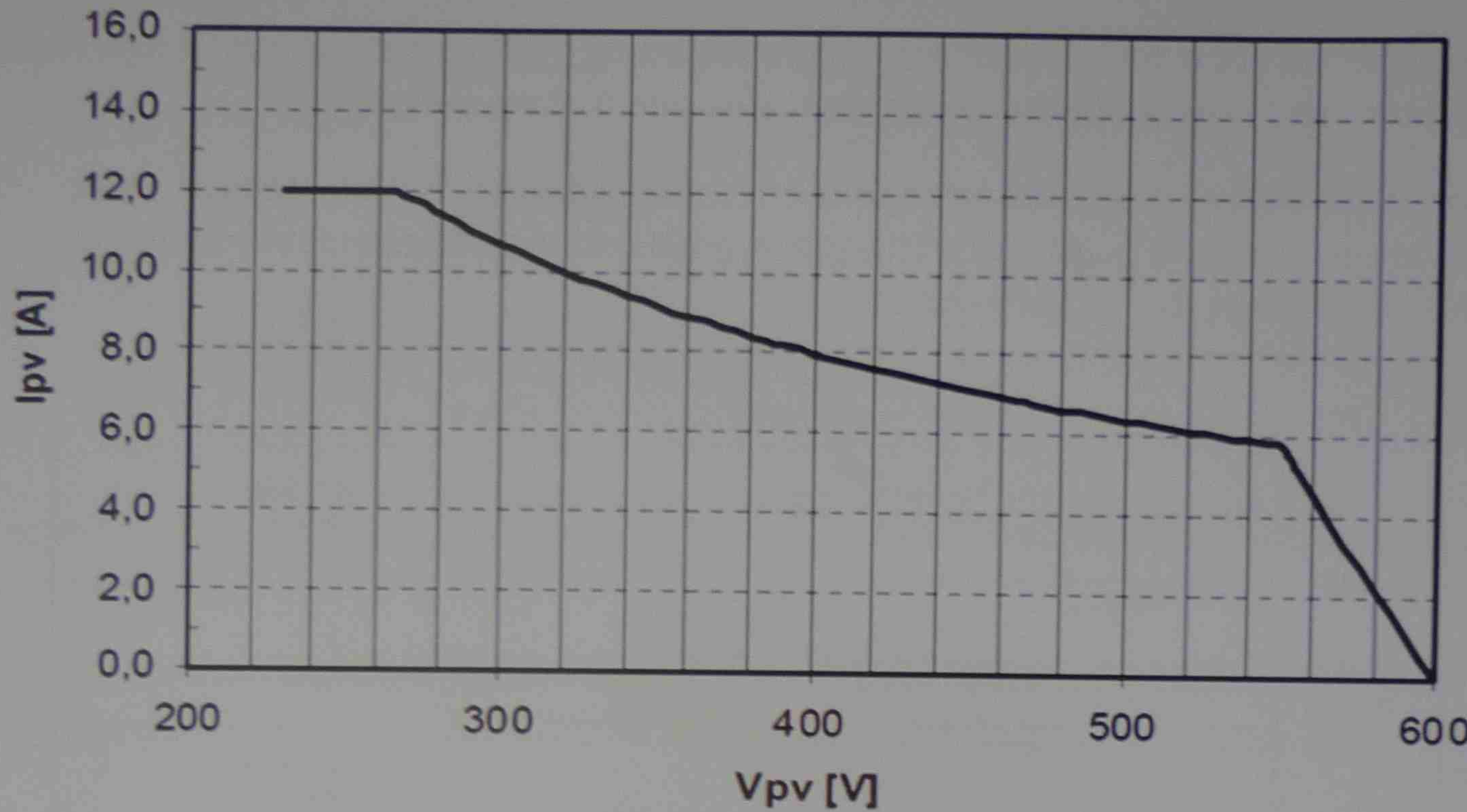
There are software programs that can check these voltages. Typical of these is the program below (front page only). This graph produced by software clearly shows the change in voltage due to temperature.



will change with the voltage of the system at the d.c. input terminals of the inverter.

The diagram below shows the current required for different values of d.c. input voltage. When calculating system sizing it i important to choose panels when configured can supply the required current at maximum power point.

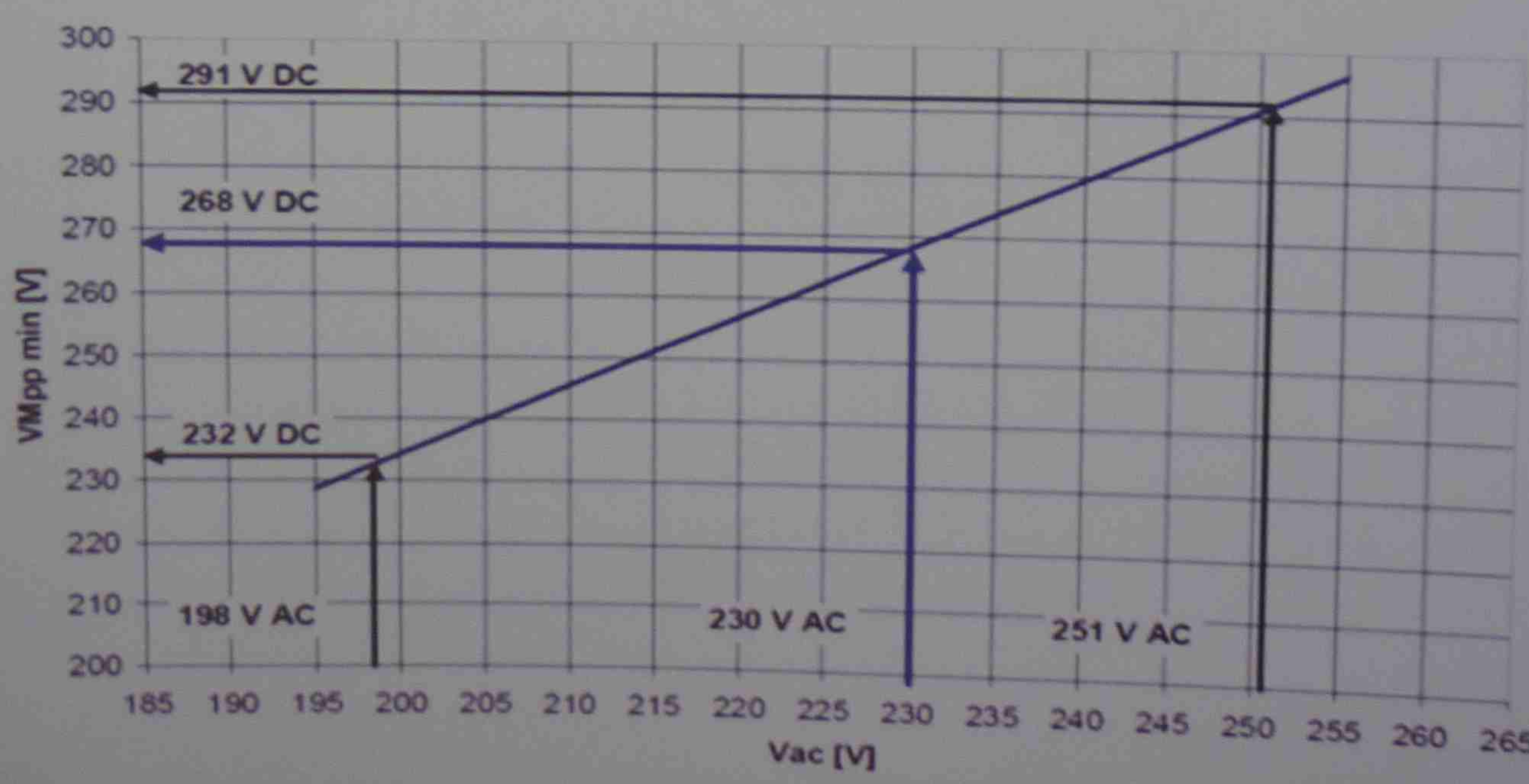
This diagram is from a Sunny Boy technical specification



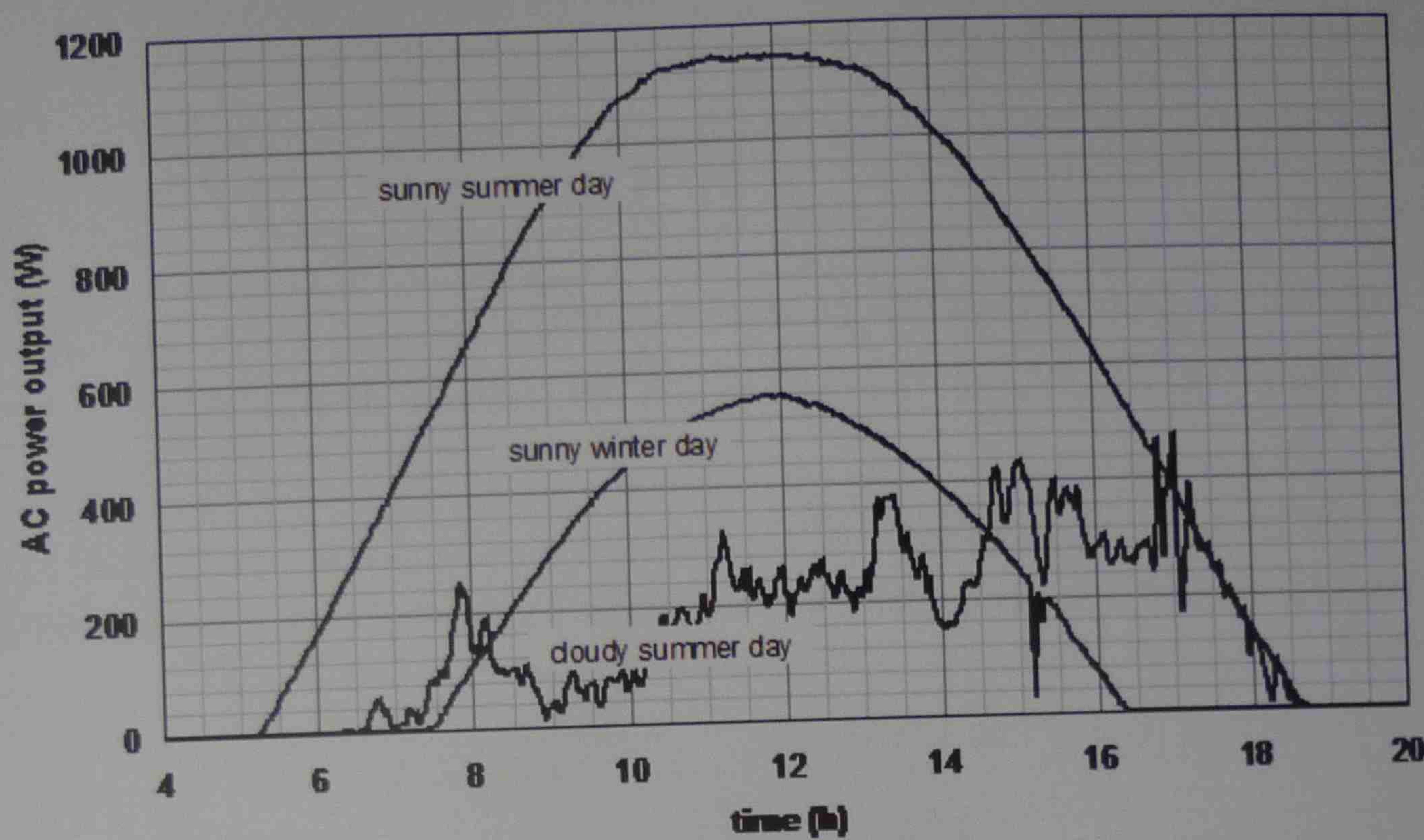
INPUT VOLTAGE REQUIREMENTS although the inverter will operate on any voltages within the specified minimum and maximum allowable input voltages there is an minimum voltage that the inverter needs for maximum power point operation .The following diagram taken from a SMA technical article shows this variation as a function of line voltage .

In this diagram a line is drawn at 230V a.c. and it can be seen that the minimum power point d.c. voltage would be almost 270V d.c.

This diagram is from a Sunny Boy technical specification



The following graph is typical power output expected for clear skies on a summer and winter day and that of a cloudy day.



A copy of a list of certified is supplied next 2 pages. Please note that this list is only current at 16th November 2007 and that certificates of suitability only last for fives and recent updates should be checked. (List next 2 pages)

Note this list is not comprehensive and further copies should be sought from BCSE or Energy Supplier.

Grid-connect Inverters - Click to download file. There are two pages of inverters listed. You may need to zoom in on this pdf file in order to read it effectively.

http://www.bcse.org.au/docs/STA/Standards/Inverters%20List%20Nov%207%202007.pdf

3.8 SIZING THE SYSTEM

Calculation of daily energy output can be done by the simple calculation.

E module = P standard condition x PSH x f derating.

Note that these values will change when the system is installed and operating.

EXAMPLE

P standard test conditions will change with irradiance values

f derating will be subject to cell temperature, dirt. This factor is dimensionless.

3.8.1 DERATING FOR TEMPERATURE

If the NOCT and the power coefficient is known the power output can be calculated as follows:

$$PT = PSTC \times (1 - y \times (T_{cell} - TSTC)$$

3.8.2 DERATING FOR IRRADIANCE

As the power from a panel is calculated by P = V x I and the voltage changes very little with cell temperature, then it can be said that power is proportional to irradiance.

$$E = \frac{(P_{stc} \times G)}{(G_{stc})}$$

EXAMPLE

An 80w poly crystalline panel is operating with an irradiance of 850W/m². Calculate its output at that irradiance.

$$P_G = \frac{850}{1,000} = 0.85 \text{ and } 0.85 \times 80 = 68W$$

OR

$$P_G = \frac{85 \times 850}{1,000}$$

$$= 68W$$

EXERCISE

Calculate:
An 80 Watt poly crystalline panel is operating with an irradiance of 20Mj/m2 per day. It is a hot day so derating can be approximated to 0.80. Answer should be in Watts. Remember to convert Mj/m2 to Watts first.

EXERCISE

10 x 185W panels are connected in a string. You have measured the irradiance with your pyranometer and have a reading of 750W/m2. Calculate the output of that string in watts.

SYDNEY

Average annual daily total irradiation (MJ/sq.m.) on an inclined plane

Latitude: 33° 55 minutes South

Longitude: 151° 10 minutes East

Elevation: 4 metres

Plane Azimuth (degrees)	Plane Inclination (degrees)									
	0	10	20	30	40	50	60	70	80	90
0	16.3	17.6	18.5	18.9	18.9	18.4	17.5	16.1	14.4	12.4
10	16.3	17.6	18.4	18.9	18.8	18.3	17.4	16.0	14.3	12.4
20	16.3	17.5	18.3	18.7	18.6	18.1	17.1	15.8	14.2	12.3
30	16.3	17.4	18.1	18.4	18.3	17.7	16.8	15.5	13.9	12.1
40	16.3	17.3	17.9	18.1	17.9	17.3	16.3	15.1	13.6	11.9
50	16.3	17.1	17.6	17.6	17.3	16.7	15.8	14.6	13.1	11.6
60	16.3	16.9	17.2	17.1	16.8	16.1	15.1	14.0	12.6	11.2
70	16.3	16.7	16.8	16.6	16.1	15.4	14.4	13.3	12.0	10.7
80	16.3	16.5	16.4	16.0	15.4	14.6	13.7	12.6	11.4	10.1
90	16.3	16.3	16.0	15.4	14.7	13.8	12.9	11.8	10.7	9.5
100	16.3	16.1	15.6	14.8	14.0	13.0	12.0	11.0	9.9	8.8
110	16.3	15.9	15.1	14.2	13.2	12.2	11.1	10.1	9.1	8.1
120	16.3	15.7	14.7	13.6	12.5	11.3	10.3	9.2	8.3	7.4
130	16.3	15.5	14.4	13.1	11.8	10.5	9.4	8.4	7.5	6.7
140	16.3	15.3	14.1	12.6	11.2	9.8	8.6	7.6	6.8	6.1
150	16.3	15.2	13.8	12.2	10.6	9.2	7.9	7.0	6.2	5.6
160	16.3	15.1	13.6	11.9	10.2	8.8	7.5	6.4	5.7	5.2
170	16.3	15.1	13.5	11.7	10.0	8.5	7.2	6.1	5.3	4.9
180	16.3	15.1	13.5	11.7	10.0	8.5	7.1	6.0	5.2	4.8
190	16.3	15.1	13.6	11.8	10.1	8.6	7.3	6.1	5.3	4.9
200	16.3	15.2	13.7	12.0	10.3	8.9	7.6	6.5	5.7	5.2
210	16.3	15.3	13.9	12.3	10.8	9.3	8.1	7.1	6.3	5.6
220	16.3	15.4	14.2	12.8	11.3	10.0	8.8	7.8	6.9	6.2
230	16.3	15.6	14.5	13.3	12.0	10.8	9.6	8.6	7.7	6.8
240	16.3	15.7	14.9	13.8	12.7	11.6	10.5	9.5	8.5	7.5
250	16.3	15.9	15.3	14.4	13.5	12.5	11.4	10.4	9.3	8.3
260	16.3	16.2	15.7	15.1	14.3	13.3	12.3	11.3	10.2	9.0
270	16.3	16.4	16.1	15.7	15.0	14.2	13.2	12.1	11.0	9.7
280	16.3	16.6	16.6	16.3	15.7	15.0	14.0	12.9	11.7	10.4
290	16.3	16.8	17.0	16.8	16.4	15.7	14.8	13.6	12.4	10.9
300	16.3	17.0	17.4	17.4	17.0	16.4	15.5	14.3	12.9	11.4
310	16.3	17.2	17.7	17.8	17.6	17.0	16.1	14.9	13.4	11.8
320	16.3	17.3	18.0	18.2	18.1	17.5	16.6	15.4	13.8	12.1
330	16.3	17.5	18.2	18.5	18.4	17.9	17.0	15.7	14.2	12.3
340	16.3	17.5	18.4	18.8	18.7	18.2	17.3	16.0	14.3	12.5
350	16.3	17.6	18.5	18.9	18.9	18.4	17.4	16.1	14.4	12.5

SYDNEY

Average daily total irradiation (MJ/sq.m.) on an inclined plane during January

Latitude: 33° 55 minutes South

Longitude: 151° 10 minutes East

Elevation: 4 metres

Plane Azimuth (degrees)	Plane Inclination (degrees)									
	0	10	20	30	40	50	60	70	80	90
0	23.3	23.7	23.4	22.7	21.4	19.6	17.4	14.8	12.1	9.2
10	23.3	23.6	23.4	22.6	21.4	19.6	17.4	14.9	12.2	9.4
20	23.3	23.6	23.4	22.6	21.3	19.6	17.5	15.2	12.5	10.0
30	23.3	23.6	23.3	22.6	21.3	19.7	17.7	15.4	13.1	10.7
40	23.3	23.5	23.3	22.5	21.3	19.7	17.9	15.7	13.5	11.3
50	23.3	23.5	23.2	22.4	21.3	19.8	17.9	16.0	13.9	11.8
60	23.3	23.4	23.1	22.3	21.2	19.7	18.0	16.1	14.2	12.2
70	23.3	23.4	23.0	22.2	21.0	19.6	18.0	16.2	14.3	12.4
80	23.3	23.3	22.9	22.0	20.8	19.4	17.8	16.1	14.2	12.5
90	23.3	23.3	22.8	21.8	20.6	19.1	17.6	15.9	14.1	12.4
100	23.3	23.2	22.6	21.6	20.3	18.8	17.2	15.5	13.8	12.1
110	23.3	23.1	22.5	21.4	20.0	18.4	16.7	15.0	13.4	11.7
120	23.3	23.1	22.4	21.2	19.6	17.9	16.1	14.4	12.7	11.2
130	23.3	23.1	22.3	21.0	19.3	17.4	15.4	13.6	12.0	10.5
140	23.3	23.0	22.2	20.8	19.0	16.9	14.7	12.8	11.1	9.7
150	23.3	23.0	22.1	20.7	18.9	16.6	14.1	11.9	10.2	8.9
160	23.3	23.0	22.1	20.7	18.8	16.5	13.8	10.9	9.2	8.1
170	23.3	23.0	22.1	20.7	18.8	16.5	13.8	10.8	8.3	7.4
180	23.3	23.0	22.1	20.7	18.8	16.5	13.8	10.8	8.1	7.2
190	23.3	23.0	22.1	20.8	18.9	16.6	13.9	10.9	8.4	7.5
200	23.3	23.0	22.2	20.8	19.0	16.7	14.0	11.2	9.4	8.2
210	23.3	23.1	22.3	20.9	19.1	16.8	14.4	12.1	10.4	9.1
220	23.3	23.1	22.4	21.1	19.3	17.2	15.1	13.1	11.4	9.9
230	23.3	23.2	22.5	21.2	19.6	17.8	15.9	14.0	12.3	10.7
240	23.3	23.2	22.6	21.5	20.0	18.3	16.5	14.8	13.1	11.5
250	23.3	23.3	22.7	21.7	20.4	18.9	17.2	15.4	13.8	12.1
260	23.3	23.3	22.8	22.0	20.7	19.3	17.7	16.0	14.3	12.5
270	23.3	23.4	23.0	22.2	21.0	19.7	18.0	16.4	14.6	12.8
280	23.3	23.4	23.1	22.4	21.3	19.9	18.3	16.6	14.8	12.8
290	23.3	23.5	23.2	22.5	21.4	20.0	18.5	16.7	14.7	12.8
300	23.3	23.5	23.3	22.6	21.5	20.1	18.5	16.6	14.5	12.6
310	23.3	23.6	23.4	22.7	21.5	20.1	18.4	16.4	14.3	12.1
320	23.3	23.6	23.4	22.7	21.6	20.1	18.2	16.1	13.8	11.5
330	23.3	23.6	23.5	22.7	21.5	19.9	18.0	15.7	13.3	10.9
340	23.3	23.7	23.5	22.7	21.5	19.8	17.7	15.3	12.7	10.1
350	23.3	23.7	23.5	22.7	21.4	19.6	17.5	15.0	12.3	9.5

Australian Bureau of Statistics
Latitude: 33.86° Longitude: 151.20° East

MONTHLY CLIMATIC STATISTICS

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yr
Highest Temp (°C)	44.2	40.8	39.8	33.9	29.0	25.2	25.9	31.3	34.5	38.2	41.8	40.9	44.2
Mean Daily Sunshine (hours)	7.6	6.9	6.8	6.2	5.7	6.1	6.4	7.7	7.8	7.8	8.2	7.7	7.1
Lowest Temp (°C)	13.8	12.7	10.1	8.4	5.6	4.5	3.1	5.0	5.2	7.3	8.3	11.1	3.1

3.9 DESIGNING THE SYSTEM SIZE

When calculating the size of the system it is important to first establish the purpose of the calculations. Different locations may require different panel types specifications and the number of panels required. In fact it is almost impossible for any two grid connected systems to be exactly the same.

The output given by any photovoltaic panel will vary according to the conditions it is exposed to (see previous chapter). In the following sizing example we will use the data for Sydney but it is an important part of designing grid connected systems to have the available data for the location in which the system is to be installed.

Large installations may require a sizeable investment in capital and so may require the organisation to prepare a budget for the capital invested in the project. This budget would surely include not only the capital investment but also the expected payback period based on the value of the annual energy output of the system.

Smaller installations may have space as the limiting factor. In such a case the system is designed around the panels installed and then the system output is calculated from this. These types of system are often rated from the panel specification sheet and may be misleading as the system will never have a output the same as that of the panel specifications rated at STC.

Calculating the expected output of an installed array is also important when fault finding a system which is not performing to expectations.

The following calculation examples will be based on a Sydney location and use the figures in the tables above.

EXAMPLE

A system is to be installed in Sydney and the actual output of the system is required to be 2KW annual average daily. The structure it is mounted on has an inclination of 30° and an azimuth of 20°

NOTE: to produce an average daily output of 2KW the system will need to produce more than 2KW at some times of the year and it will also produce less than 2KW during times when the irradiation is lower.

If the system produces an average of 2KW over a day then if we use the average hours in a day taken from the table in the previous page we can calculate the average KWh per day.

So 22KW x 7.1 = 14.2 KWh

As there are 365 days in a year this system should produce:

365 x 14.2 = 5,183 Wh per year

OR

5.183 MWh per year

EXERCISE

A customer is expecting a yield of 10MWh per year from the system about to be installed. Determine the average output required at the terminals in the meter board.

Part 1. Calculate how many KwH per day

Part 2. Using the table containing sunshine hours, calculate average output of system Kw per day.

For calculation of cable sizes, voltage drop and efficiency losses it is necessary to determine the peak output of this system.

To do this we need to look at how irradiance varies throughout the day and the peak value as compared to the average daily radiation.

If we refer to the Australian Radiation Data Handbook (not given in this manual) it can be seen that the maximum value of irradiance occurs at noon in January and that it is close enough to 32% higher than the daily average for the year.

This means that a average 2KW system will produce about 32% more power on January day at 12pm (solar noon).

So 2KW x 1.32
= 2.64 KW

If the maximum input to the grid is 2.64 KW cable sizes can now be calculated.

NOTE: Cable run lengths and installation methods must be known as well as the grid voltage. The grid voltage may also vary depending on the exact location. It may be necessary to monitor the grid voltage using a data logger for a week or more to determine peak demand voltage values. This is important where inverter voltage values are very close to maximum and minimum values as the grid voltage may alter the voltage value of the inverter depending on the inverter design.

STEP 3

Determine the cable resistance using the equation:

$$R = \frac{\rho l}{A}$$

Due to the higher temperature of the cables and using the temperature coefficient of resistance for copper cable at a more realistic temperature ρ (rho) at around 60° C becomes 2.2 x 10 − 8.

$$Rac = \frac{2.2 \times 10 - 8 \times 50m\ (2 \times 25m)}{6mm \times 10 - 6}$$

Where l = cable length
A = area of the cable used

Simplified it becomes:

$$Rac = \frac{2.2 \times 0.50}{6}$$

So $Rac = = 0.183\ \Omega$

STEP 4

Check for voltage drop requirements stipulated in AS 4777 which require a voltage drop of no less than 1%.

$$Vd = I \times R$$

So $Vd = 13.75 \times 0.183$
$= 2.51\ V$

So the percentage voltage drop is

$$Vd\ \% = \frac{2.51}{240V} \times \frac{100}{1}$$

$$= 1.04\%$$

As this voltage drop is near close enough to comply it may be advisable to use the next cable size available as the line voltage may change and most inverters have a feature that they will not switch on if the AC cable losses are greater than 1% (Check SMA data sheets).

STEP 3

Determine the cable resistance using the equation:

$$R = \frac{\rho l}{A}$$

Due to the higher temperature of the cables and using the temperature coefficient of resistance for copper cable at a more realistic temperature ρ (rho) at around 60° C becomes 2.2 x 10 – 8.

$$Rac = \frac{2.2 \times 10 - 8 \times 50m\ (2 \times 25m)}{6mm \times 10 - 6}$$

Where l = cable length

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Simplified it becomes:

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STEP 3

Determine the cable resistance using the equation:

$$R = \frac{\rho l}{A}$$

Due to the higher temperature of the cables and using the temperature coefficient of resistance for copper cable at a more realistic temperature ρ (rho) at around 60° C becomes 2.2 x 10 − 8.

$$Rac = \frac{2.2 \times 10 - 8 \times 50m\ (2 \times 25m)}{6mm \times 10 - 6}$$

Where l = cable length
A = area of the cable used

Simplified it becomes:

$$Rac = \frac{2.2 \times 0.50}{6}$$

So Rac = = 0.183 Ω

STEP 4

Check for voltage drop requirements stipulated in AS 4777 which require a voltage drop of no less than 1%.

$$Vd = I \times R$$

So $Vd = 13.75 \times 0.183$
$= 2.51\ V$

So the percentage voltage drop is

$$Vd\ \% = \frac{2.51}{240V} \times \frac{100}{1}$$

$= 1.04\%$

As this voltage drop is near close enough to comply it may be advisable to use the next cable size available as the line voltage may change and most inverters have a feature that they will not switch on if the AC cable losses are greater than 1% (Check SMA data sheets).

STEP 5

Determine cable losses in AC run. This is necessary because the losses will need to be added to the output required of the array.

Pac losses = V x I

= 2.51 x 13.75

= **34.51 W**

STEP 6

The inverter will now need to be able to supply 34.51 w + 2640W as originally calculated.

The inverter must be 2674.1W rating @ 240V.

As the rating of the inverter is limited by its output current the inverter must be sized in VA.

So inverter power is now = 240v x 13.75A

3,300W plus losses 34.51W = **3,334.51W**

Select a suitable inverter. In this case we have chosen from the SMA range. See the information from SMA product brochure.

Powerful

- Efficiency of up to 95.6 %
- OptiCool active temperature management
- The best tracking efficiency with OptiTrac MPP tracking

Safe

- Galvanic isolation
- Integrated ESS DC switch-disconnector

Flexible

- For indoor and outdoor installation
- Suitable for generator grounding

Simple

- DC plug system SUNCLIX

SUNNY BOY 3300 / 3800

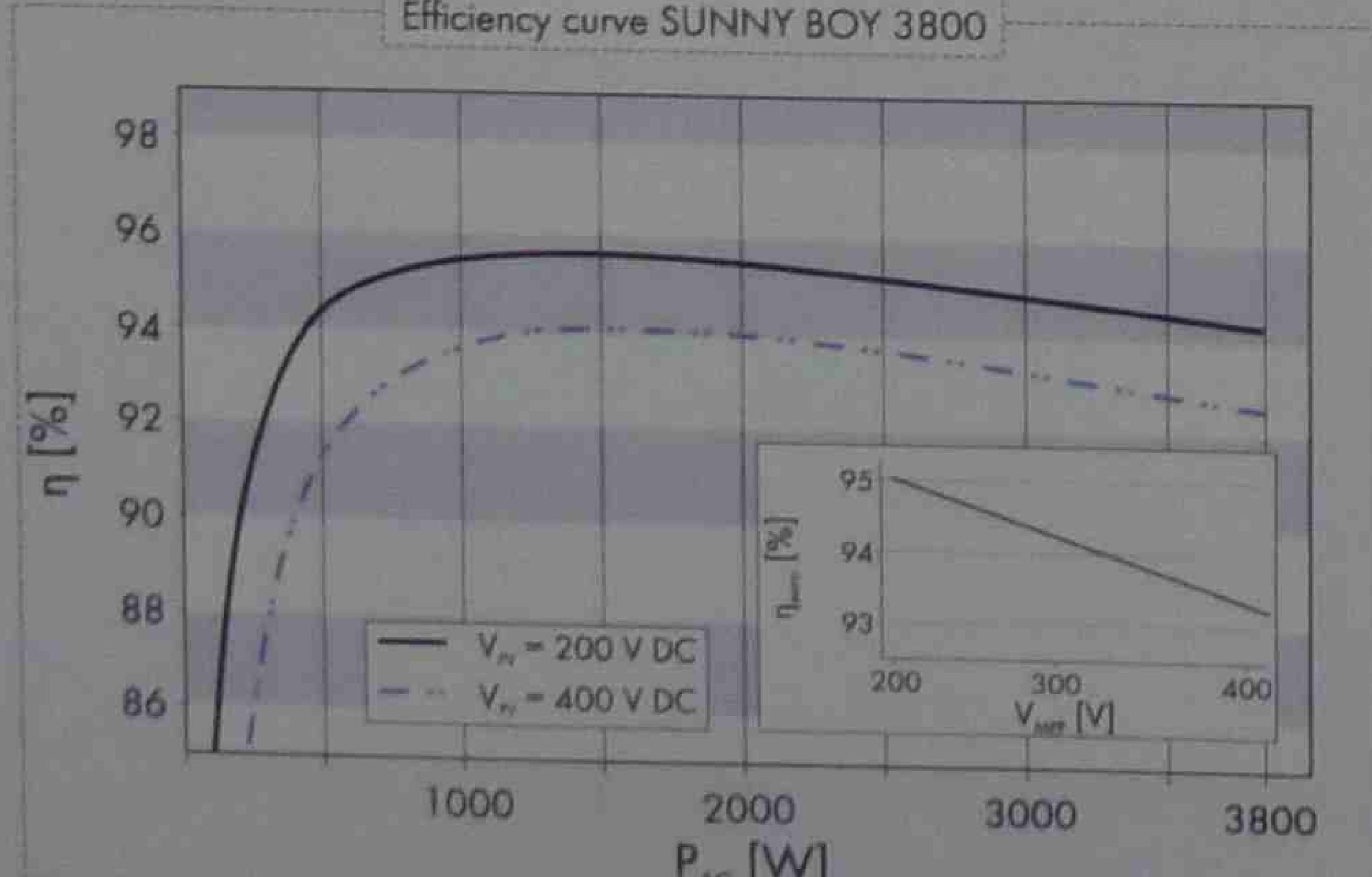
The generalist

It is robust, easy-to-handle, and, thanks to its galvanic isolation, can be used in all kinds of AC grids: the Sunny Boy 3300 / 3800. Due to its suitability for generator grounding, it can be combined with all module types. The die-cast aluminum enclosure, with the OptiCool active cooling system, guarantees the highest yields and a long service life, even under extreme conditions.

Technical data	Sunny Boy 3300	Sunny Boy 3800	Sunny Boy 3800/V
Input (DC)			
Max. DC power (@ cos φ =1)	3820 W	4040 W	3900 W
Max. DC voltage	500 V	500 V	500 V
MPP voltage range	200 V - 400 V	200 V - 400 V	200 V - 400 V
DC nominal voltage	200 V	200 V	200 V
Min. DC voltage / start voltage	200 V / 250 V	200 V / 250 V	200 V / 250 V
Max. input current / per string	20 A / 16 A	20 A / 16 A	20 A / 16 A
Number of MPP trackers / strings per MPP tracker	1 / 3	1 / 3	1 / 3
Output (AC)			
AC nominal power (@ 230 V, 50 Hz)	3300 W	3800 W	3680 W
Max. AC apparent power	3600 VA	3800 VA	3680 VA
Nominal AC voltage; range	220, 230, 240 V; 180 V - 265 V	220, 230, 240 V; 180 V - 265 V	220, 230, 240 V; 180 V - 265 V
AC grid frequency; range	50, 60 Hz; ± 4.5 Hz	50, 60 Hz; ± 4.5 Hz	50, 60 Hz; ± 4.5 Hz
Max. output current	18 A	18 A	16 A
Power factor (cos φ)	1	1	1
Phase conductors / connection phases	1 / 1	1 / 1	1 / 1
Efficiency			
Max. efficiency / Euro-eta	95.2 % / 94.4 %	95.6 % / 94.7 %	95.6 % / 94.7 %
Protection devices			
DC reverse-polarity protection	●	●	●
ESS switch-disconnector	●	●	●
AC short circuit protection	●	●	●
Ground fault monitoring	●	●	●
Grid monitoring (SMA Grid Guard)	●	●	●
Galvanically isolated / all-pole sensitive fault current monitoring unit	●/–	●/–	●/–
Protection class / overvoltage category	I / III	I / III	I / III
General data			
Dimensions (W / H / D) in mm	450 / 352 / 236	450 / 352 / 236	450 / 352 / 236
Weight	38 kg	38 kg	38 kg
Operating temperature range	-25 °C ... +60 °C	-25 °C ... +60 °C	-25 °C ... +60 °C
Noise emission (typical)	≤ 40 dB(A)	≤ 42 dB(A)	≤ 42 dB(A)
Internal consumption (night)	< 0.1 W	< 0.1 W	< 0.1 W
Topology	LF transformer	LF transformer	LF transformer
Cooling concept	OptiCool	OptiCool	OptiCool
Electronics protection rating / connection area (as per IEC 60529)	IP65 / IP65	IP65 / IP65	IP65 / IP65
Climatic category (per IEC 60721-3-4)	4K4H	4K4H	4K4H
Features			
DC connection: SUNCLIX	●	●	●
AC connection: screw terminal / plug connector / spring-type terminal	–/●/–	–/●/–	–/●/–
Display: text line / graphic	●/–	●/–	●/–
Interfaces: RS485 / *Bluetooth*®	○/○	○/○	○/○
Warranty: 5 / 10 / 15 / 20 / 25 years	●/○/○/○/○	●/○/○/○/○	●/○/○/○/○
Certificates and permits (more available on request)	UTE C 15-712-1 *, CE, VDE 0126-1-1, DK 5940**, RD 1663 , G83/1-1, CER/06/190, PPC, AS4777, EN 50438***, C10/C11, PPDS		
Type designation	SB 3300	SB 3800	SB 3800/V 0153

* On demand
** Only applies to IT variants
*** Does not apply to all national deviations of EN 50438
● Standard features ○ Optional features – not available, data at nominal conditions

Efficiency curve SUNNY BOY 3800



Accessories


RS485 interface of type 485PB-NR


Bluetooth® Piggy Back BTPBINV-NR


Grounding set "Positive" ESHV-P-NR


Grounding set "Negative" ESHV-P-NR

From this information it can be seen that the SB3300 grid interactive inverter is a close enough fit. The specification shows that it can provide AC apparent power of 3,600VA.

Look at the efficiency curve and determine the efficiency at the load calculated previously. From the graph in the data sheet it can be seen that the efficiency varies with both the load and the input (DC Voltage).

NOTE: It is necessary at this stage to choose a targeted input DC voltage which will be used when selecting panel type.

The voltage selected in this case will be 300V as this is mid range and will still be in range even if the panel voltage varies with temperature. The maximum DC voltage input is 500V and this voltage must not be exceeded. If this voltage is exceeded it is possible to damage the inverter.

Minimum voltage is 200V and should a high panel temp cause the voltage to fall below this the inverter my switch of on hot days. The voltage range for Mpp is 200V – 400V.

From the efficiency verses voltage graph it can be seen that efficiency at 300V will be close enough to 94% at the required load.

STEP 7
Calculate DC input to the inverter.

The DC input into the inverter will need to be higher than the required output of 3,334.51W to allow for efficiency losses of the inverter.

So

$$P\ in\ DC = \frac{3334.51}{0.94}$$

= 3547.35W into the inverter terminals

STEP 8
Determine the DC cable current

So

$$P = \frac{3334.51}{300V}$$

= 11.11 Amps

STEP 9
Select cable size and type.

NOTE: AS/NZ 4777 allows only a 5% voltage drop and the voltage drop will need to be calculated to ensure this is not exceeded.

When selecting cable sizes it is good practice to minimise cable losses as cable cost less than photovoltaic panels.

The cable used must also be as per Clean Energy Council requirements for DC cable. As first choice we will select 6mm^2 cable and then check for voltage drop.

STEP 10
Check cable requirements.

Cable resistance.
So

$$R = \frac{\rho l}{A}$$

So as before

$$R = \frac{2.2 \times 0.50}{6}$$

$$= \mathbf{0.183\Omega}$$

Voltage drop DC $= I \times R$
$= 11.11A \times 0.183\Omega$
$= \mathbf{2.04V}$

Voltage drop compliance

$$Vd\,\% = \frac{2.04}{300V} \times \frac{100}{1}$$

$= 0.68\%$ COMPLIES

If the cable size chosen does not comply a choice has to be made here and it can be a very economic one.

The cable size could be increased or the system array voltage could be increased.

As the inverter specification states that Mpp voltage must be below 400V raising the voltage too 400V will still not comply so it remains that larger cable must be used or 2 separate strings be wired to the inverter thus halving the current requirements of the cable.

If this is done it will mean that when panel type are chosen it mst be done using 2 strings.

Calculate DC power losses
Power DC = V x I
= 2.04 x 11.11
= **22.66W**

EXERCISE

The design choice is to us a smaller cable and 2 strings.
Select a suitable cable size and recalculate for each string.
Cable resistance

Current per string

Voltage drop per string

Percentage voltage drop per string

State if this now complies with the requirements of AS/NZS 4777

STEP 11

Find total power input by adding losses to average output requirements of the panels.

Total losses = 200W inverter + 34.51 AC cable + 22.6 DC cable

= 257W (almost one complete panel)

So

Total average daily power required by the panels is

= 200 + 34.51 + 22.6 + 2000

= **2,257W**

The location of the installation (Latitude) and the inclination of the panels will determine the number of panels required or area of the array required to give desired output.

For example a particular panel installed in Brisbane will produce a higher average daily KWh than the same panel installed in Hobart.

The difference being that each location has different irradiance values and the Australian Bureau of Meteorology data must be consulted at the time of designing the system.

The inclination of the panels will also influence the energy received by the panels.

In this example we are intending to install this system in a Sydney location.

STEP 1

Using the data supplied above it can be seen that the average annual daily radiation for Sydney with that inclination and azimuth is 22.6MJ/m2.

STEP 2

Convert MJ/m2 into a more convenient form (KWh/m2)

$$= \frac{22.6MJ}{3.6}$$

$$= 6.28 \text{ KWh/m}^2$$

This means that for every m2 of surface area on the specified inclination and azimuth, 6.28 KWh/m2 derived from the sun. The panels however cannot convert all of this energy and are on an average only able to convert 13%.

STEP 3

$$= 6.28 \text{ KWh/m}^2 \times 0.13 \text{ (13\%)}$$

$$= 674 \text{ Wh/m}^2$$

So for every m2 of panel area 674Wh of energy should be produced from the panels average per day in Sydney.

STEP 4

If W/h were divided by the hours then only Wm2 would be left, so from the date in the table above we find that the average sunshine hours for Sydney is 7.1.

So

$$= \frac{674}{7.1}$$

$$= 94.92 \text{ W/m}^2 \text{ of panel}$$

Now it is necessary to determine the type of panel and then derive the size of the panel from the information given.

In this case we will chose between several different types of panel.

STEP 5

It will be necessary to have data on various panels on hand, as the array design will need to be able to supply the inverter DC electrical requirements.

Average daily output of the panels should be 2,257W as calculated previously.

So

$$= \frac{2257}{94.92}$$

$$= 23.78\text{m}^2 \text{ of panels}$$

STEP 6

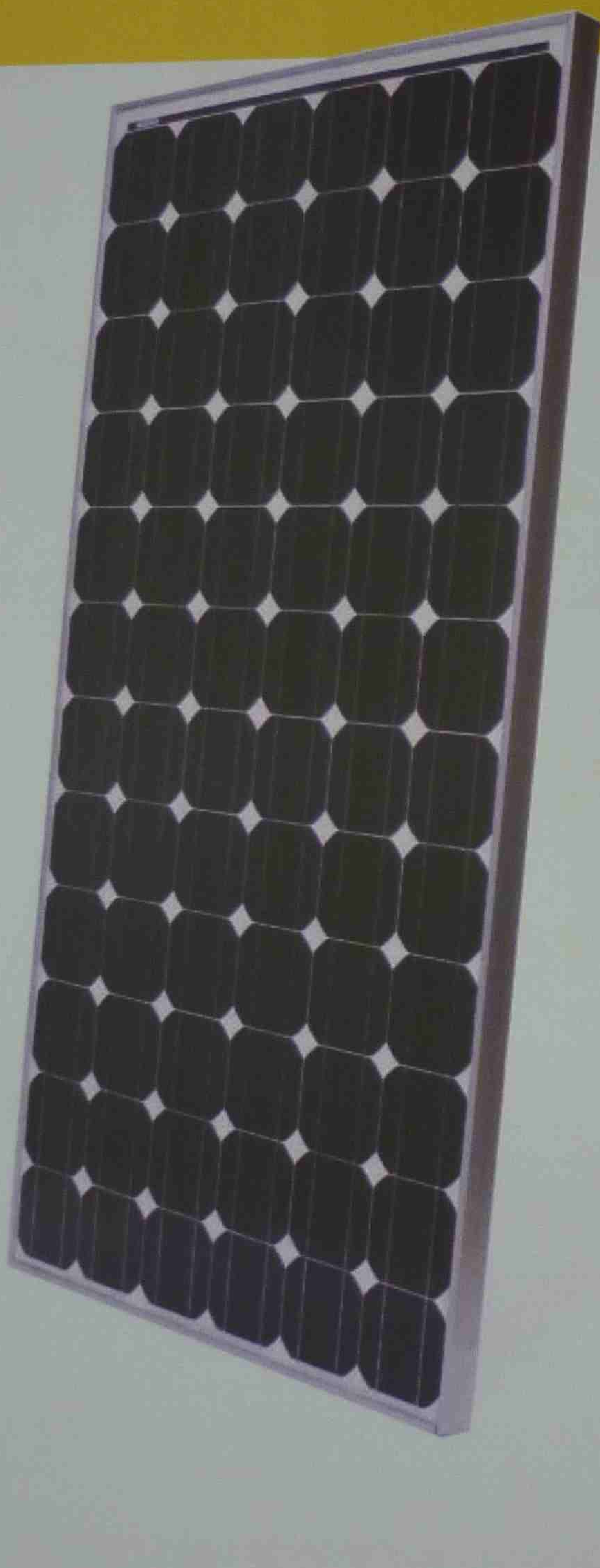
In this example we have to confine our choice of panel to be between the 2 panels as shown below. It will be necessary to examine all the data given but for this step examine the panel dimensions:

bp solar

180W Photovoltaic module

BP 4180T

10 2056E-1 01/10



BP Solar has been manufacturing solar wafers, cells and modules for more than 35 years. This experience shows that the best way to optimize module life and electrical energy production is to attend to every detail in the design and manufacture of our products, our process controls and testing methods. BP Solar's latest generation of 72 cell, Monocrystalline T Series solar modules offers the following benefits:

Positive measured power, more energy production
All modules are factory tested and classified such that measured power is greater than nominal to take into account the LID effect. This means extra kWh produced in the field.

Long lasting, innovative frame design
The aluminum frame has a rounded profile for better handling comfort and is optimized for use with anti-theft bolts to increase security. It can withstand heavy snow loads (5400Pa - 540kg/m²) even in end mounting.

Increased energy production
High transmission ARC glass and enhanced design push the laminate to the front, maximizing the energy production and reducing dirt accumulation and soiling losses.

Improved reliability with effective cooling
IntegraBus™ technology ensures reliable cable management while positioning the bypass diodes and junction box away from the cells ensuring cooler operation and greater energy production.

Enhanced warranty offer
BP Solar launches an industry leading warranty offer, with lower degradation rates on our modules manufactured beginning January 1st, 2010. Our internal testing standards that go well beyond international requirements back this innovative offer.

ISO 9001
ISO 14001
PV CYCLE

180W Photovoltaic module

BP 4180T

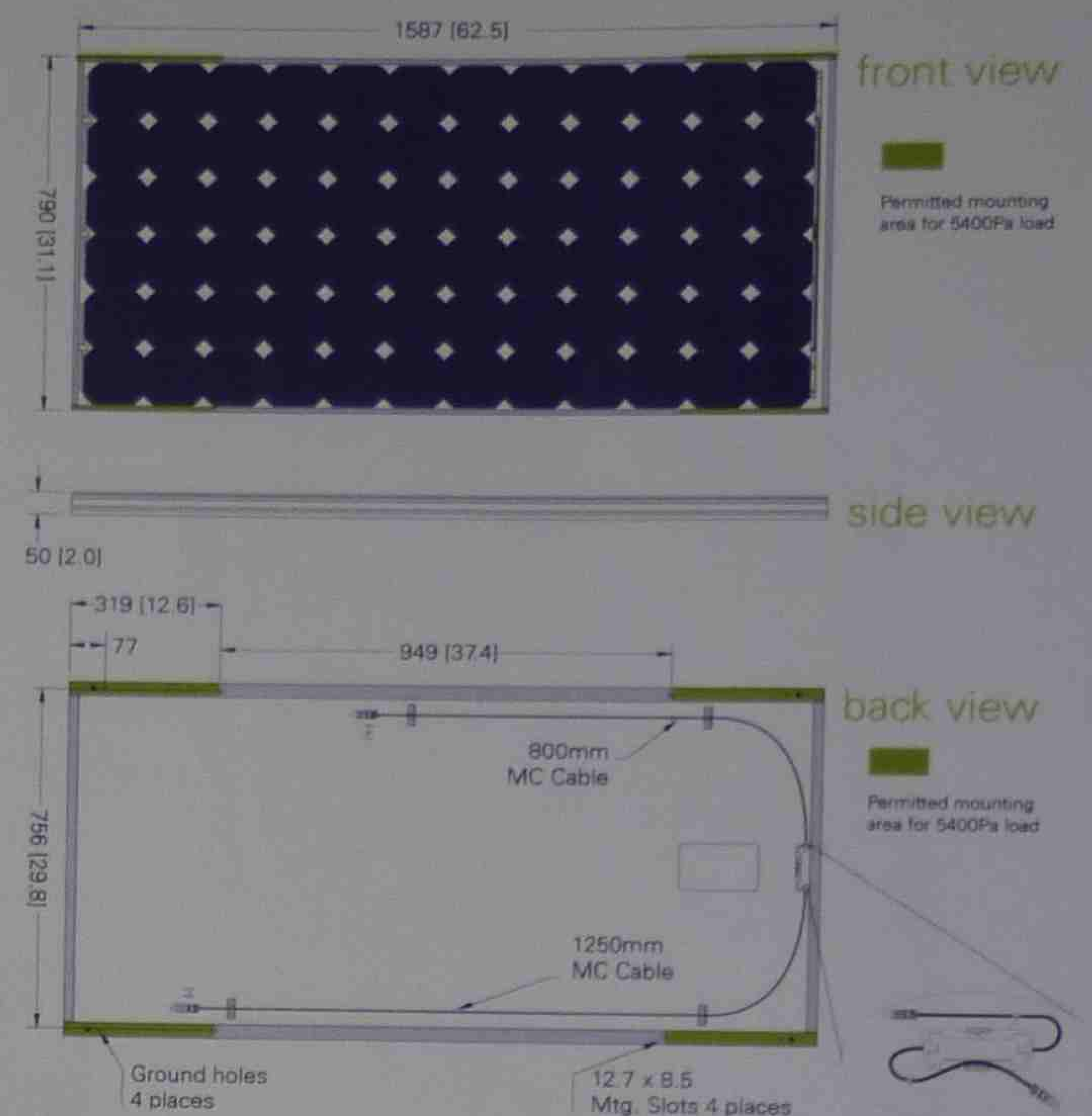
bp solar

Electrical characteristics

	[1] STC 1000W/m²	[2] NOCT 800W/m²
Maximum power (P_{max})	180W	129.6W
Voltage at P_{max} (V_{mpp})	35.8V	31.9V
Current at P_{max} (I_{mpp})	5.03A	4.02A
Short circuit current (I_{sc})	5.58A	4.52A
Open circuit voltage (V_{oc})	43.6V	39.7V
Module efficiency	14.4%	
Tolerance	-3/+5%	
Nominal voltage	24V	
Efficiency reduction at 200W/m²	<5% reduction (efficiency 14.1%)	
Limiting reverse current	5.58A	
Temperature coefficient of I_{sc}	(0.065±0.015)%/°C	
Temperature coefficient of V_{oc}	-(0.36±0.05)%/°C	
Temperature coefficient of P_{max}	-(0.5±0.05)%/°C	
[3] NOCT	47±2°C	
Maximum series fuse rating	20A	
Application class (according to IEC 61730:2007)	Class A	
Maximum system voltage (U.S. NEC rating)	600V (U.S. NEC) 1000V (IEC 61730:2007)	

1: Values at Standard Test Conditions (STC): 1000W/m² irradiance, AM1.5 solar spectrum and 25°C module temperature
2: Values at 800W/m² irradiance, Nominal Operation Cell Temperature (NOCT) and AM1.5 solar spectrum
3: Nominal Operation Cell Temperature: Module operation temperature at 800W/m² irradiance, 20°C air temperature, 1m/s wind speed

All solar modules are individually tested prior to shipment; an allowance is made within our factory measurement to account for the typical power degradation (LID effect) which occurs during the first few days of deployment.



Dimmensions in mm (in).

JUNCTION BOX DETAIL
(with wire-hold feature)
39.60 x 100.60 x 13.20 (mm)
1.56 x 3.96 x 0.52 (in)

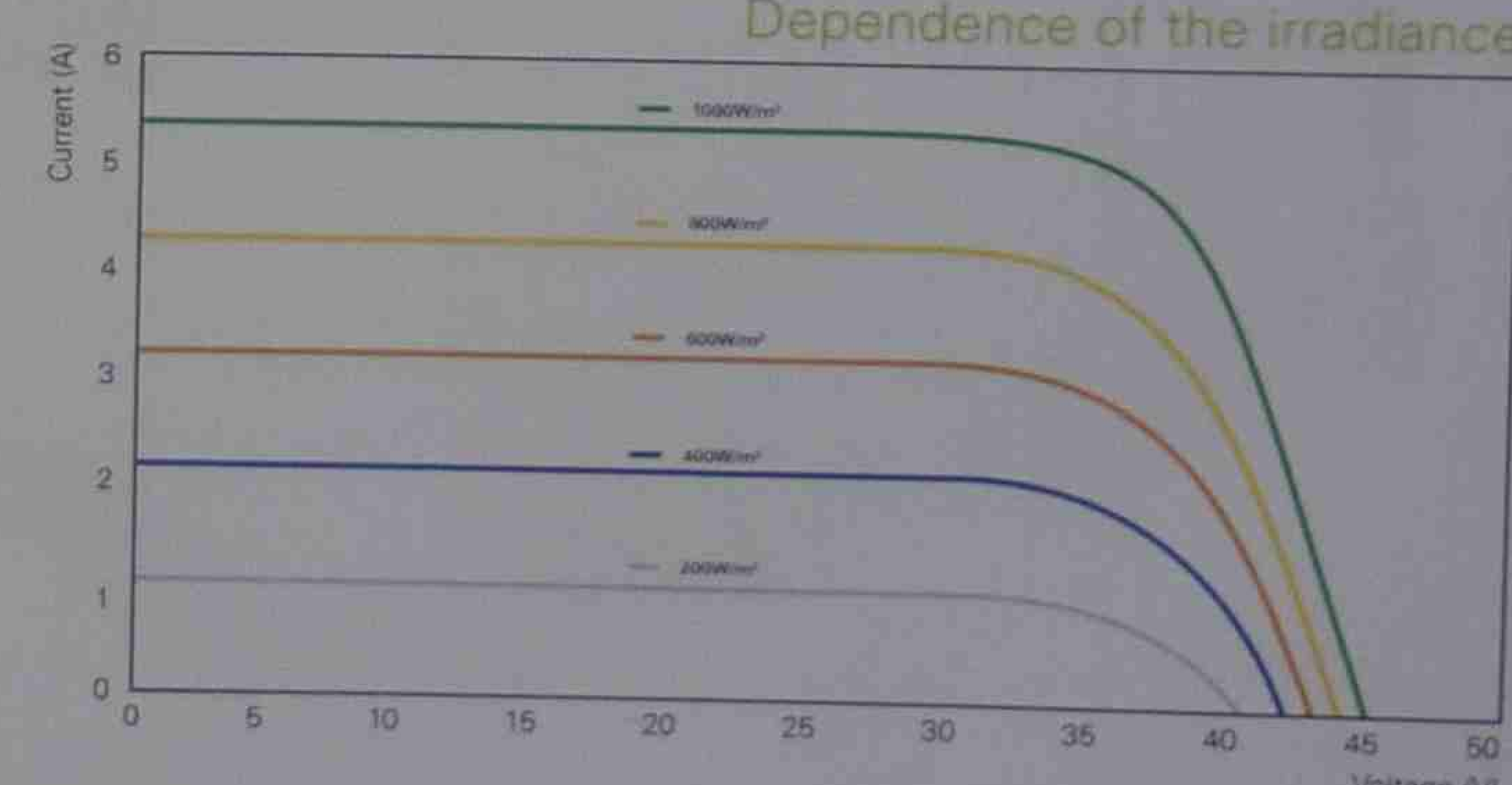
Mechanical characteristics

Solar cells	72 monocrystalline 5" silicon cells (125x125mm) in series
Front cover	High transmission 3.2mm (1/8th in) glass
Encapsulant	EVA
Back cover	White polyester
Frame	Silver anodized aluminum (Universal II)
Diodes	IntegraBus™ with 3 Schottky diodes
Junction box	Potted (IP 67); certified to meet UL 1703 flammability test
Output cables	4mm² cable with latching MC4 connectors Asymetrical cable lengths: (-)1250mm (49.21in) / (+)800mm (31.50in)
Dimensions	1587x790x50mm / 62.5x31.1x2in
Weight	15.4kg / 33.95lbs

All dimensional tolerances within ±0.1% unless otherwise stated.

Dependence of the temperature

Dependence of the irradiance



Warranty

- Free from defects in materials and workmanship for 5 years
- 93% power output over 12 years
- 85% power output over 25 years

Certification

Certified according to the extended version of the IEC 61215:2005 (Crystalline silicon terrestrial photovoltaic modules - Design qualification and type approval)

Certified according to IEC 61730-1 and IEC 61730-2. (Photovoltaic module safety qualification, requirements for construction and testing)

Manufactured in ISO 9001 and ISO 14001 certified factories

Module electrical measurements are calibrated to World radiometric reference via third party international laboratories

This data sheet complies with the EN 50380 requirements.
This publication summarises product warranty and specifications which are subject to change without notice

Contact:

Your BP Solar partner

Find more information in: www.bpsolar.com

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Previous page is: BP 4180T

Dimensions given are width 0.790m length 1.587m.

So area of panel required is

$$0.790 \times 1.587$$

$$= 1.25\ m^2$$

So

$$\frac{23.78}{1.25}$$

= **19.02 panels**

As there but are not fractions of panels available we assume the choice would be 19 or 20 panels.

OPTION 1
If 2 strings are used each string will need to have the same amount of panels in each string. This would mean either 2 strings of 10 or 2 strings 9 panels.

OPTION 2
We could also consider using the panels in series again 23 or 22 panels would be required.

OPTION 1
This panel has a Voc of 43.66V at STC. So a string of 10 panels would give a Voc of 436.6V.

To quick check the Voc add 15 % for cold mornings. (Exact calculation of panel voltage will be completed later).

436.6 x 1.15 = 502V. At first check this voltage is too high for the inverter input (500V see spec).

Choose 2 strings of 9 panels. This would provide a Voc string voltage of 393 Voc.

Check voltage rise.

393 x 1.15 452V. Voltage check OK but not as required.

Total current available at Mpp 5.03 A x 2 (parallel strings) = 10.06A (under required current rating of 11.11A).

But at 393V Mpp the input current to the inverter would drop to 8.48A due to higher DC voltage.

This current would be Acceptable.

OPTION 2
It is obvious that the series connected panels would provide a voltage too high for the inverter and a current far too small for the inverter to operate on Mpp.

180 WATT

BIG POWER, SMALL FOOTPRINT

SINGLE CRYSTAL SILICON PHOTOVOLTAIC MODULE WITH 180W MAXIMUM POWER

This single crystal 180watt module features 15.5% encapsulated cell efficiency and 13.7% module efficiency. Using breakthrough technology perfected in Sharp's space cell program, the **NU-S0E3E** module allows for maximum usable power per square metre of solar array.

A safe, clean, reliable source of energy, Sharp's NU-S0E3E photovoltaic module is designed for large electrical power requirements. Based on the technology of crystal silicon solar cells developed over 45 years, this module has superb durability to withstand rigorous operating conditions and is suitable for grid connected systems.

Common applications for the Sharp NU-S0E3E include residences, office buildings, solar power stations and solar suburbs. As the world's leading manufacturer of photovoltaic modules, Sharp produces an extensive line of high power modules for every electrical power requirement.

FEATURES

- High-power module (180W) using 155mm square single crystal silicon solar cells with 13.7% module conversion efficiency
- Photovoltaic module with bypass diode minimises the power drop caused by shade
- Textured cell surface to reduce the reflection of sunlight and BSF (Back Surface Field) structure to improve cell conversion efficiency: 15.5%
- White tempered glass, EVA resin and a weatherproof film, plus aluminum frame for extended outdoor use
- Output terminal: Lead wire with waterproof connector
- Certifications: IEC 61215
- SHARP modules are manufactured in ISO 9001 certified factories

SHARP

NU-S0E3E – MAXIMUM POWER

ELECTRICAL CHARACTERISTICS

Cell	48 Monocrystalline (155.55mm)[2] Sharp silicon solar cells
No. of Cells and Connections	48 in series
Open Circuit Voltage (Voc)	30.0V
Maximum Power Voltage (Vpm)	23.7V
Short Circuit Current (Isc)	8.37A
Maximum Power Current (Ipm)	7.60A
Maximum Power (Pm)[1]	Min. 171W Typical 180W
Encapsulated Solar Cell Efficiency (ηc)	15.5%
Module Efficiency (ηm)	13.7%
Maximum System Voltage	DC 1000V
Series Fuse Rating	15A
Type of Output Terminal	Lead Wire with MC Connector

Specifications are subject to change without notice
[1] (STC) Standard Test Conditions: 25°C, 1 kW/m², AM 1.5

MECHANICAL CHARACTERISTICS

Dimensions	1318 x 994 x 46mm
Weight	16.0kg

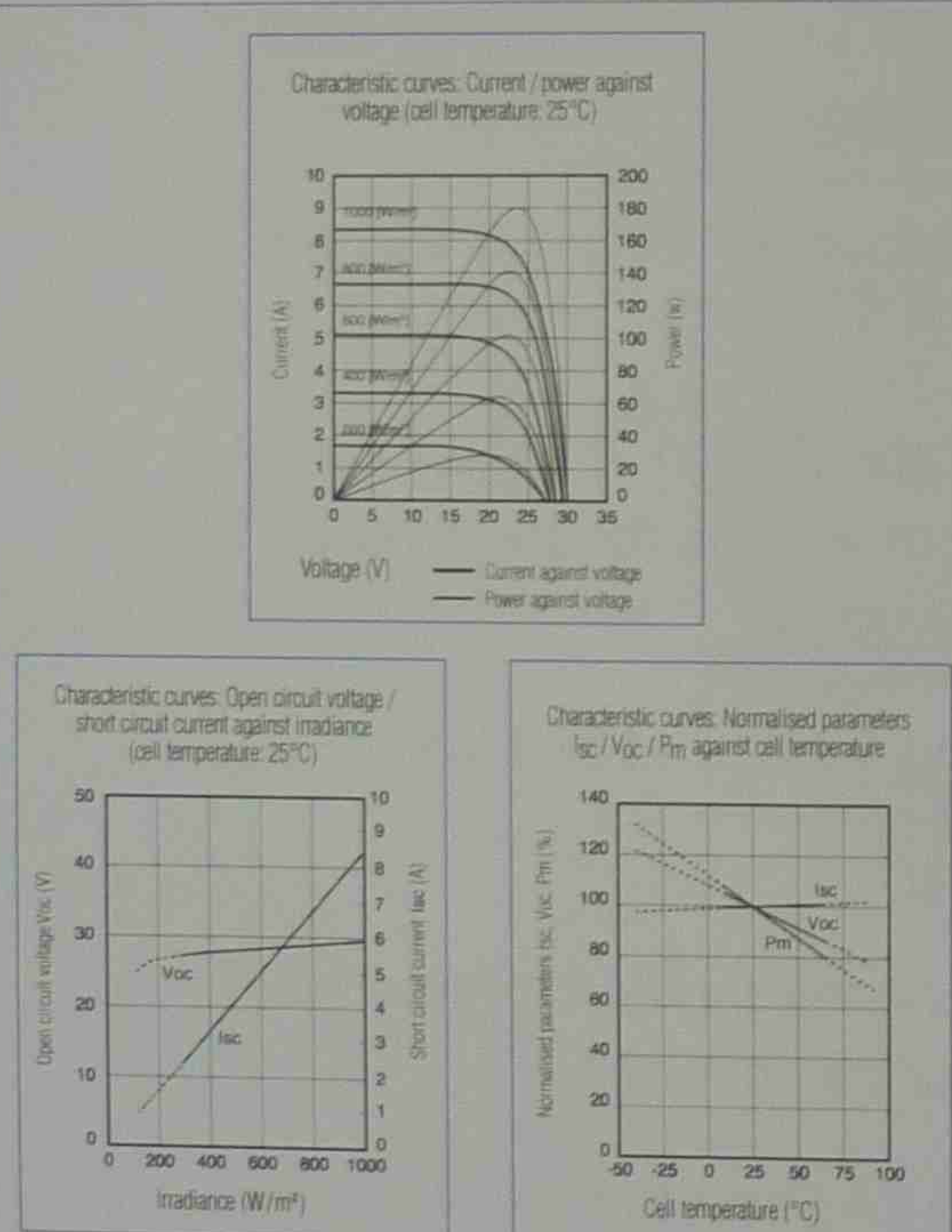
TEMPERATURE COEFFICIENT

Temp. Coefficient of Pmax	-0.485	% / °C
Temp. Coefficient of Voc	-0.104	V / °C
Temp. Coefficient of Isc	0.053	% / °C

ABSOLUTE MAXIMUM RATINGS

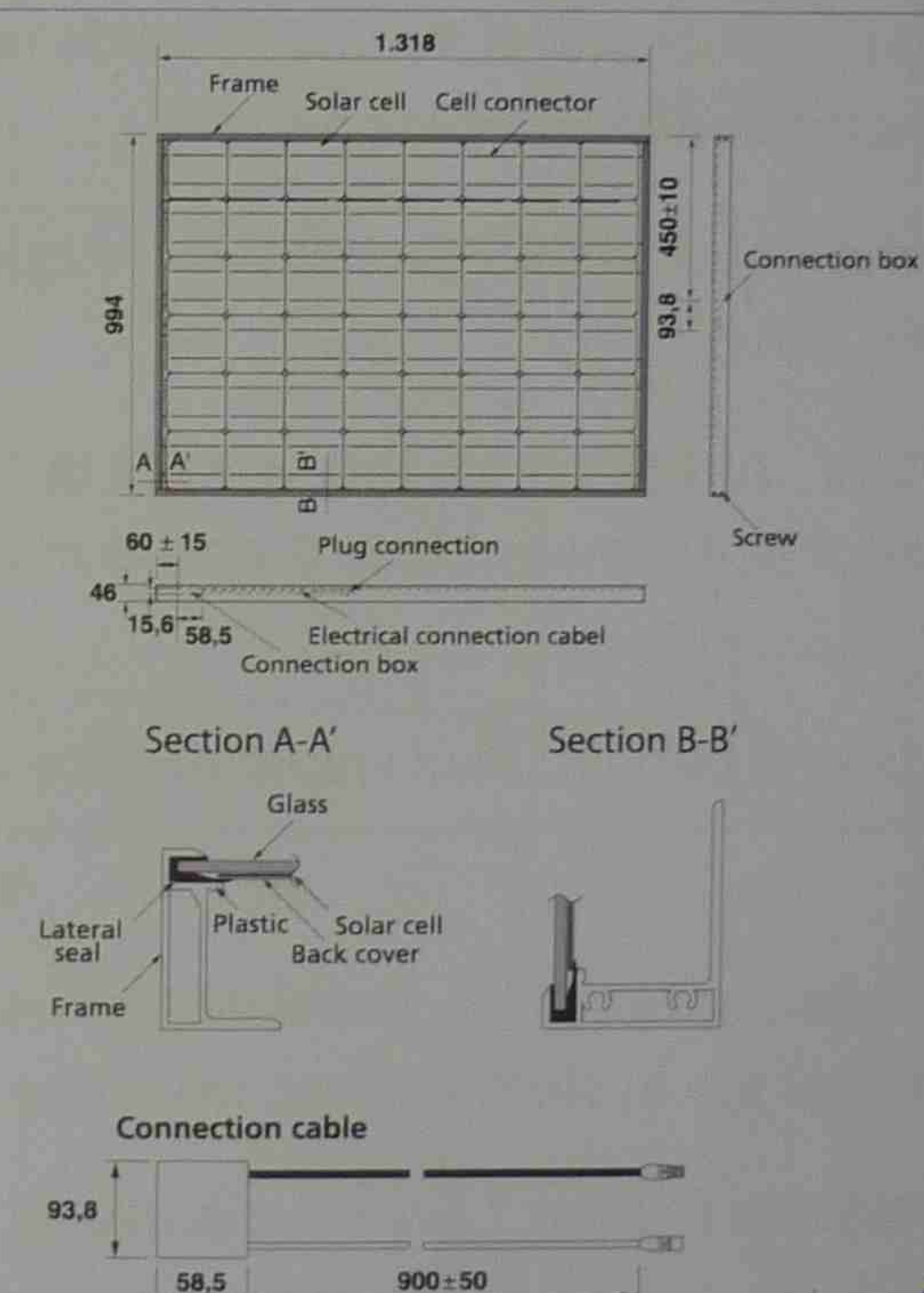
Parameters	Rating	Unit
Operating Temperature	-40 to +90	°C
Storage Temperature	-40 to +90	°C
Dielectric Voltage Withstood	3000 max.	V-DC

IV CURVES

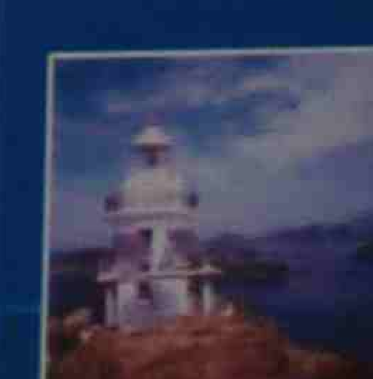


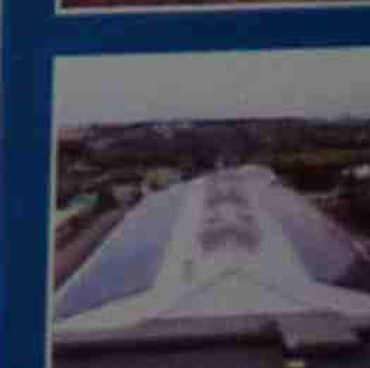
Specifications are subject to change without notice

DIMENSIONS



Specifications are subject to change without notice





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SHARP ······· be sharp

Sharp Corporation of Australia
1 Huntingwood Drive, Huntingwood, NSW 2148.
Phone: (02) 9830 4600 E-mail: sales@sharp.net.au
www.sharp.net.au

SHARP Solar

Previous page is: SHARP NU-SoE3E

Dimensions given are width 0.994m length 1.318m

So area of panel required is 0.994m x 1.318m = 1.31 m2

So

$$\frac{23.78}{1.31}$$

= 18.15 panels

With the SHARP panels it can be seen that we need only 18 panels as compared to the BP panels. This could represent a considerable saving in labour and parts.

OPTION 1

If 2 strings are used each string will need to have the same amount of panels in each string. This would mean either 2 strings of 9 panels.

OPTION 2

This panel has a Voc of 30.0V at STC. So a string of 9 panels would give a Voc of 270V.

Note: this voltage is much more suitable for this system as it is lower than the BP and would provide increased inverter efficiency.

To quick check the Voc add 15% for cold mornings (exact calculation of panel voltage will be completed later).

270 x 1.15 = 310V. At first check this voltage is still around the design voltage for this system. It is also a safe amount less than the maximum input voltage for the inverter (500V see spec).

Choose 2 strings of 9 panels. This would provide a Voc string voltage of 393 Voc.

OPTION 3

We could also consider using the panels in series again 18 panels would be required but it is obvious that the system voltage would be too high for the inverter.

Total current available at Mpp 7.6A x 2 (parallel strings) = 15.2A (over the required current rating of 11.11A).

But at 270V Mpp the input current to the inverter would increase to 13.13A due to lower DC voltage.

This current would be Acceptable.

CONCLUSION

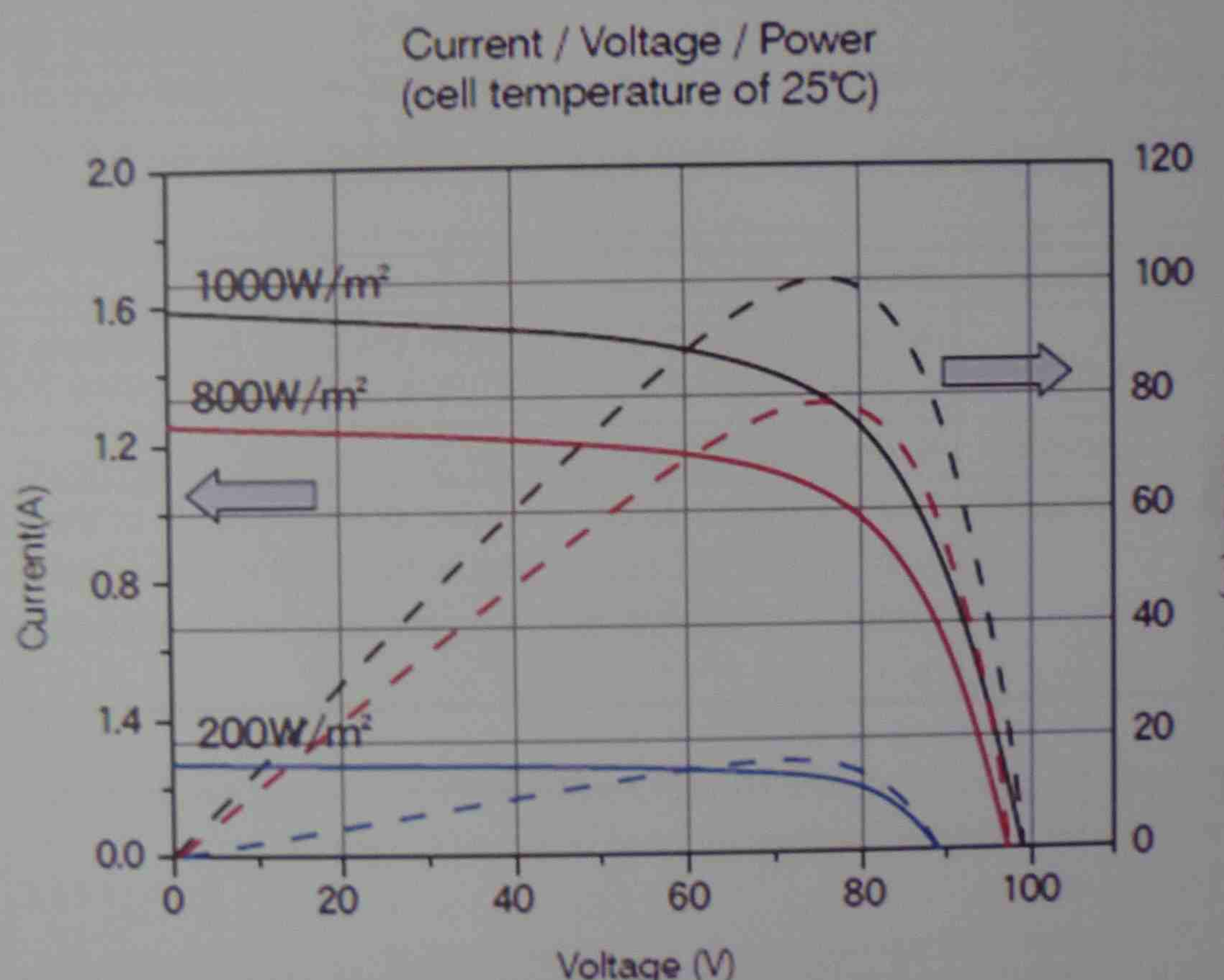
Of the 2 panels the choice may be for the SHARP panels as there are savings to be made in reduction of parts to be installed.

3.9.3 DETERMINING THE OUTPUT OF AN INSTALLED SYSTEM

Often a system is already installed and it is necessary to determine if the system performing as it was designed to do therefore it is necessary to calculate what the system should be producing at the time and compare this with the actual output. As previous sections have indicated that the panel rating will vary according to the irradiance, mounting geometry, temperature and also accumulation of dirt on the panels.

To determine the output is necessary to measure the irradiance and then consult the IV specifications as in the chart below.

NOTE in this case the PYRANOMETER measured the irradiance to be 800Wm2. From the power curve the lines are drawn on the power curve which represents 800Wm2. This indicates that the panel will have a current of 1.25 A and a power of 78W.



4 GRID CONNECTED DESIGN ASSESSMENT

This assignment is a major part of your assessment for the Grid Connected Design and Install Course. Please bring finished assignment to your practical class. It covers the following important aspects of Grid Connected System Design.

- Determining the position of all components in consultation with the client and in accordance with Australian Design Standards.
- Determining the PV array operating parameters such as voltage window and power levels.
- Calculating system losses and documenting them.
- Matching the array to a commercial IG inverter to ensure efficient and safe operation of the Inverter. Run the system through the SMA software located in the SMA folder on your memory stick.
- Calculating the realistic energy output of the inverter for a year.
- Calculating the income generated by a Gross feed-in tariff.

System Size	3kWp
Inverter	An approved IG inverter from the CEC list available from their website.
Installation Location	Sydney NSW.
Client Requirements	The inverter is to be mounted on the outside of the garage wall, on the NE corner just behind the existing Main switch-board. The panels are to be mounted on the North facing roof.

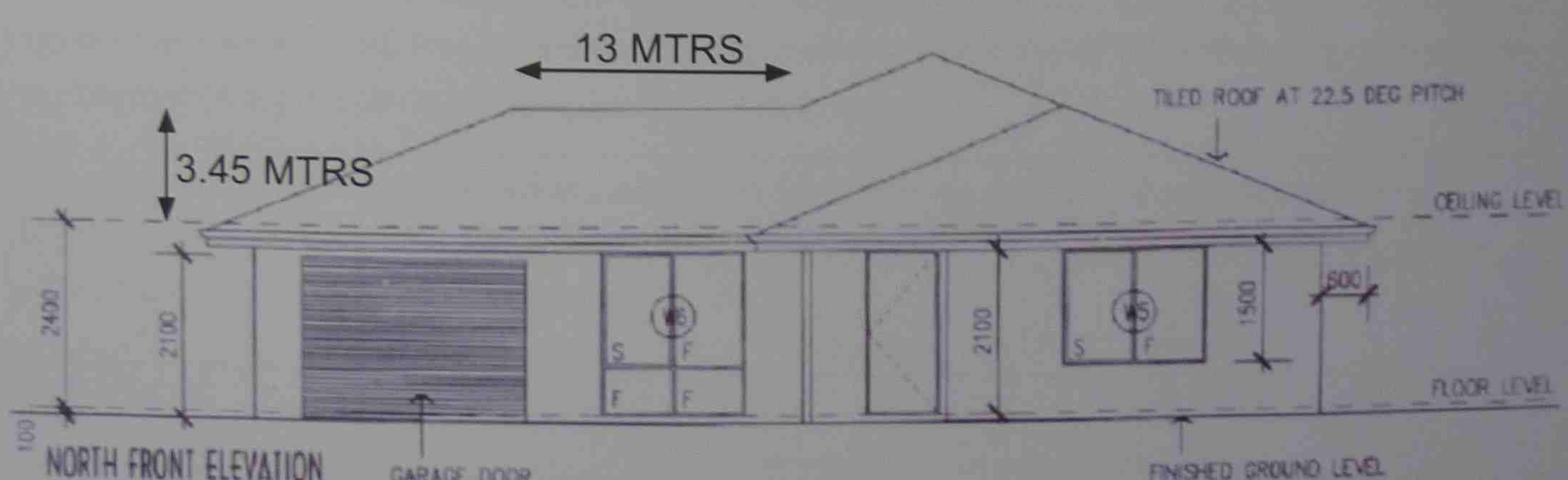
The criteria may be presented in a Report format with numbered sections as indicated below. They can be submitted either by post or email to NECATec. (training@neca.asn.au)

All text is to be word processed including calculations. Schematics and Wiring diagrams may be done by hand but must be neatly drawn. Freehand drawings are not acceptable, use a ruler and drawing templates and instruments.

Design Criteria
Calculation of Array output voltage range.
Calculation of Array output power range.
Calculation of Inverter input voltage window allowing for safety margins and if the Inverter and Array are matched correctly.
Calculation of the annual and averaged daily energy output of the system in AC kWh.
Calculation of the yearly income generated by this system using Gross metering at $0.20 per kWh.
Calculation of appropriate cable sizes to keep the total cable losses (AC and DC) at no more than 1%.
Circuit schematic showing all DC & AC breakers and their ratings. Show the metering arrangements and all main switchboard connections.
Wiring diagram showing the wiring of the panels, roof mounted DC breaker enclosure, inverter, DC inverter breaker and connection to the main switchboard. Show all cable types and sizes and conduit types.
Product brochures for PV panels and Inverter.
List of all the following components including make model and serial numbers.
1. PV Panels
2. Inverter

Temperature data for Sydney - Maximum daily temperature is 45 C. Minimum is 0 C

Domestic Dwelling PV System is to be installed on -



5.1 INSTALLATION

Photovoltaic (PV) arrays may mounted either on the building itself or mounted freestanding .This is often the case where solar tracking systems are used .In such a case the array is mounted on a single pole providing structural problems due to the concentration of weight and wind loading on a single point.

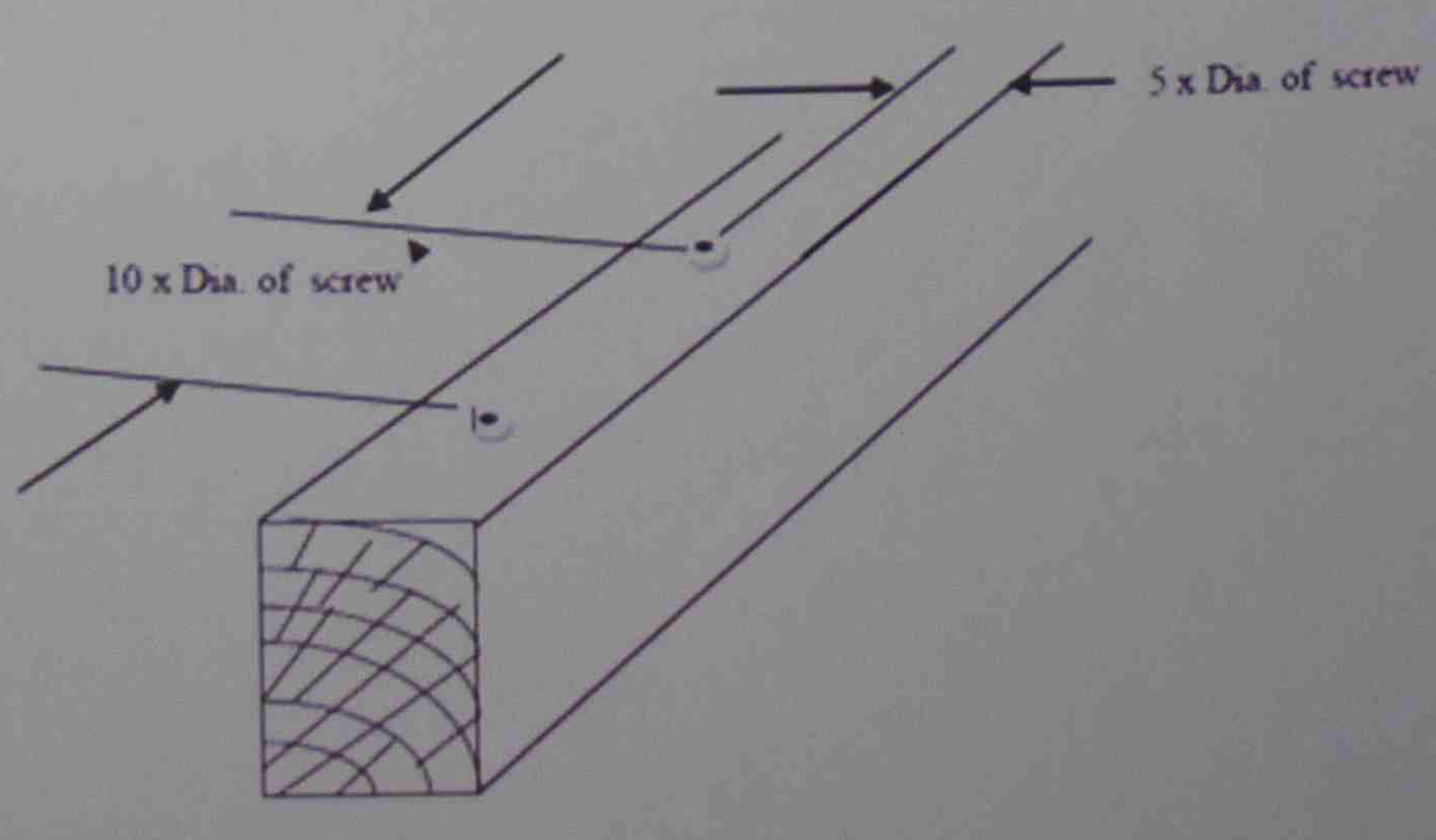
The photo opposite shows a 2.5KW system being mounted on a single axis tracker. This type of installation requires professional advice on the structure of the in-ground mounting point. Sometimes a concrete base is used and often a screw in device such as a Krinner can be used. It is necessary to check with the manufacturer for the correct size and type for both wind loading and soil type.

In either case reference to AS/NZS 5033:2005 stipulates that in both cases the array must be readily accessible. Meaning there should be no obstacles to climb over and nor should it be necessary to use a device such as a ladder to gain access due to the height .In all cases they should be no more than 2m above the normal standing surface.

The location of the array should be such that should a short circuit (Isc) of such magnitude that it could cause molten metal, the location or installation must be such that it cannot cause property damage or pose a risk to people or animals. This may be overcome by using panels designed in such a way that they prevent molten metal from falling from them (See section on panel arcing).

In most domestic applications the system will be positioned on the roof and the mounting will be fixed to the timber fame work inside the roof. When using screws directly into timber framing it is important to look at building code AS1720 which stipulates the requirements for screwing into light timber frames.

This diagram shows that when installing on light timber framing there are minimum distances the screws can be screwed into the timber .The reason for this is possible weakening or splitting of the timber.



In such a case where the timber frame is of the prefabricated type with a width of 40mm maximum the greatest distance from the edge of the timber is 20mm .So 20mm divided by 5 is 4. This means that the maximum size screw that can be used directly into the timber is a 4mm diameter screw and to be spaced 40mm apart lengthways. It is now worth checking that the withdraw strength and breaking strength is sufficient to hold the array.

NOTE Any screws used should be either galvanised or stainless steel. Check also for the wind loading for the area in which it is about to be installed.

When installing on tiled roofs the option is to use off the shelf under tile brackets. These brackets are usually manufactured from heavy duty stainless steel and come with certification for loading.

These come in different forms and it is necessary to have a range of different brackets on hand to suit tiles and roofing structures.

Below are form Alzone and are designed for straight forward installations and for side mounting where the timber frame does not align with the tile and also for the case above where the timber dimensions are too small to allow for the correct size screw.

The mounting system below is from the Clenergy installation manual. Web site references are given in each section.

SolarRoof™ products, when installed in accordance with this guide, will be structurally adequate and will meet the AS/NZS1170 standards. During installation and especially when working on the roof be sure to observe the appropriate safety regulations and please pay attention to the relevant regulations of your local region. Please check that you are using the current version of the installation manual by contacting Clenergy Australia by email on Sales@clenergy.com.au, or your local representative in Australia. For metal roofs such as corrugated and clip lock there are also an assortment of brackets.

The installer is solely responsible for:

- Complying with all applicable local or national building codes, including any that may superseded this manual.
- Ensuring that PV-ezRack and other products are appropriate for the particular installation and the installation environment.
- Ensuring that the roof, its rafters, connections, and other structural support members can support the array under building live load conditions (this total assembly is hereafter referred to as the roof rafter assembly).
- Using only PV-ezRack parts and installer-supplied parts as specified by PV-ezRack (substitution of parts may void the warranty and invalidate the letter of certification on page 2).
- Ensuring that lag screws have adequate pullout strength and shear capacities as installed.
- Maintaining the waterproof integrity of the roof, including selection of appropriate flashing; and
- Ensuring safe installation of all electrical aspects of the PV array.

Installation tools

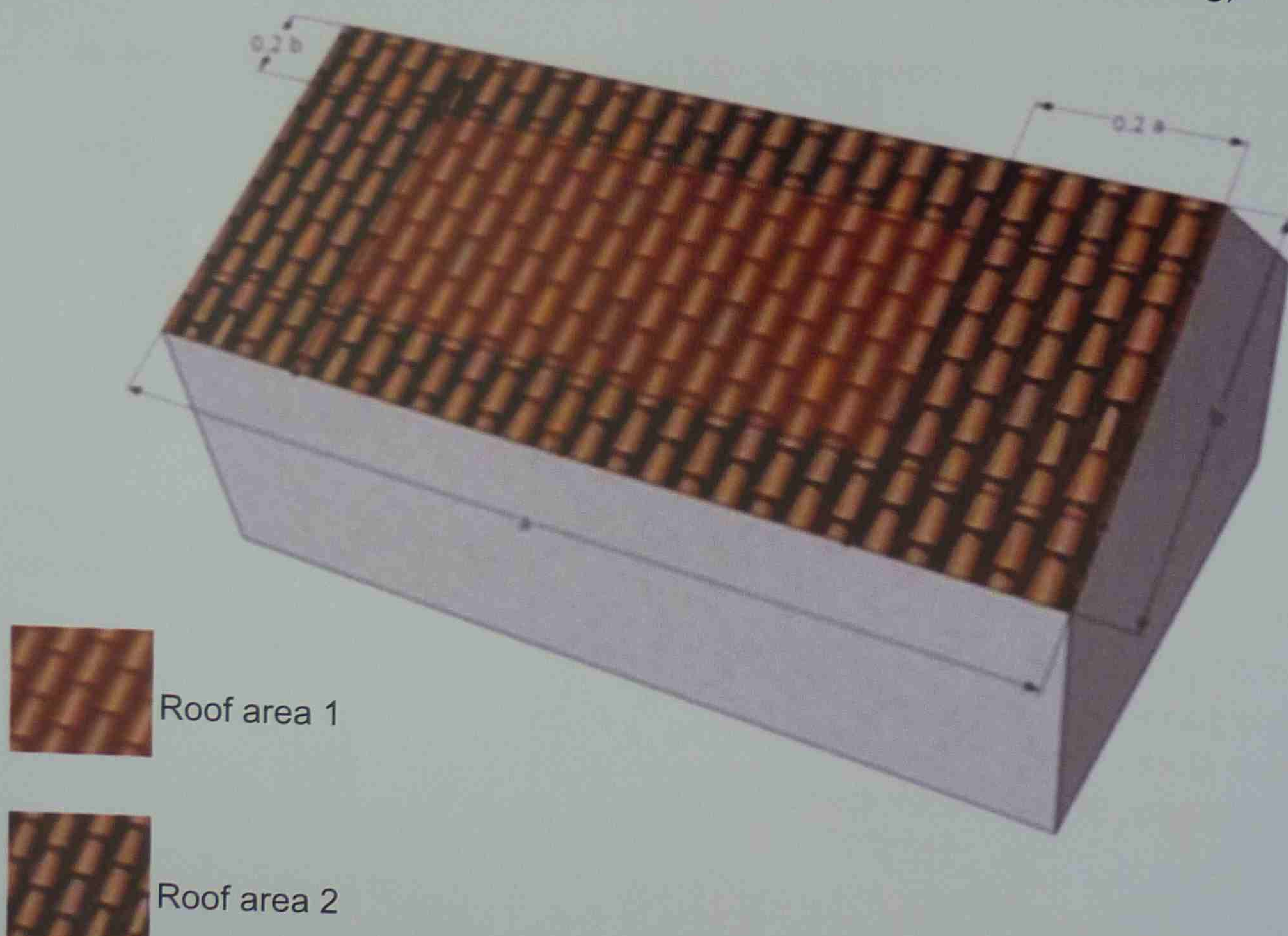
- 6 mm Allen key,
- Cordless drill,
- Open-end spanner set 9, 10, 17, 19 mm (required only for mounting with hanger bolts),
- Torx-30 (AW 30) bit,
- Angle grinder with stone disk,
- Power Cord.
- If necessary, timber to shim the roof hooks.

Mounting System, manufactured by Clenergy Co. Ltd. Follow the six steps below and the installation instructions section to install SolarRoof™ in compliance with the AS/NZS1170.

Before proceeding, note the following:

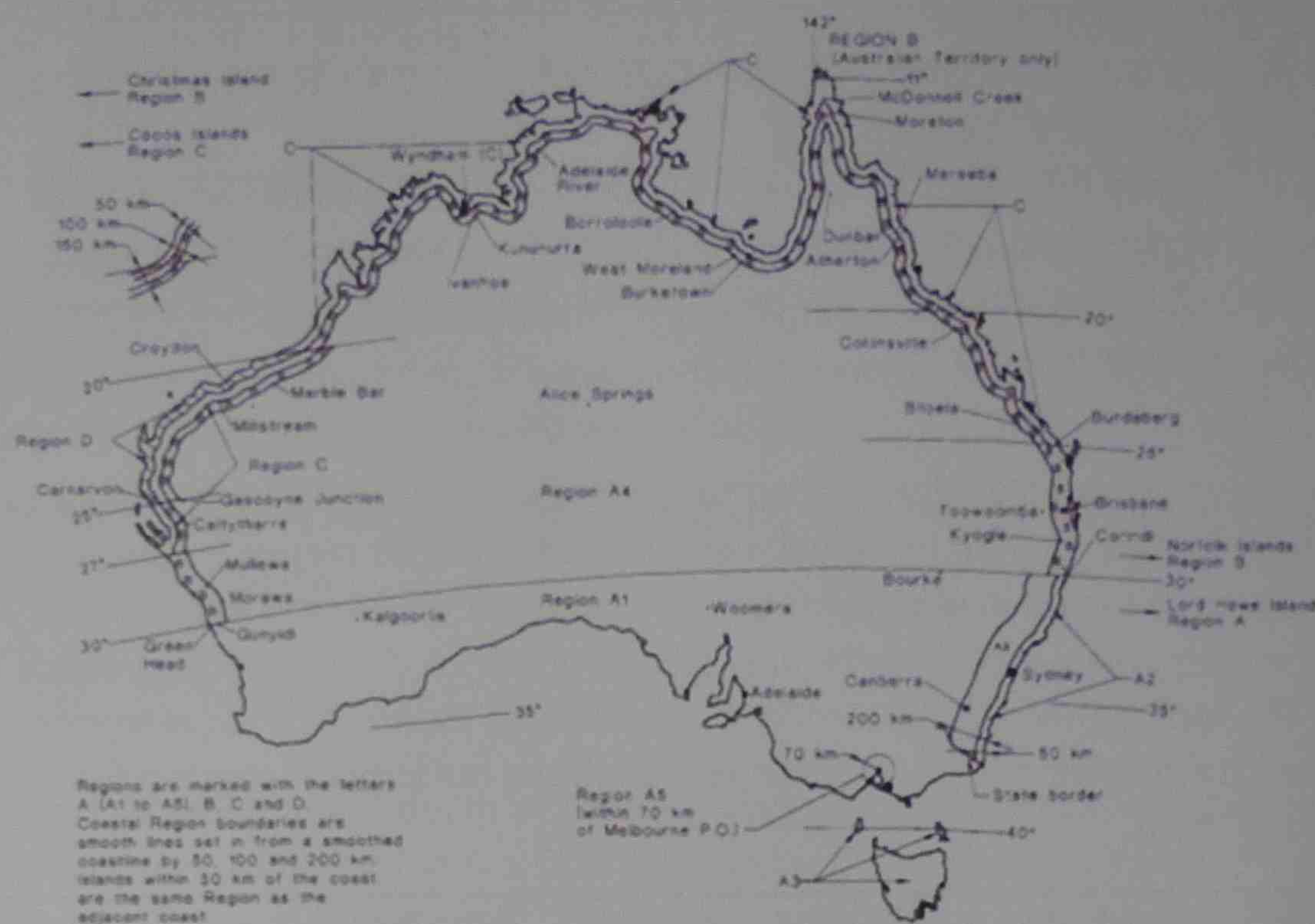
- This document addresses only wind loads on the assumption that wind produces the maximum load factor affecting an installation. Verify that other local factors, such as snow loads and earth quake effects, do not exceed the wind loads. Give precedence to any factor that does. Wind loads are considered to act on the entire projected area, or may be perpendicular to any surface.
- The roof on which the SolarRoof™ will be installed must have the capacity to resist the combined Design Dead Load and Live Load per footing.
- To determine the part you need you can used our PV-ezRack SolarRoof Calculator

Determine the installation area on the roof. Clenergy PV-ezRack SolarRoof may be installed anywhere on a roof but fixing centres are required to be reduced at ridges and edges. The diagram below shows the area of higher wind loadings within 0.2a and 0.2b of a roof edge or ridge (where a and b are the plan dimension of the building).



The following table will help you determine the maximum rail support spacing for your project. Also note that if the roof slope is less than 10 degree the reduction on spacing does not apply.

5.1.1 DETERMINE THE WIND REGION OF YOUR INSTALLATION SITE



(a) Australia

FIGURE 3.1 (in part) WIND REGIONS

Region Definition:

Wind regions are pre defined for all of Australia by Australian Standard 1170.
The Wind Region has nothing to do with surrounding topography or buildings.

- Most of Australia 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 referred to as Cyclonic and are generally limited to northern coastal areas. Most Region C zones end 100km inland.
- Region D (80msec) Australia's worst Cyclonic Region between Carnarvon and Pardoo in Western Australia.

5.1.2 DETERMINE THE HEIGHT OF YOUR INSTALLATION SITE

This document provides sufficient information for SolarRoof™ system installation height less than 20 meters. If your installation site is more than 20 meters in height, please contact Clenergy to obtain engineering data to support your installation.

5.1.3. DETERMINE THE MAXIMUM RAIL SUPPORT SPACING

Region Definition:

Wind regions are pre defined for all of Australia by Australian Standard 1170. The Wind Region has nothing to do with surrounding topography or buildings.

- Most of Australia 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 referred to as Cyclonic and are generally limited to northern coastal areas. Most Region C zones end 100km inland.
- Region D (80msec) Australia's worst Cyclonic Region between Carnarvon and Pardoo in Western Australia.

This document provides sufficient information for SolarRoof™ system installation height less than 20 meters. If your installation site is more than 20 meters in height, please contact Clenergy to obtain engineering data to support your installation.

a) Tile roof

Please use the following table to determine the base rail support spacing for tile roof installations (mm).

	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 Metres	2130	1500	1690	1200	1380	980	1080	
10 Metres	1940	1370	1540	1090	1260	890	990	
15 Metres	1840	1230	1460	980	1190	800	940	
20 Metres	1740		1380		1130		890	

- The figures above are based on attaching 200W PV modules (length of 1675 mm, weight of 23 kg) to SolarRoof system. These figures should be sufficient for installing smaller PV modules. Please consult Clenergy for installing PV modules greater than length of 1675mm and weight of 23 kg.
- The Tile roof hooks should be fixed to the rafter using at least two 12Gx80mm wood screws minimum.

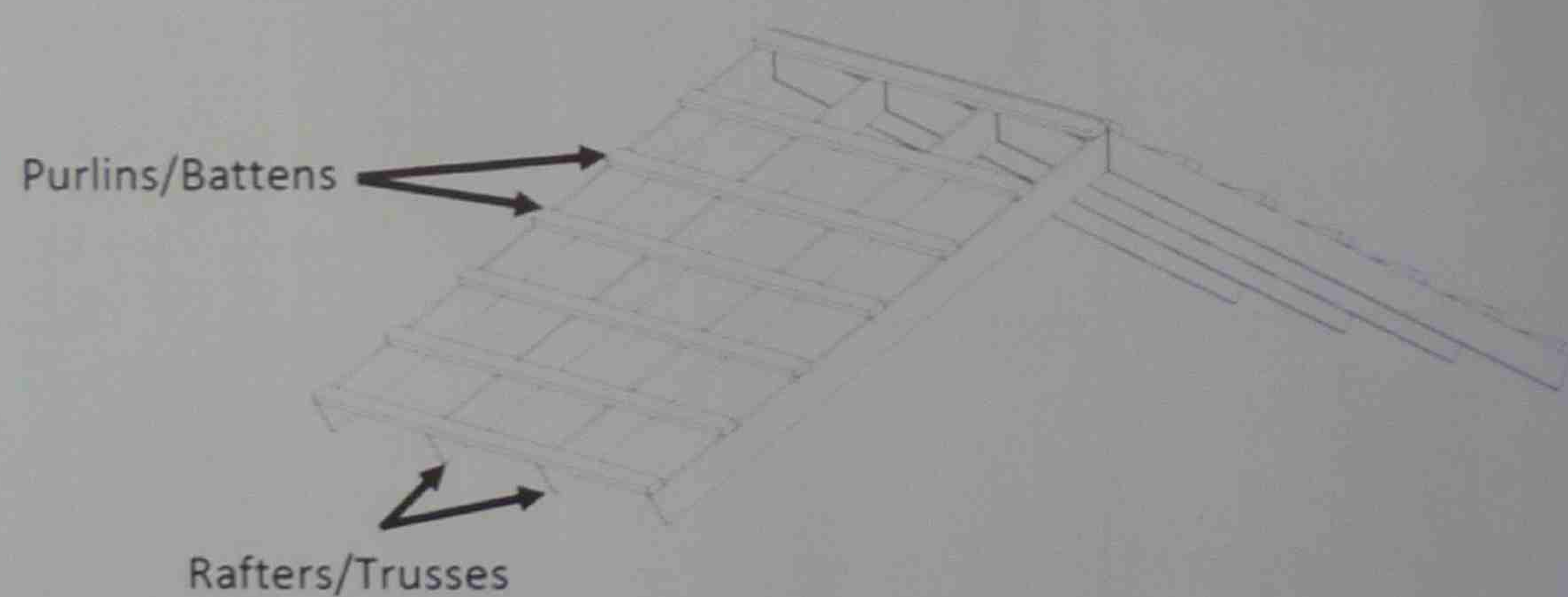
b) Tin roof

Please use the following table to determine the base rail support spacing for sheet metal roof installations (mm).

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

- The figures above are based on attaching 200W PV modules (length of 1675mm, weight of 23 kg) to SolarRoof system. These figures should be sufficient for installing smaller PV modules. Please consult Clenergy for installing PV modules greater than length of 1675mm and weight of 23 kg.
- The L Feet should be fixed to the purlings using 12GX90 screws through sheet metal roofs with gasket.

  The above spacing's apply for fixing through thin sheet and purling (greater than 1mm thickness) or a minimum embedment of 50mm into timber purling.
- Based on an embedment depth of 35mm (fixing into the battens) the spacing's remain unchanged for region A and B. For region C, the spacing's should be reduced by 10% and for region D, the spacing's should be reduced by 30%.

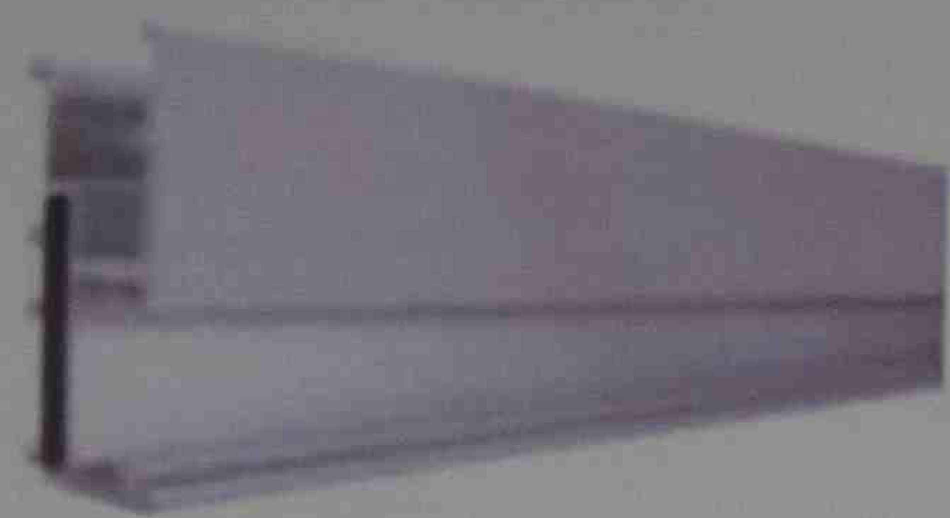


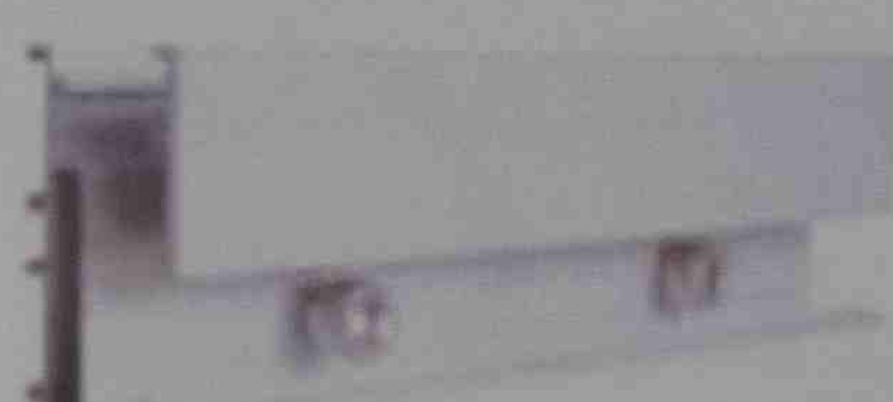
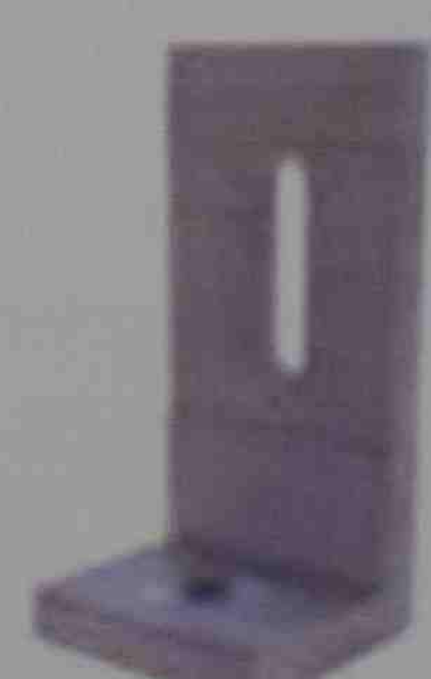
5.1.4.1 VERIFY ACCEPTABLE RAIL END OVERHANG

Rail End Overhang must equal 50% or less of foot spacing. Thus, if foot spacing is 1200 mm, the Rail End Over hang can be up to 600 mm. In this case, two feet can support a rail of as much as 2400 mm (1200 mm between the feet and 600 mm of overhang at each end).

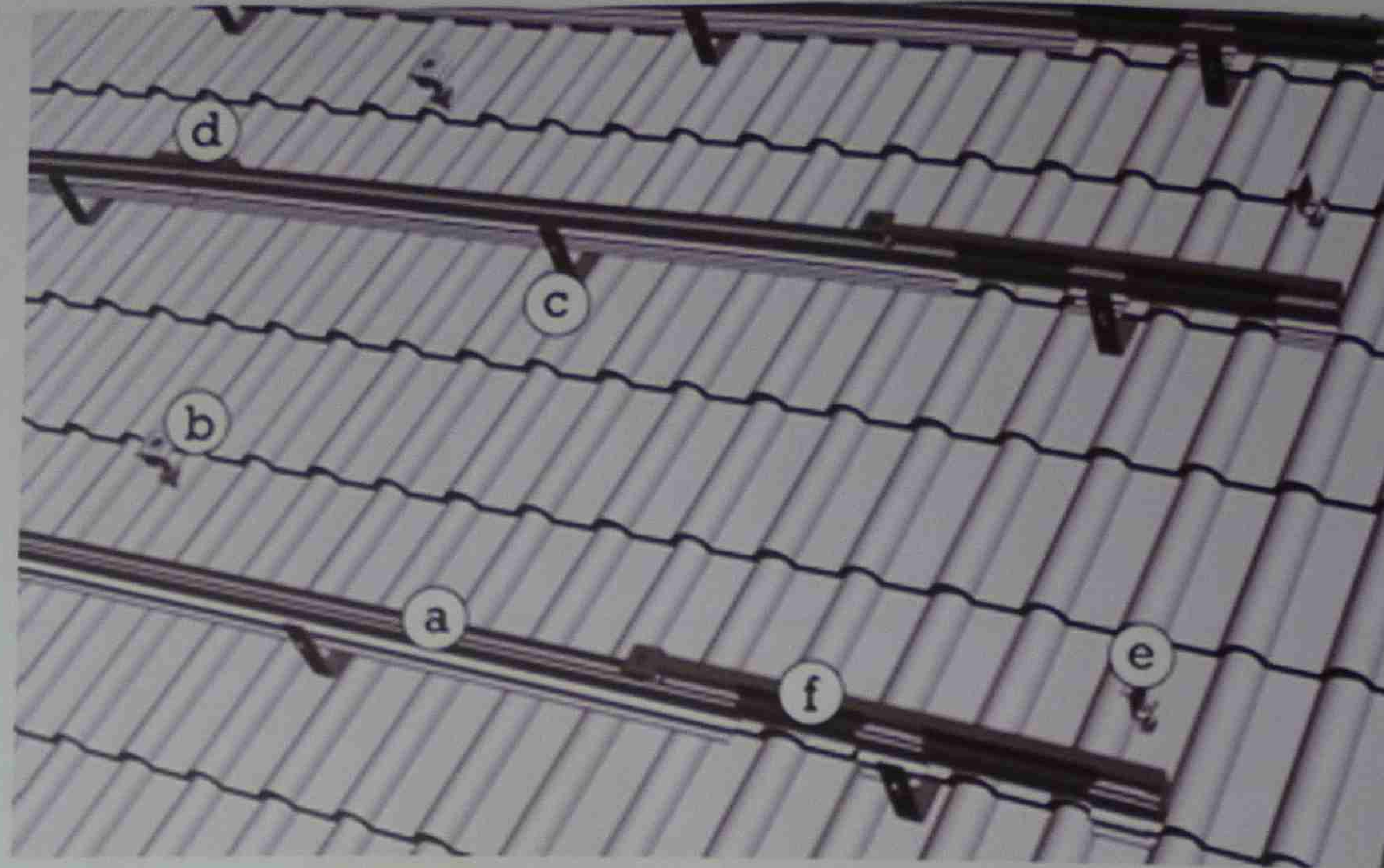
5.1.4.2 DETERMINE ROOF SLOPE

Solar roof systems can be used for roof slopes up to 60 degrees. It is important to verify the roof slope is between 0 degrees and 60 degrees.

Overview of system components for Tile Roof		
 PV-ezRack Rails	 PV-ezRack Splice	 Inter Clamp with Z Module
 End Clamp with Z Module	 Tile interface with Z module	 Wood screw 6x80 mm

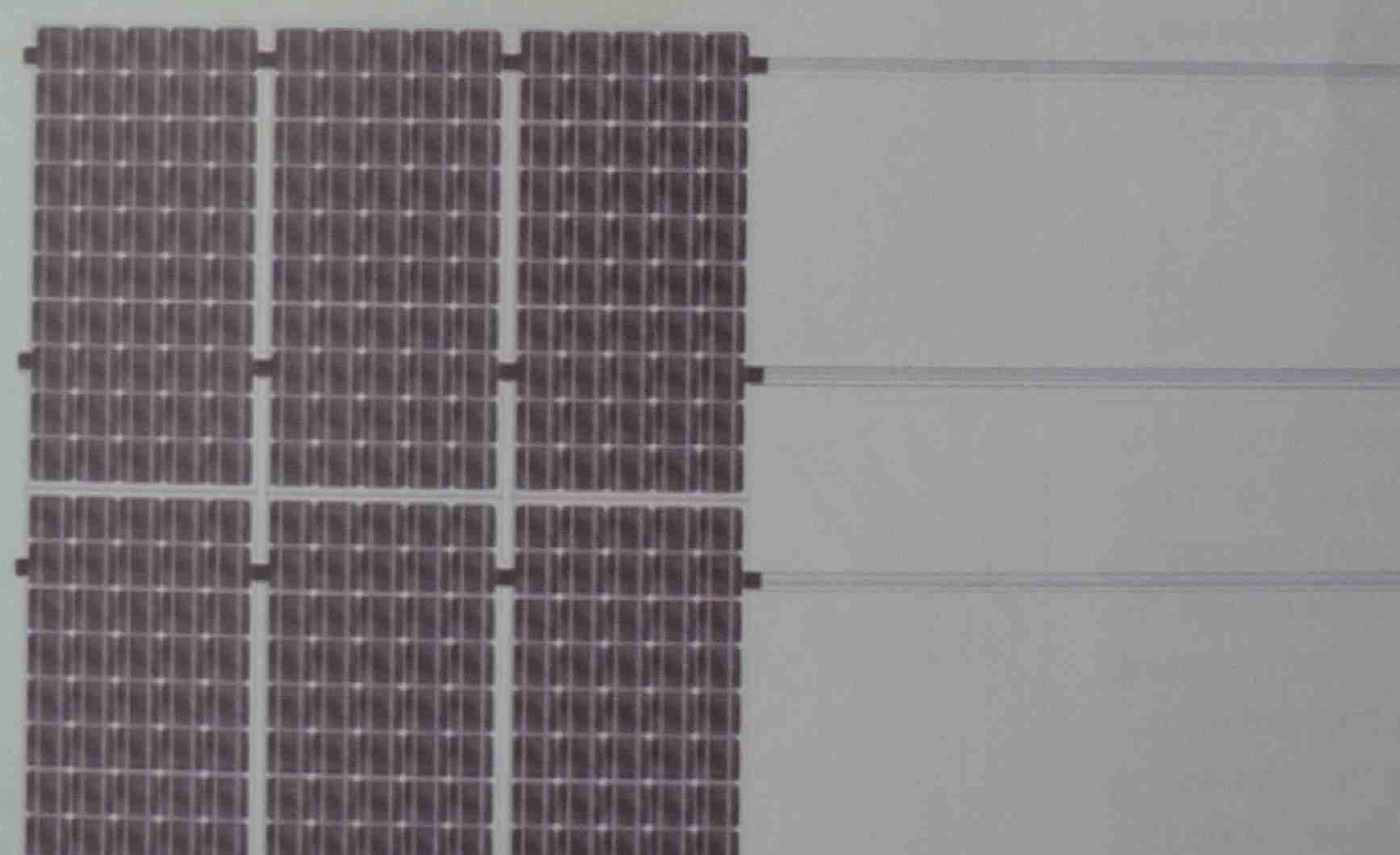
Overview of system components for Tin Roof		
 PV-ezRack Rails	 PV-ezRack Splice	 Inter Clamp with Z Module
 End Clamp with Z Module	 Tin interface with Z module	 Wood screw 6x90 mm

NOTE when mounting metals of a different kind a galvanic action may occur and cause severe corrosion so it is therefore necessary to use isolators or insulators must be used under each bracket.



5.1.5 OVERVIEW OF SYSTEM COMPONENTS

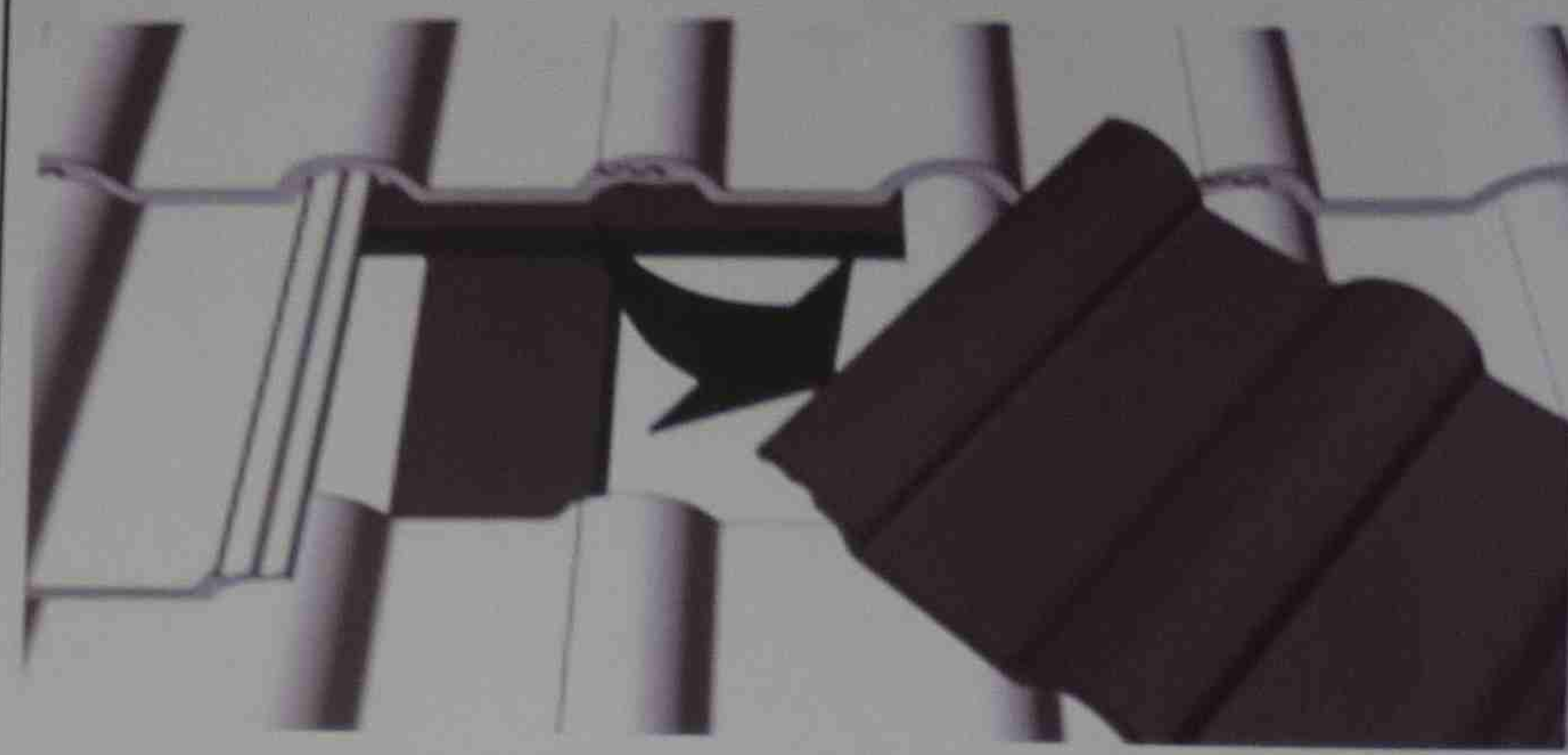
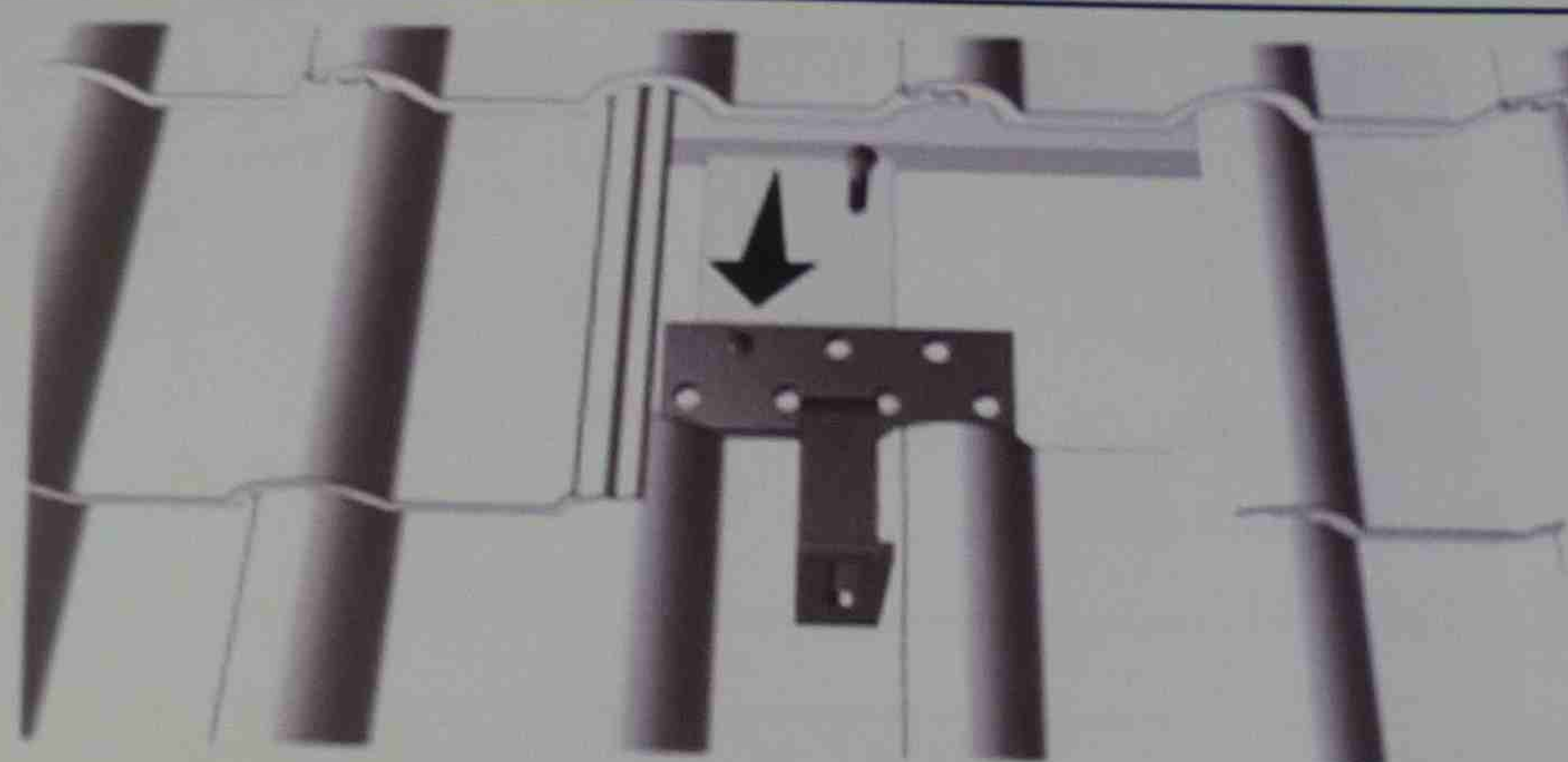
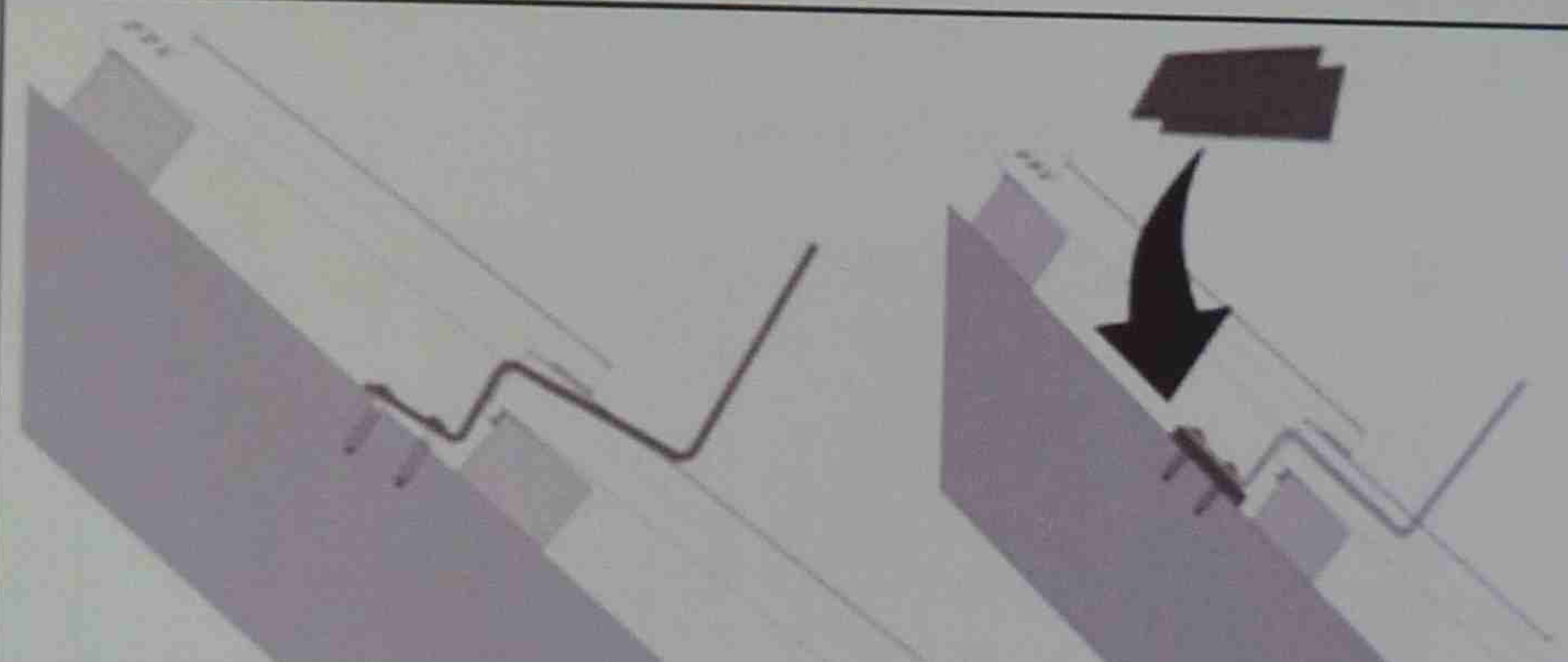
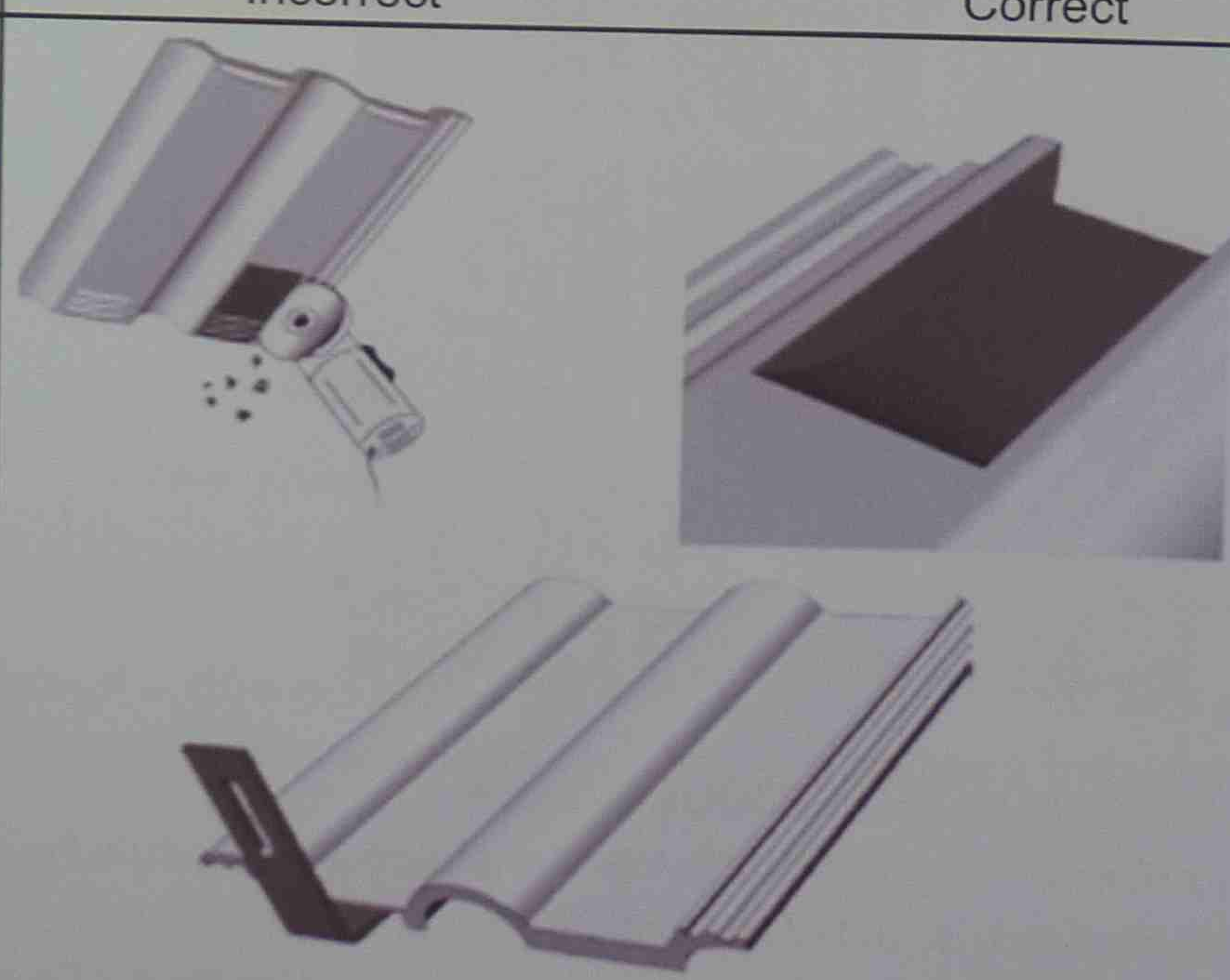
A PV-ezRack rail
B Inter Clamp
C Roof hook
D Splice
E End Clamp
F Telescopic mounting (optional)

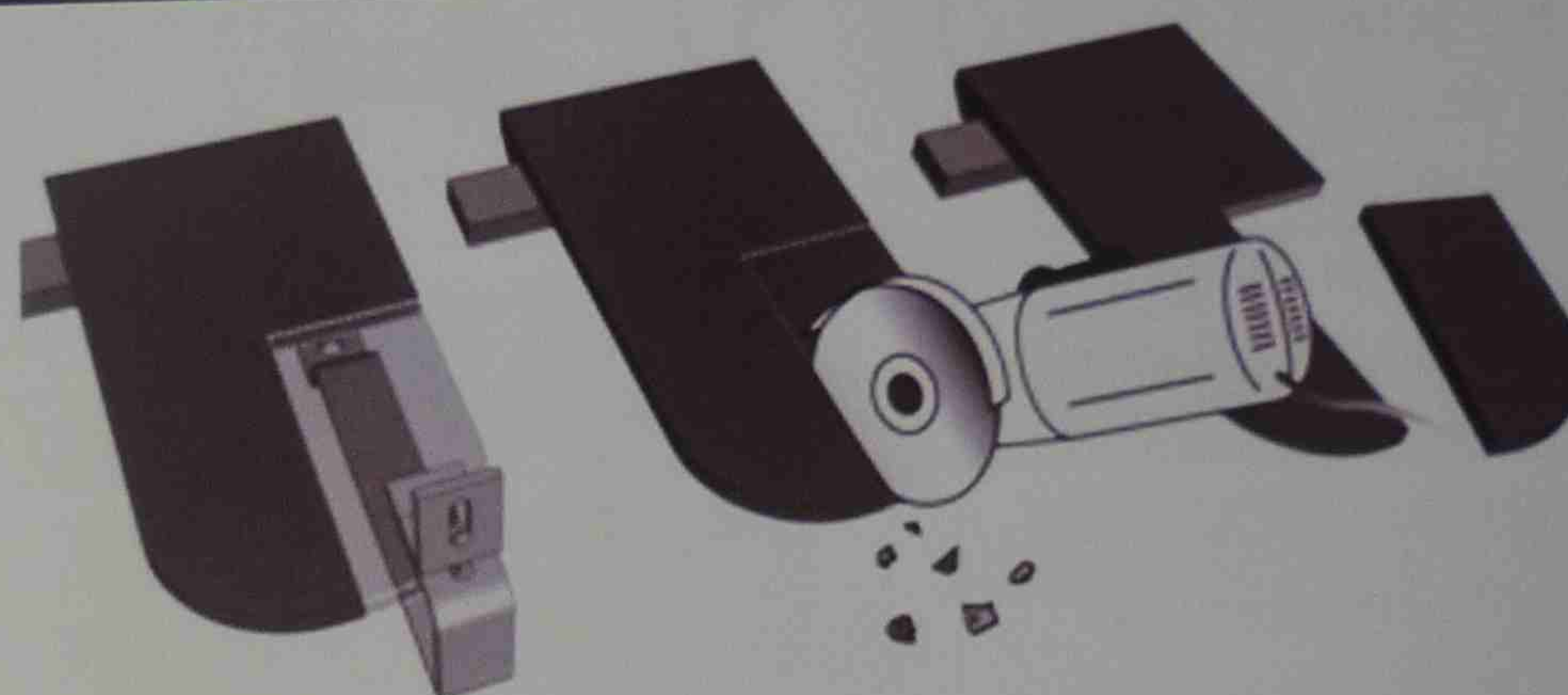


5.1.6 PLANNING THE MODULE AREA

1. Number of modules in the vertical direction x module height (please check also the installation manual of the manufacturer of the solar module)
2. Number of modules in horizontal x (module width + 18mm) + 32mm
3. Horizontal spacing of the roof hooks up to 2.0 m
4. Vertical spacing of the roof hooks = approx. 1⁄2 to 3⁄4 of module height
5. Distance between the modules: 17 mm

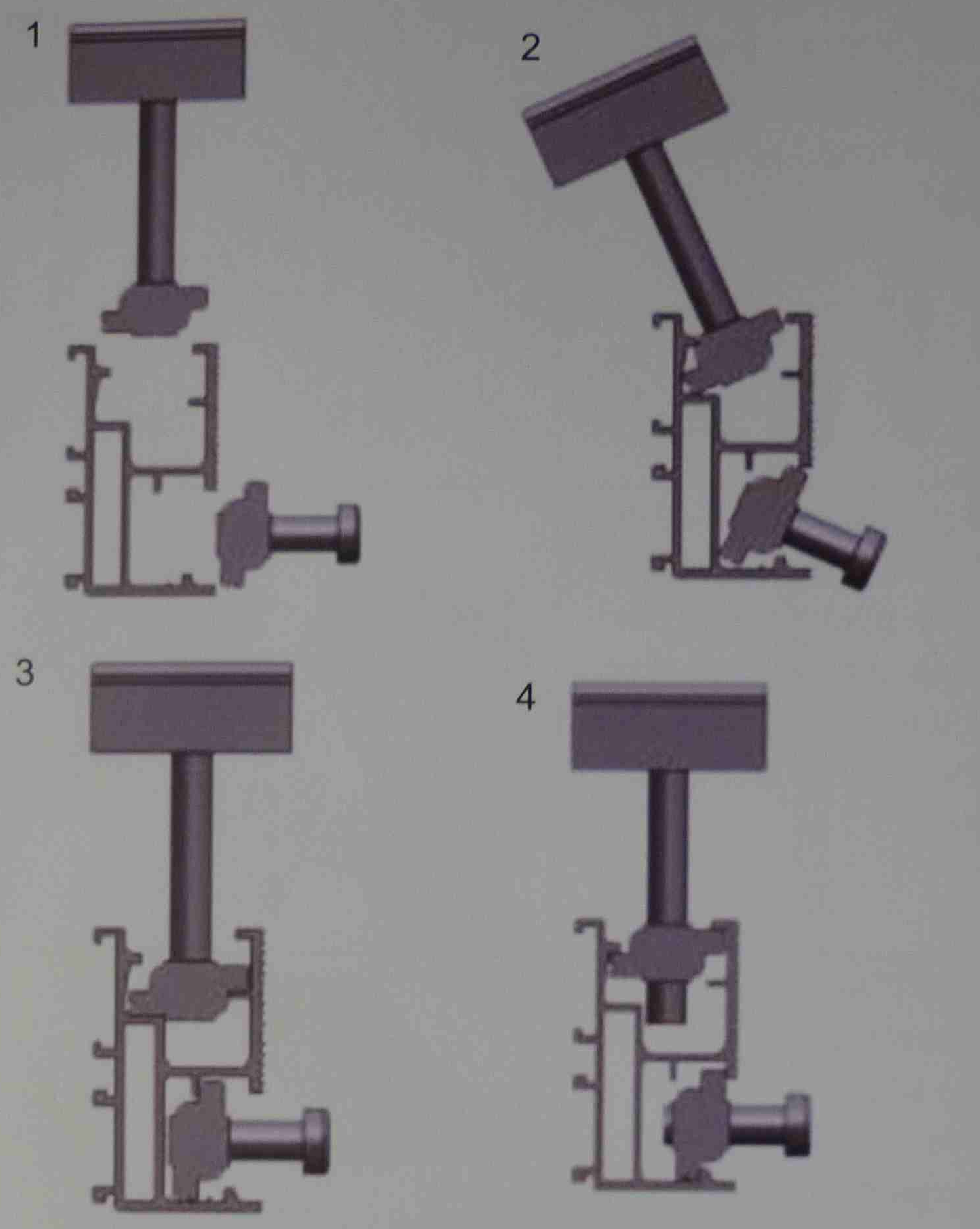
5.1.7 Tile Roof Hook Installation

1. Determine the positions of the roof hooks according to your plans. Remove the roof tiles at the marked positions or, if possible, simply lift them up slightly.	
2. Fix the roof hooks to the rafter using three 6 x 80 mm wood screws.	
3. The roof hook must not press against the roof tile. If necessary, shim the roof hook with wood.	 Incorrect Correct
4. If necessary, use an angle grinder or hammer to cut a recess in the tile that covers the roof hook at the point where the roof hook comes through so that the tile lies flat on the surface. If grooved tiles are used, it will also be necessary to cut a recess in the lower tile.	

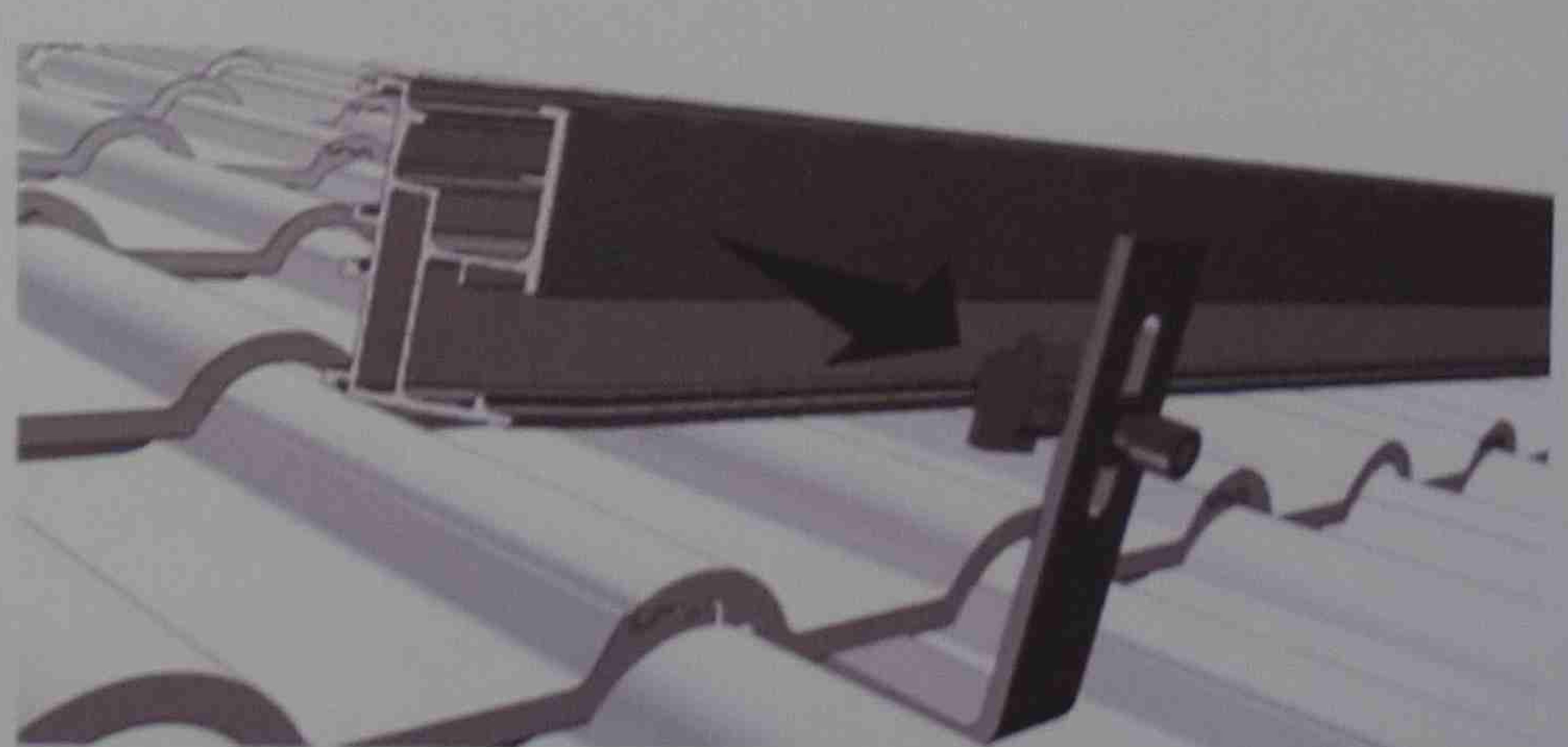
5.1.7 Tile Roof Hook Installation (cont'd)	
5. Caution! Do not use fitted roof hooks as a ladder, as this extreme point load could damage the tile below.	
6. Variation for installation on plain tile roofs With plain tile roof cladding, a recess must be cut into the tiles around the position of the roof hook	
7. A titanium zinc metal sheet must be cut to fit on site, with an overlap of at least 20 mm around the recess, and installed under the roof hooks. Caution! Please take note of Figure 3.	

5.1.7 Tile Roof Hook Installation (cont'd)

8. For easy use of the Z module, you must make sure that the thread of the screws does not project through the lower side of the Z Module (max. flush). Position the Z Module in the rail channel and fasten it loosely with 2 to 3 turns of the screw.
The screws can still be freely moved in the rail channel. Slide the screws to their final position in connection with the inter-module clamp, module end clamp or roof hooks/hanger bolts and fasten firmly (recommended torque is 8 Nm).



9. Installation of the rails on roof hooks.
If your set of rails consists of rails of different lengths, always begin with the shortest piece. Install the framing for each row of modules loosely on the roof hooks, using an M8 x 25mm Allen bolt, washers, retaining washers and the Z Module (2 to 3 turns of the screw are adequate for loose installation). Please take note of Figure 10.

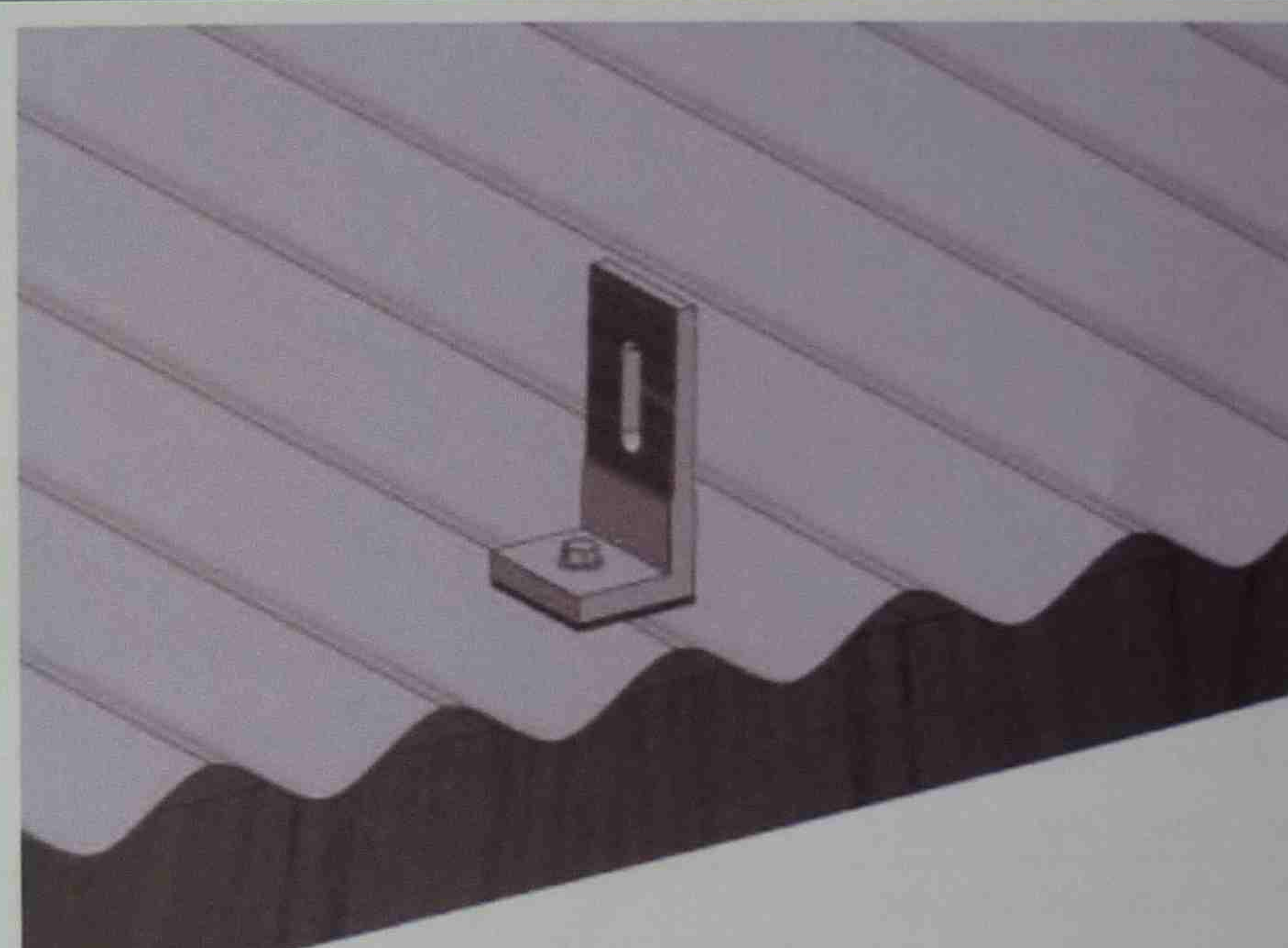


5.1.7 Tile Roof Hook Installation (cont'd)

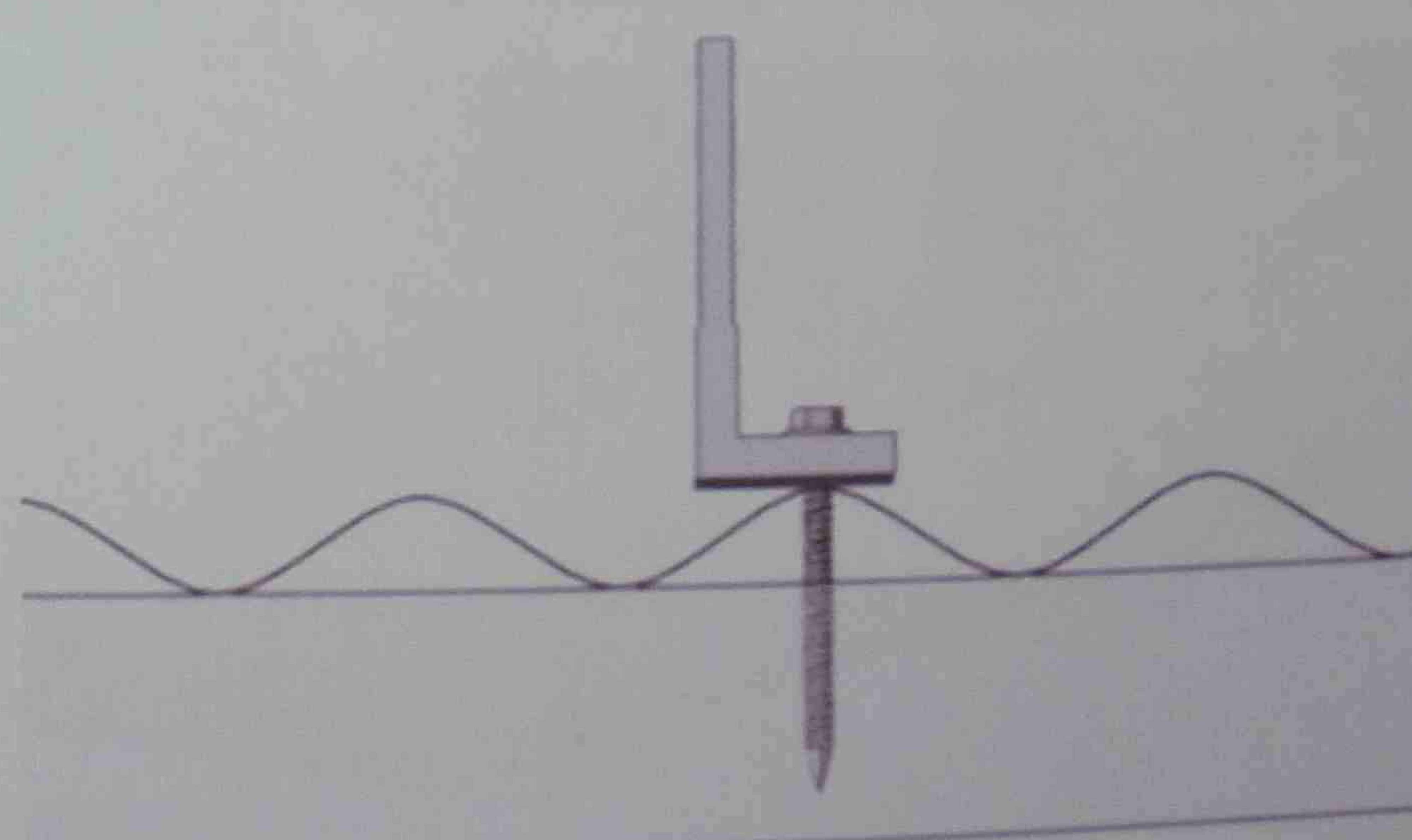
10. An optimum adjustment of the vertical and horizontal position can be made by taking advantage of the long hole in the roof hooks and the still loose connection of the Z Module or T-head bolts in the rail. Please take note of Figure 13 below. Position

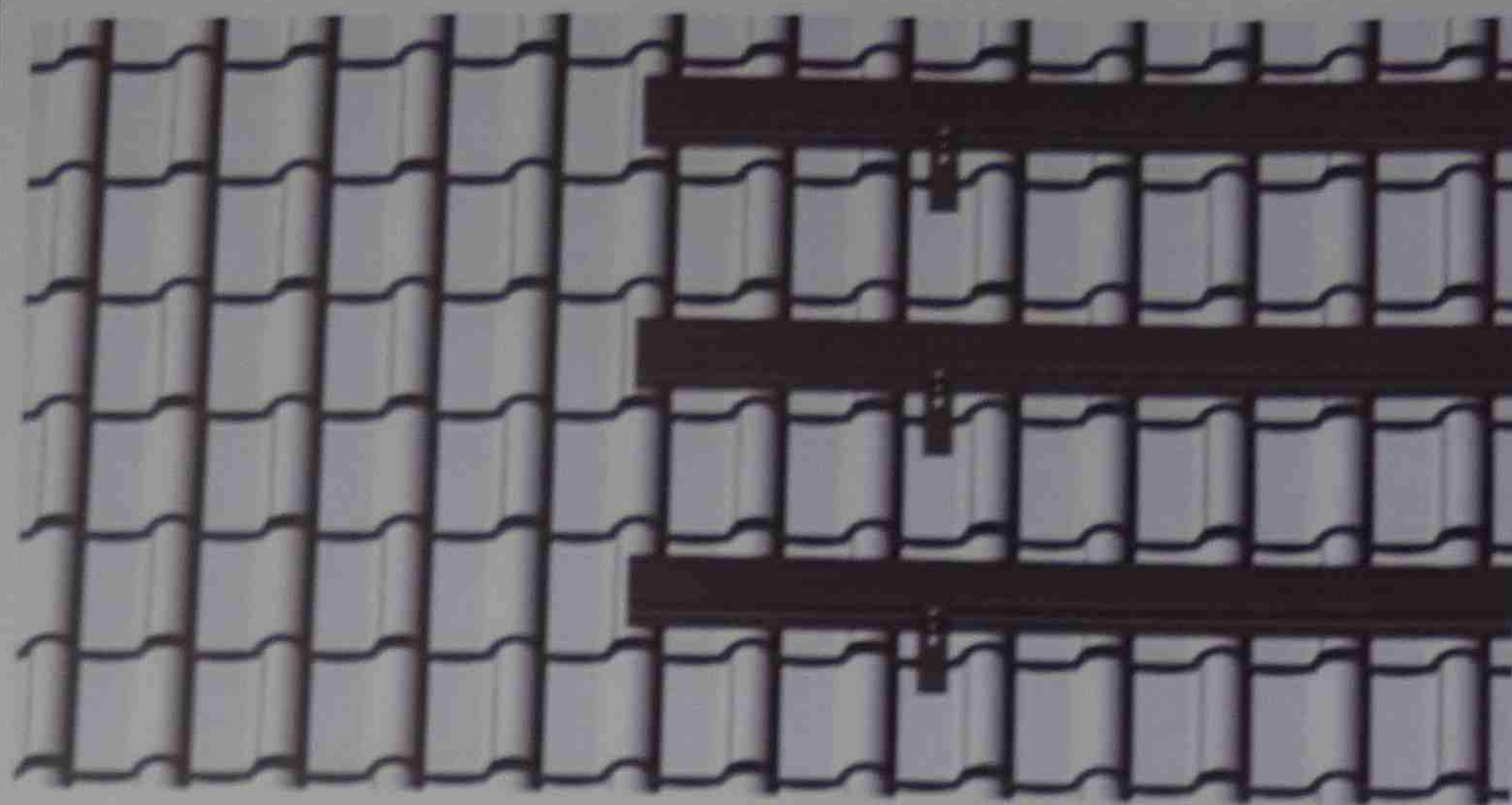
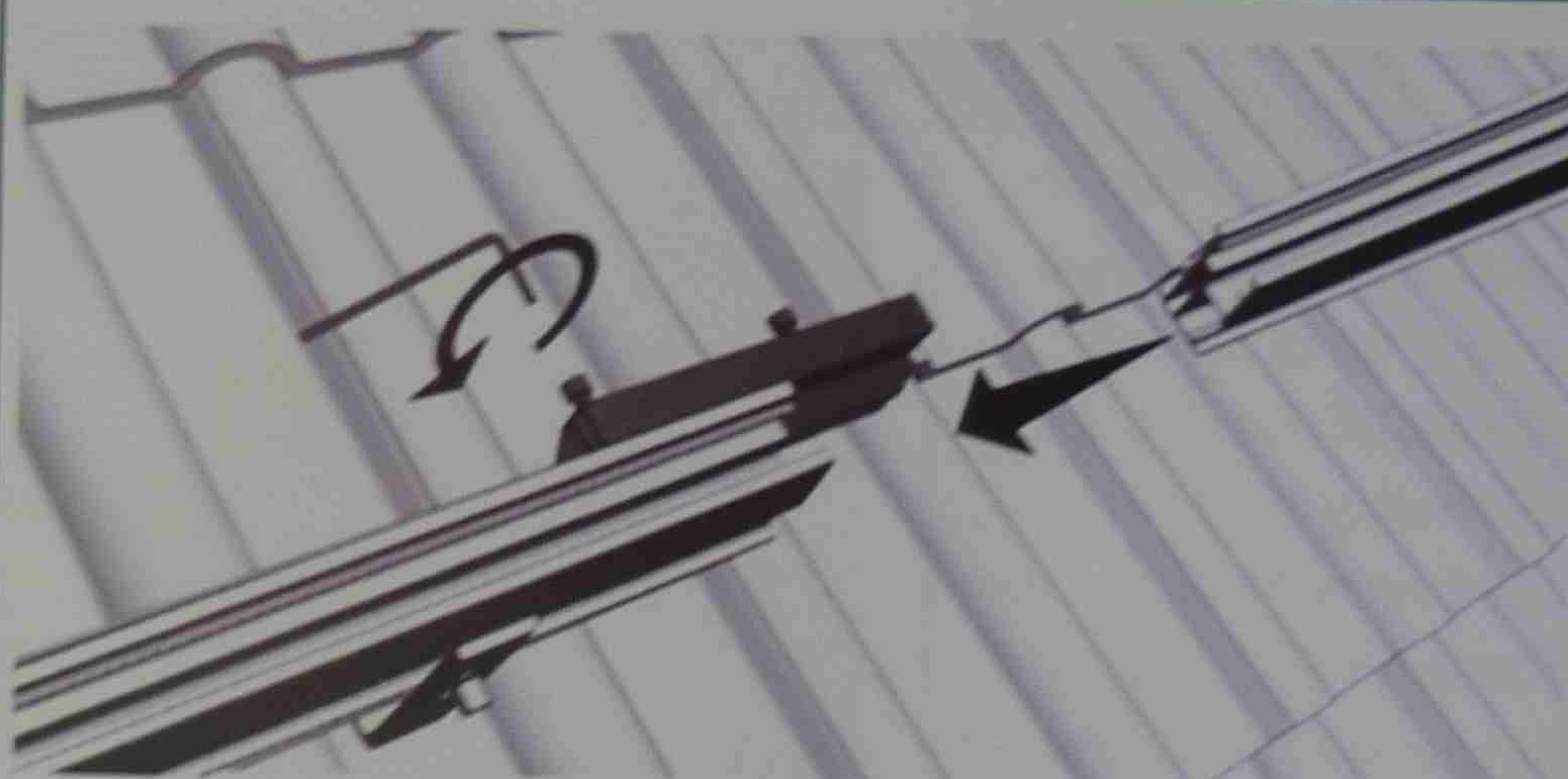
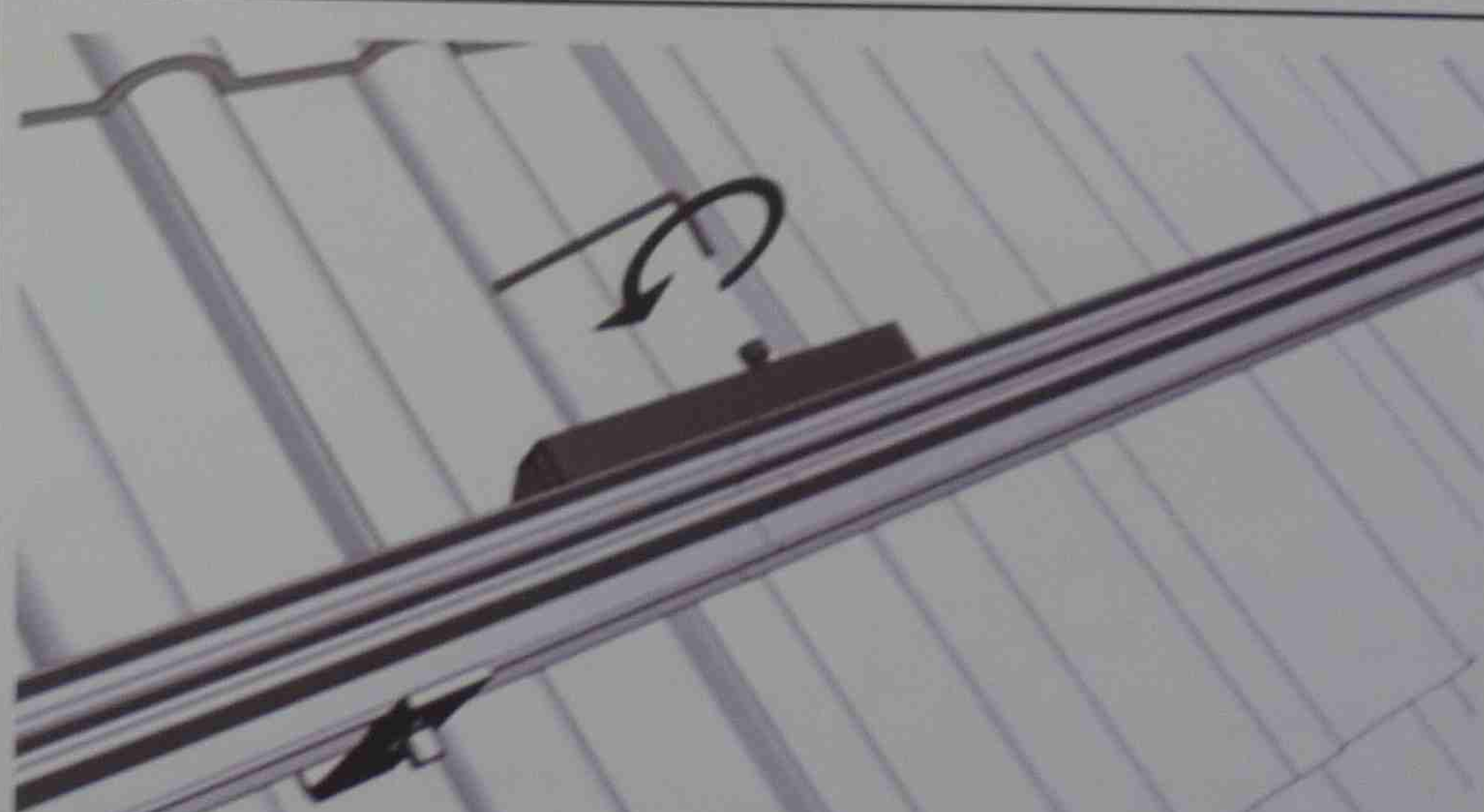
5.1.8 Tin Roof Hook Installation

11. In the case of corrugated roof cladding, hanger bolts are used instead of roof hooks. Drill through the roof cladding at the planned location and screw the hanger bolts into the purlins. Then mount the L-brackets.



12. Cross-section of a hanger bolt installation. Take special care that the nut tightly fastens the sealing washer without damaging the roof cladding. When performing the installation, take care that the thread of the hanger bolt does not cover the long hole in the L-bracket.

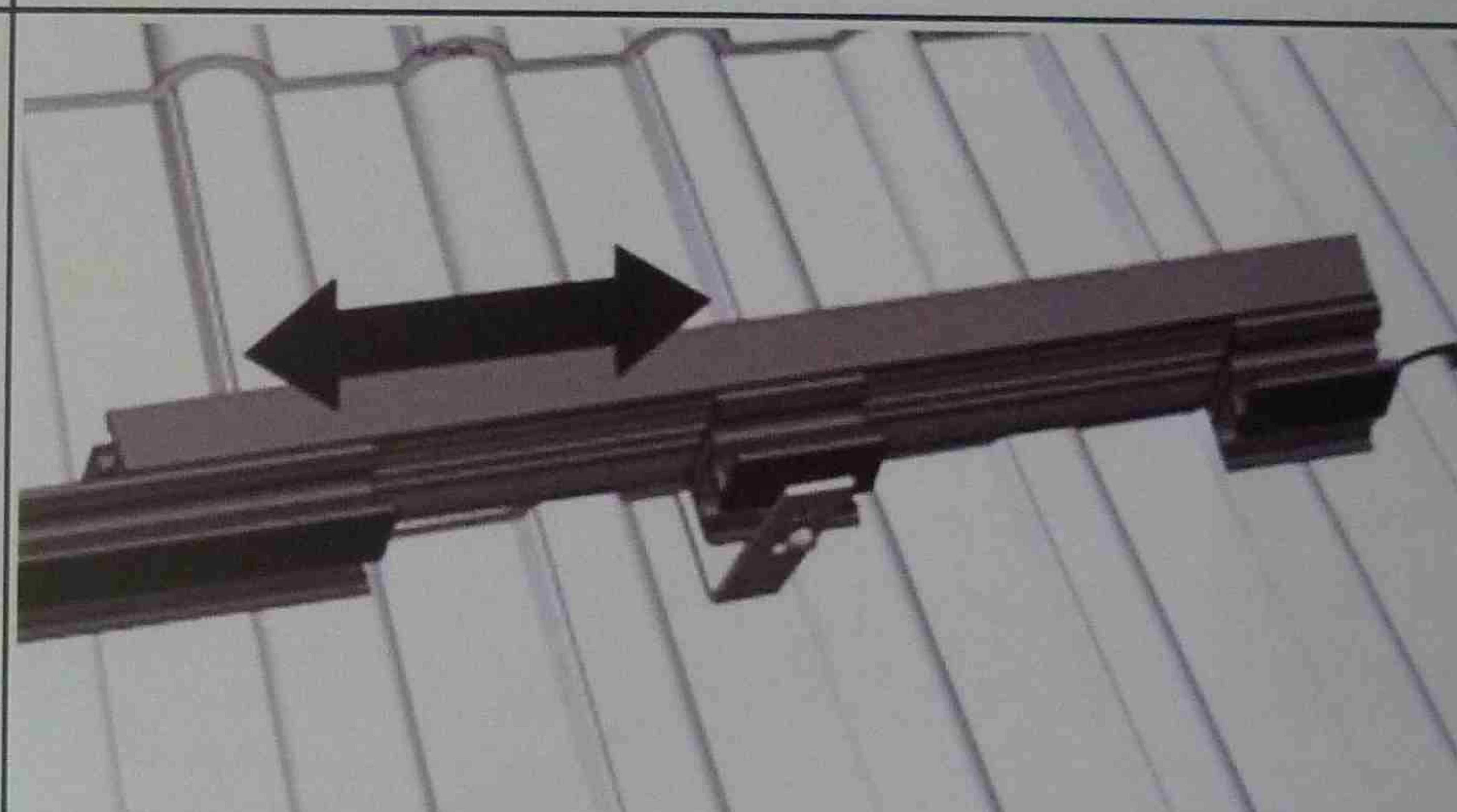


5.1.9 Base Rail Installation	
13. Position the first frame rails for each row and fasten them temporarily to the roof cladding using a cord. Tighten the Allen bolts or the nuts on the T-head bolts that are used to fasten the roof hooks/ hanger bolts (recommended torque is 8 Nm). Please also pay attention to Figure 10.	
14. To connect multiple rails together, slide the splices on the rear side of the pre-assembled rails halfway to the side. Fasten the first M8 Allen bolt firmly using the Allen key. Now slide the next rail segment into the splice.	
15. Tighten the second M8 Allen bolt using the Allen key. The connection is finished. An expansion gap at the rail joints is recommended. For this purpose, leave a gap about the same width as a finger between the rail joints and then loosely tighten the M8 allen bolt.	

5.1.9 Base Rail Installation (cont'd)

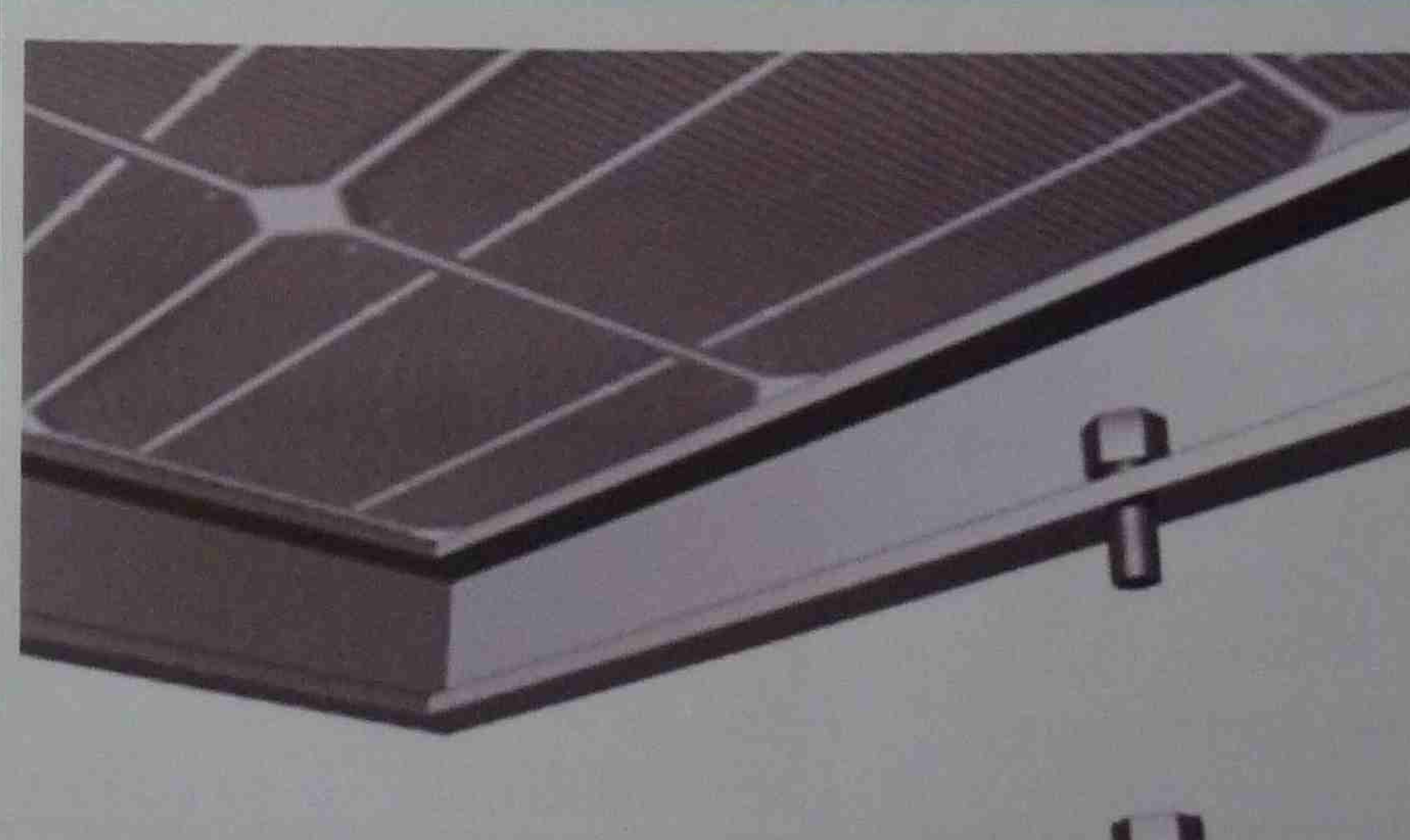
16. When planning a system using a telescopic mounting, please mount a telescopic mounting at the end of every row of rails. To do this, you insert the end of the telescopic mounting into the rail. The mountings can be adjusted to their correct positions later. For this reason, you should not yet fasten the M8 Allen bolt to the rear of the telescopic mounting.

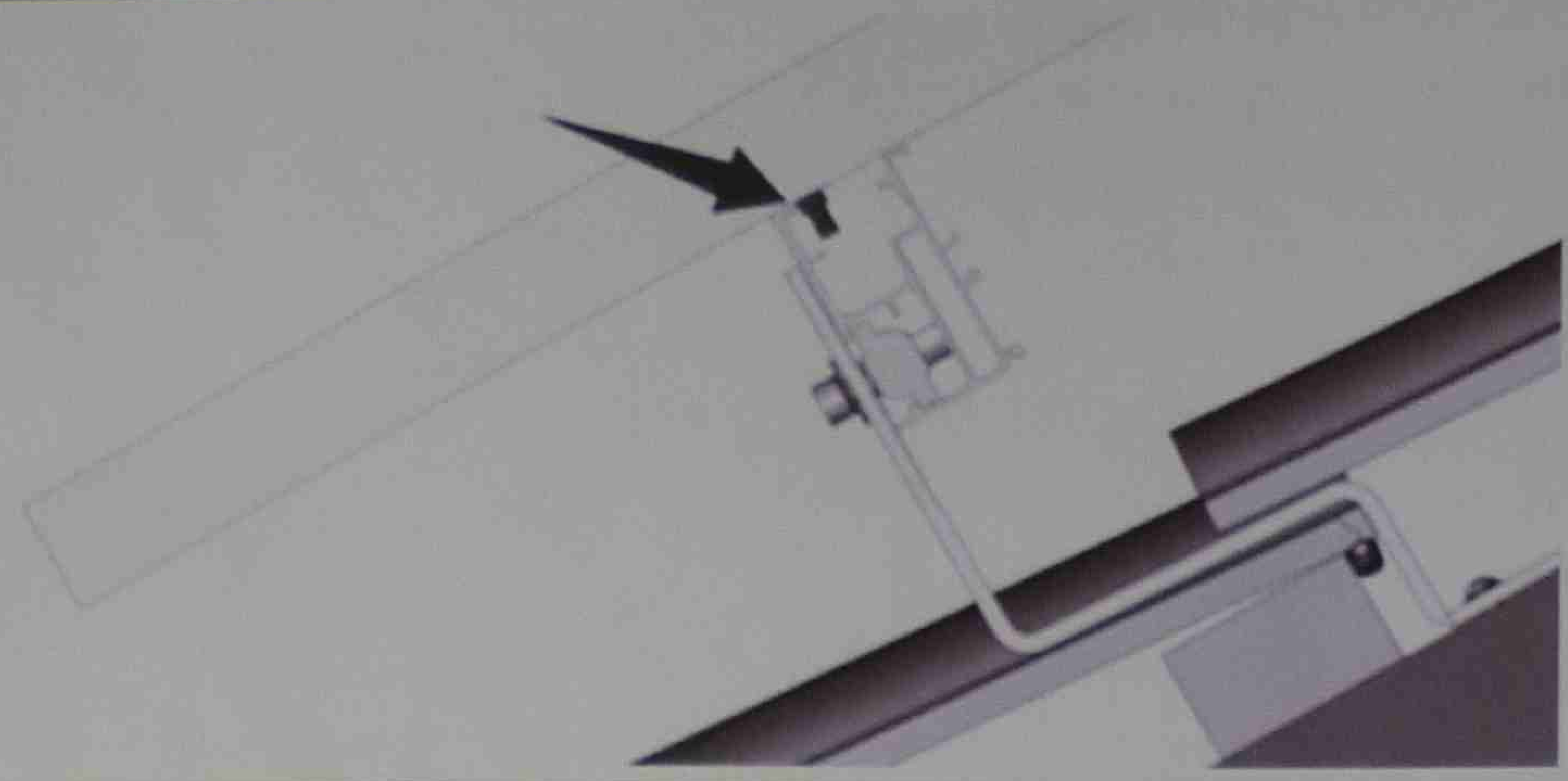
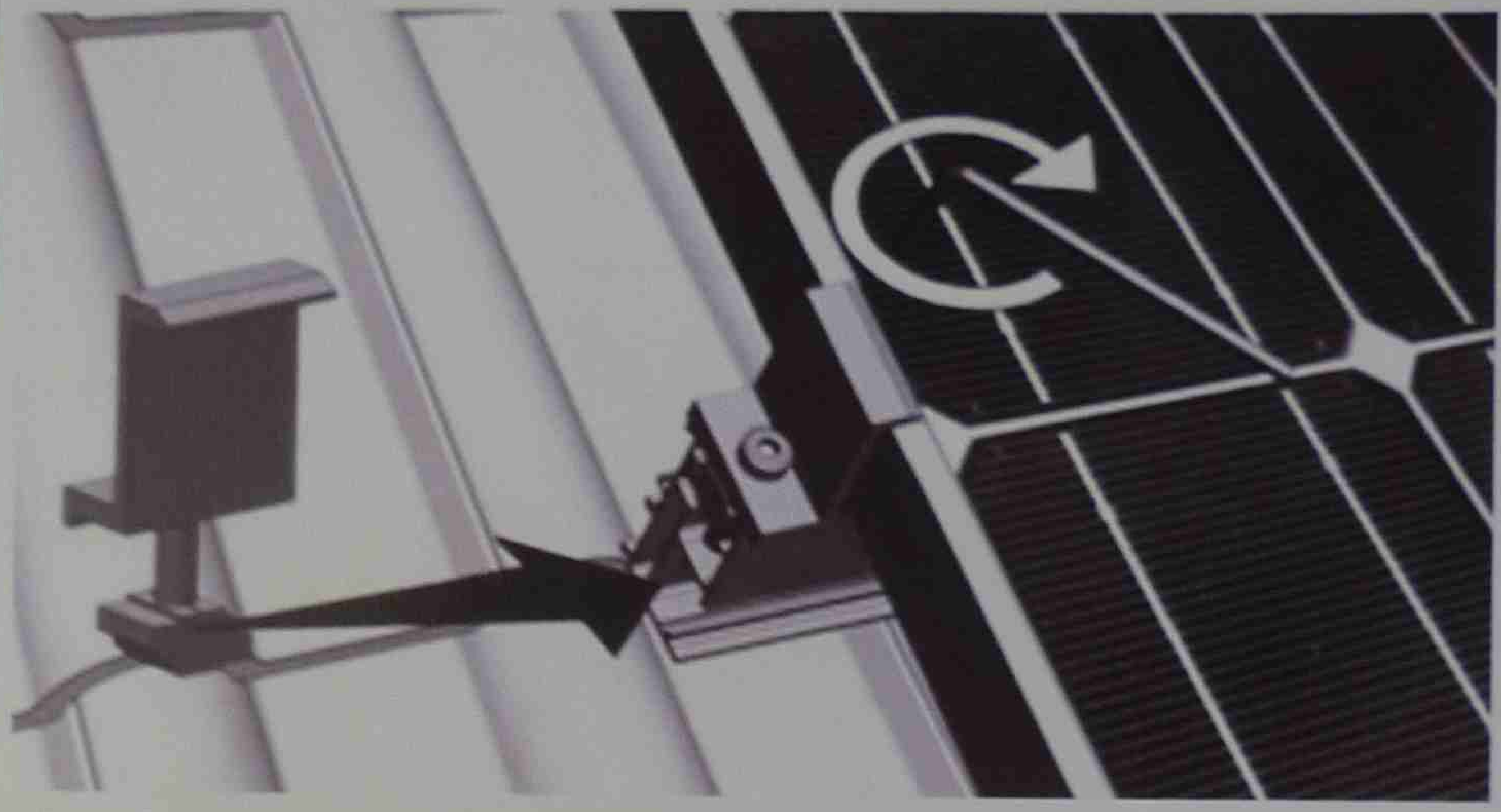
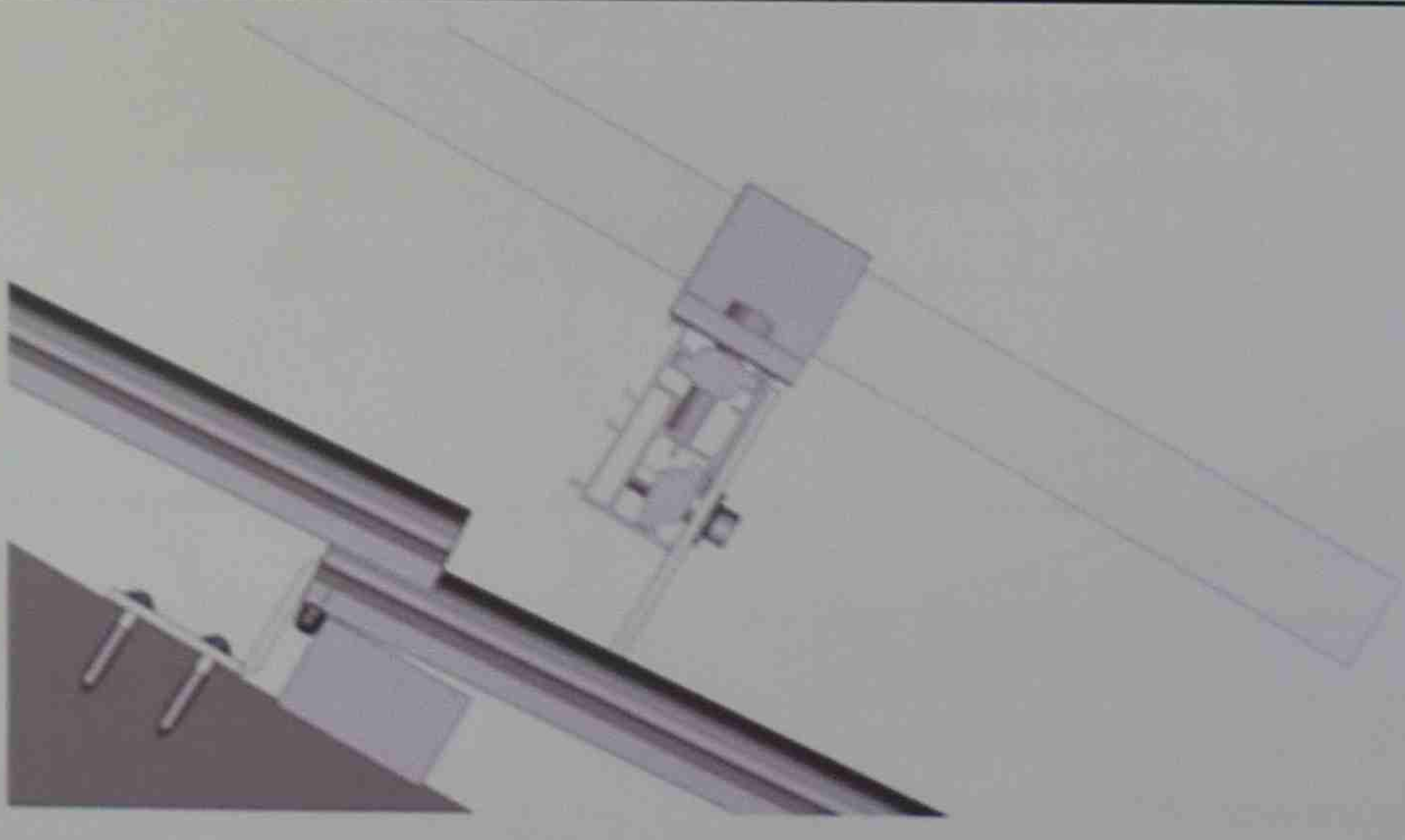
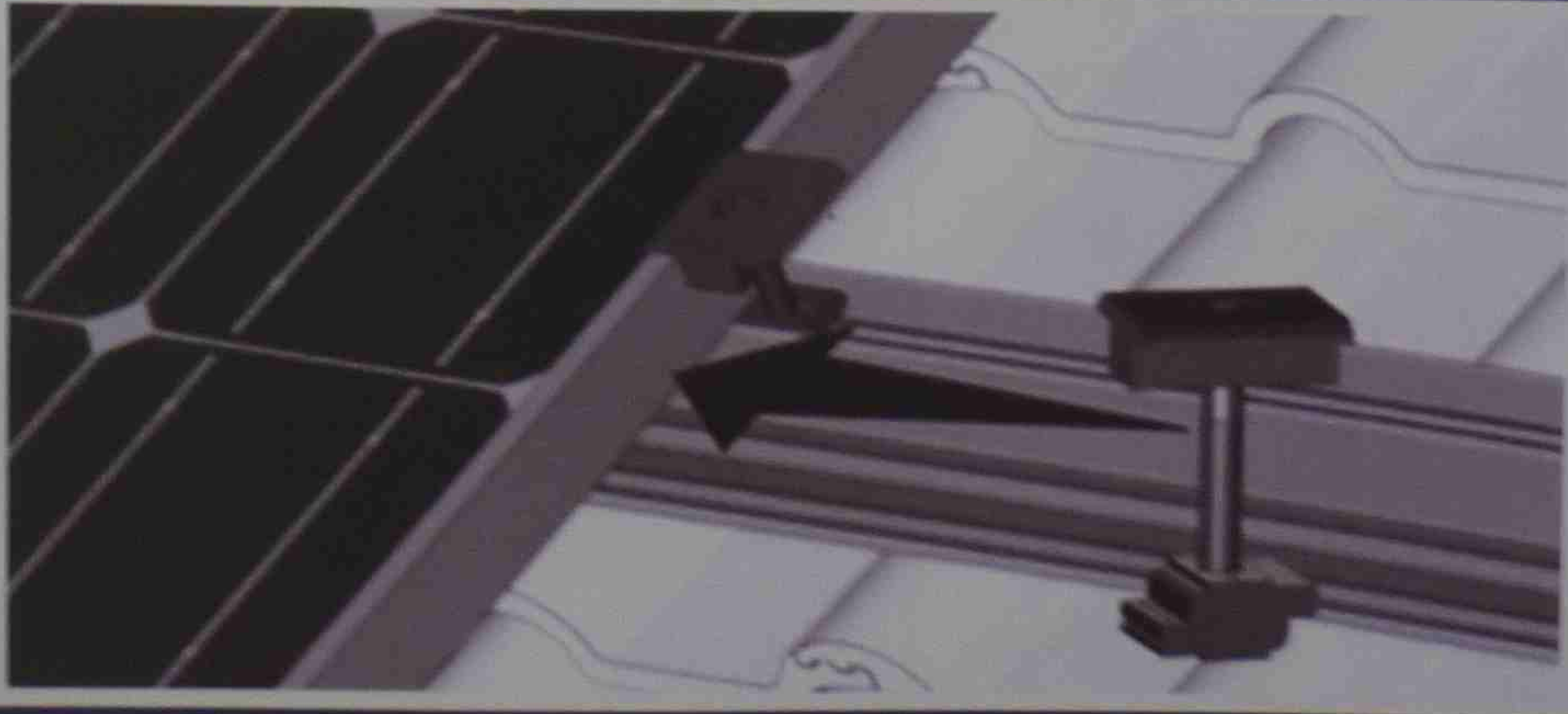
17. Fasten any remaining roof hooks to the movable rail element of the telescopic mounting. Please repeat steps 14 to 16 until all base rail rows in your system are installed.

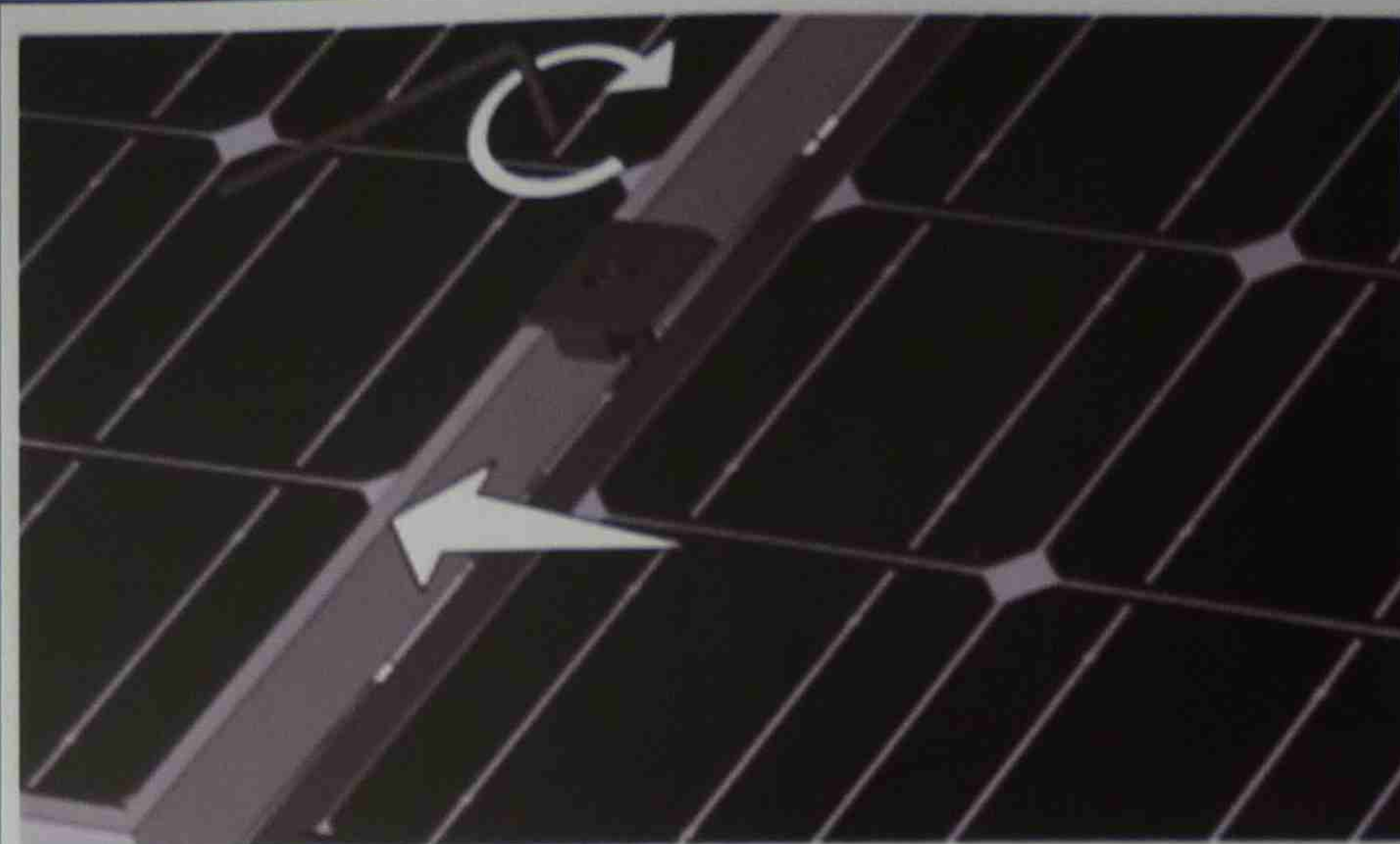
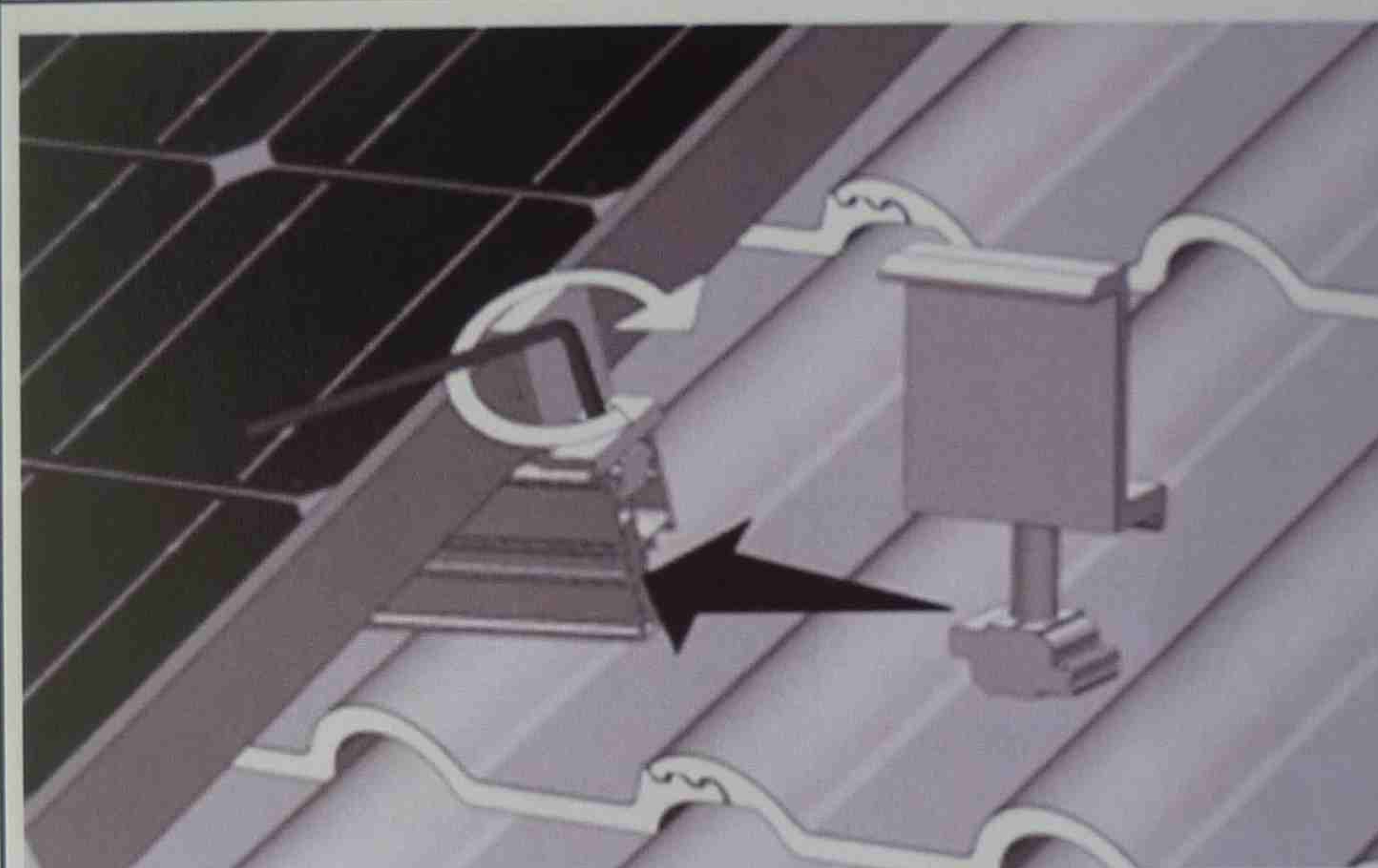
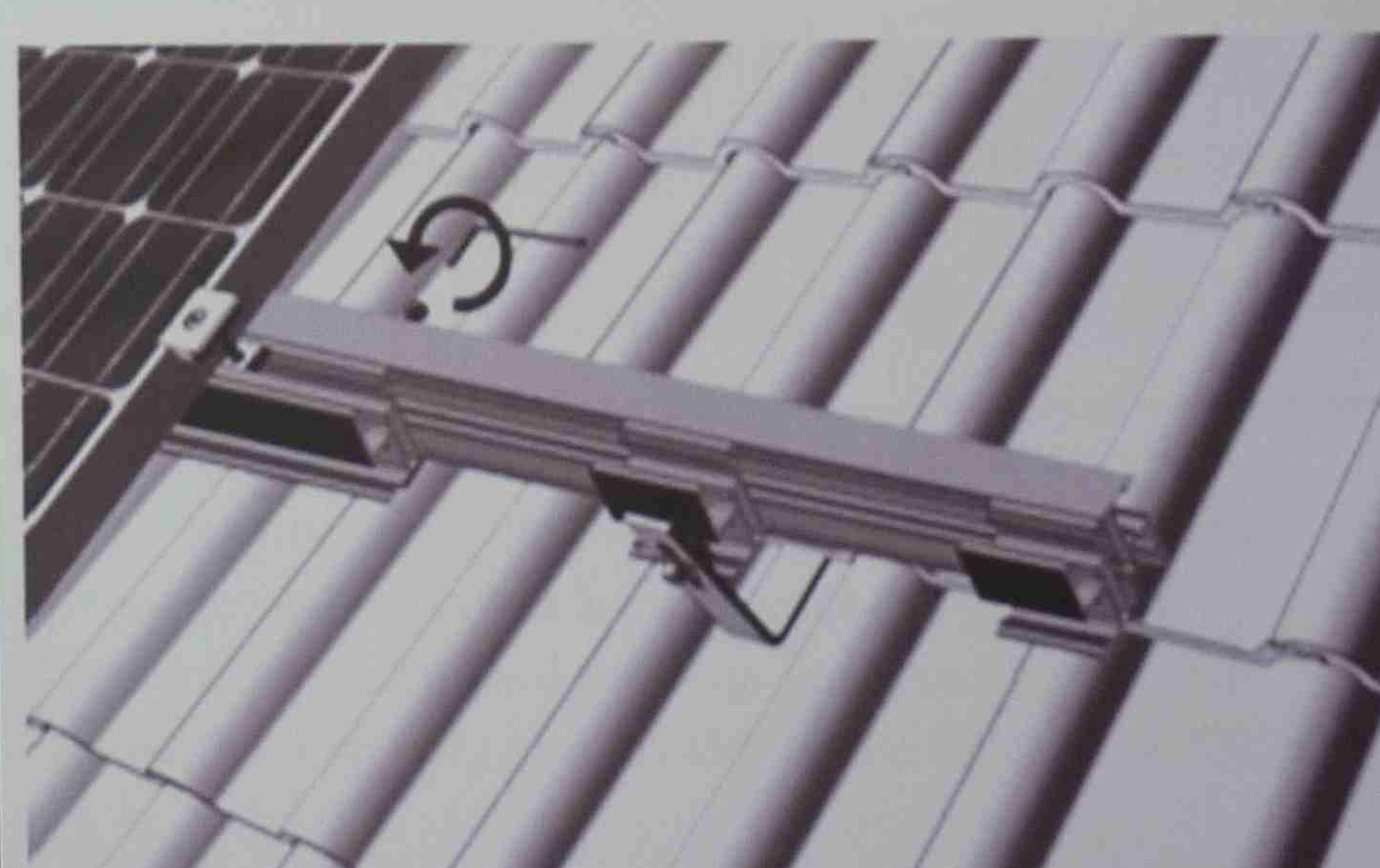


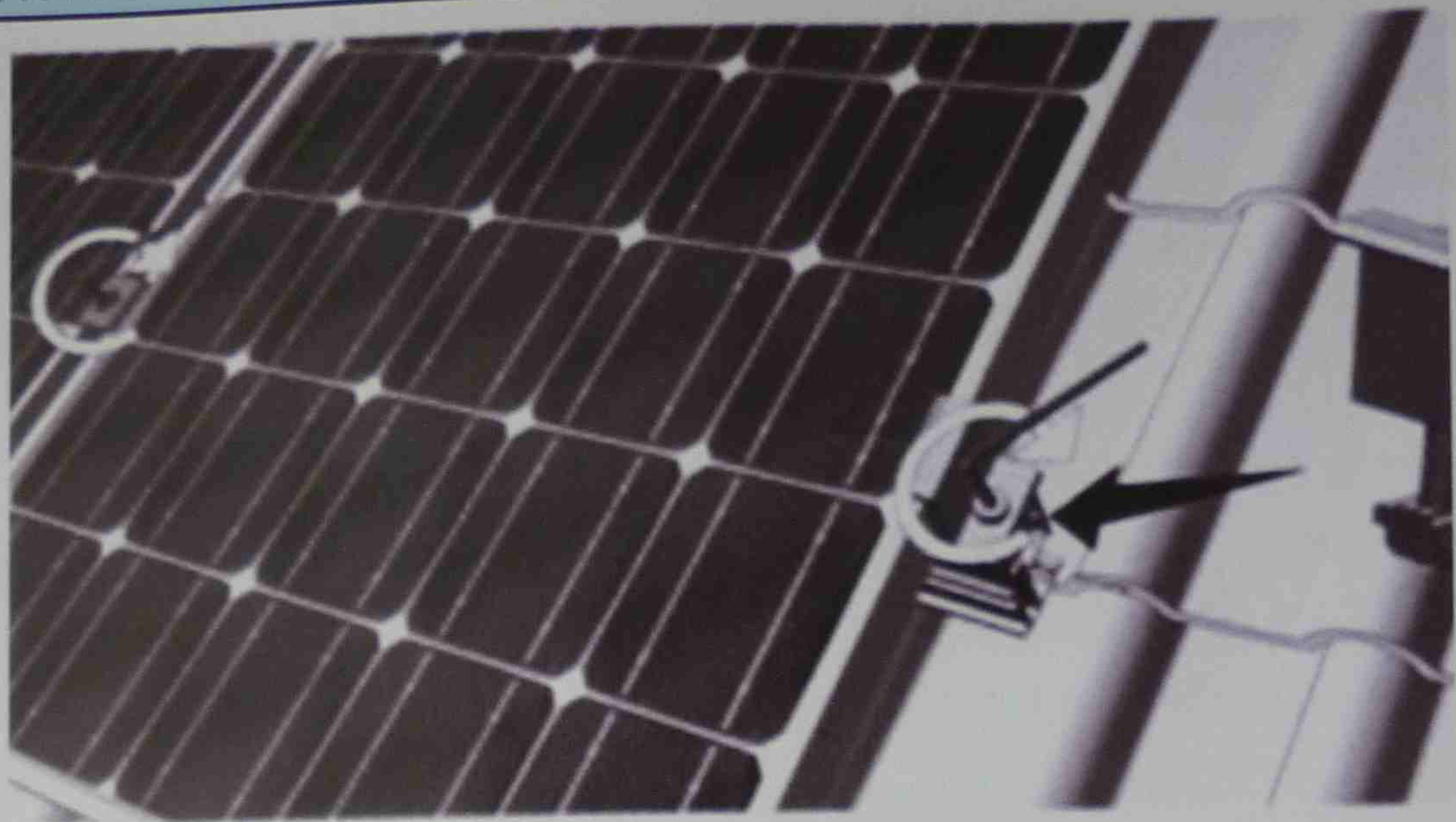
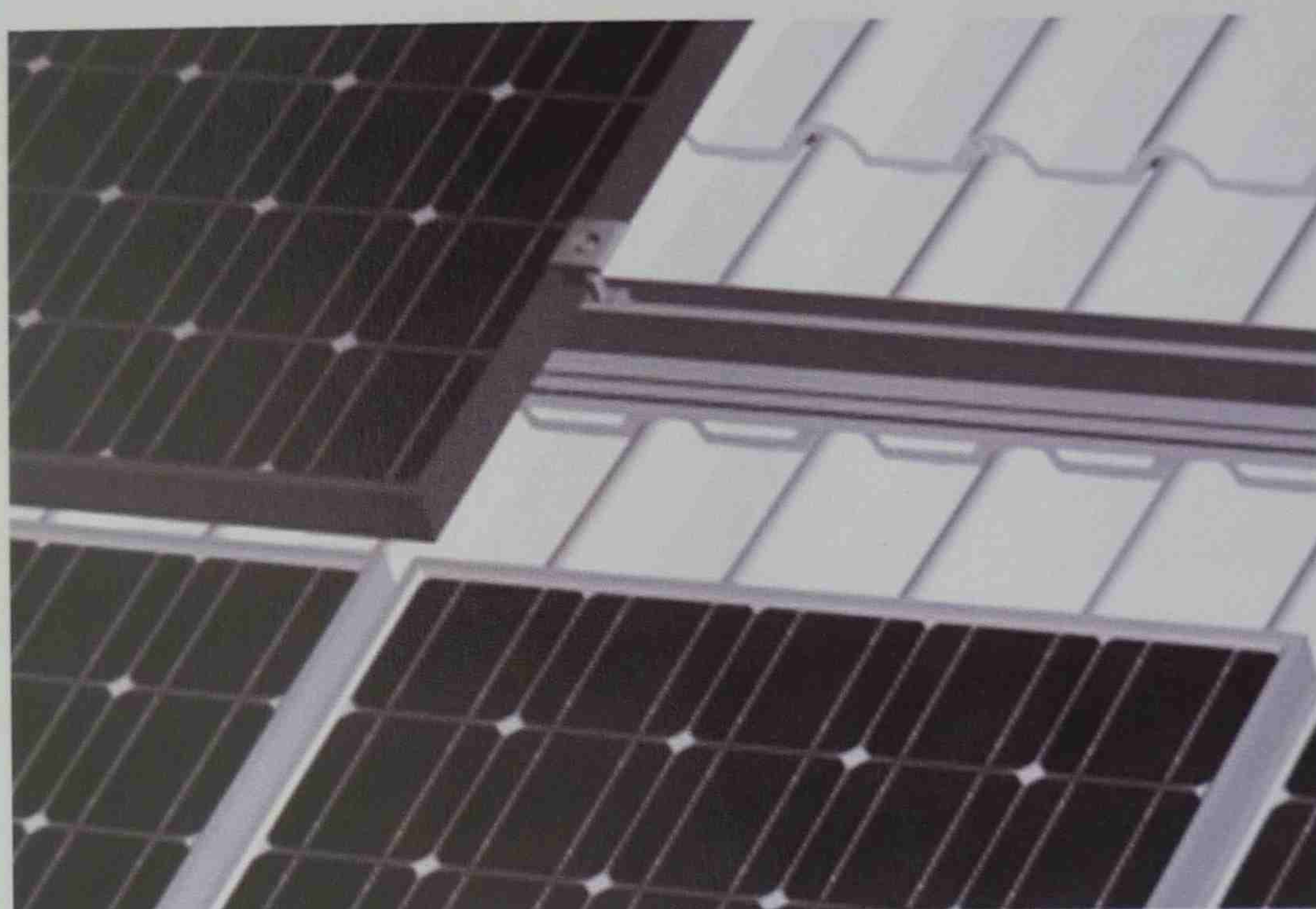
5.1.10 PV Module Installation

18. Before installing the modules, add anti-slip protection to the lowest row of modules (horizontal rail installation only). To do this, fasten M6 x 20 mm bolts (with the shank downwards) to the lower mounting holes of the module frame using M6 nuts. When installing large modules (e.g. ASE250) M8 x 20 mm bolts must be used.



5.1.10 PV Module Installation (cont'd)	
19. Place the first module of the bottom row so that the anti-slip protection sits in the rail channel of the lowest row of rails.	
20. Slide the module end clamp tightly against the module and fasten tightly using the Allen bolt (recommended torque is 8 Nm). Please take note of Figure 10.	
21. Cross-section through the module end clamp when installation step 20 has been correctly performed.	
22. Slide the pre-assembled inter-module clamp into the rails from above, place it firmly against the module and fasten loosely (approx. 2 - 3 turns). Please also take note of Figure 10.	

5.1.10 PV Module Installation (cont'd)	
23. Now slide the next module against the previously installed module and tighten the inter-module clamp using the Allen key (recommended torque is 8 Nm). Take care that the anti-slip protection sits in the rail channel of the lowest row of rails. Please also take note of Figure 10.	
24. If your system does not use a telescopic mounting, position the last module of the row in the base rail and fasten the module using the module end clamp (recommended torque is 8 Nm). For systems with telescopic mount-ings, please take note of Figure 25 below.	
25. Installation using telescopic mounting Position the telescopic mounting, which was loosely mounted in step 16, so that there is suf-ficient room for the last module, the last inter-module clamp and the end clamp (calculation: module width or length in mm + 43 mm). Now tighten the telescopic mounting using the Al-len key.	

5.1.10 PV Module Installation (cont'd)	
26. Place the last module in the row on the rails (with the first row of modules, take care that the anti-slip protection sits properly in the rail channel) and fasten the last inter-module clamp and the module end clamp using the Allen key (torque 8 Nm).	
27. Now slide in the first module of the next row from above onto the corresponding module of the row beneath. A separation from the lower module can be maintained for optical reasons. An inter-module clamp can be used as a separator, so that the vertical and horizontal separation of the modules is identical. Continue mounting the modules as described in steps 20 to 26 until all modules are installed. The installation is finished.	

5.2 SOLAR ROOF ADJUSTABLE TILT LEGS

Code-Compliant Planning and Installation with Australia AS/NZS1170

Clenergy Solar Roof Adjustable Tilt Legs have been developed as a universal PV modules mounting system for the flat/tilt roof. The innovative and patented aluminium base rails, the Z modules and the rail extension technology eliminate the need for onsite cutting and enables quick and easy field PV module installations.

NOTE: check the current version of the installation manual under www.clenergy.com.au.

The installer is solely responsible for:

- Complying with all applicable local or national building codes, including any that may supersede this manual;
- Ensuring that ezRack and other products are appropriate for the particular installation and the installation environment;
- Ensuring that the roof, its rafters, connections, and other structural support members can support the array under building live load conditions (this total assembly is hereafter referred to as the roof rafter assembly);
- Using only ezRack parts and installer-supplied parts as specified by ezRack (substitution of parts may void the warranty and invalidate the letter of certification on page 2);
- Ensuring that lag screws have adequate pullout strength and shear capacities as installed;
- Maintaining the waterproof integrity of the roof, including selection of appropriate flashing;
- Ensuring safe installation of all electrical aspects of the PV array.

5.3 PLANNING

This document is designed to support for installations using SolarRoof™ Adjustable Tilt Legs, manufactured by Clenergy Co. Ltd. Follow the six steps below and the installation instructions section to install Clenergy Adjustable Tilt Legs in compliance with the AS/NZS1170.

Before proceeding, note the following:

- This document addresses only wind loads on the assumption that wind produces the maximum load factor affecting an installation. Verify that other local factors, such as snow loads and earth quake effects, do not exceed the wind loads. Give precedence to any factor that does. Wind loads are considered to act on the entire projected area, or may be perpendicular to any surface.
- The roof on which the SolarRoof™ will be installed must have the capacity to resist the combined Design Dead Load and Live Load per footing.

Installation tools

- 6 mm and 4mm Allen key
- Cordless drill
- Open-end spanner set 9, 10, 17, 19 mm (required only for mounting with Nut)
- Torx-30 (AW 30) bit
- Power Cord

5.3.1 DETERMINE THE WIND REGION OF YOUR INSTALLATION SITE

(a) Australia

Region Definition:
Wind regions are pre defined for all of Australia by Australian Standard 1170. The Wind Region has nothing to do with surrounding topography or buildings.

- Most of Australia 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 referred to as Cyclonic and are generally limited to northern coastal areas. Most Region C zones end 100km inland.
- Region D (80msec) Australia's worst Cyclonic Region between Carnarvon and Pardoo in Western Australia.

5.3.2 DETERMINE THE HEIGHT OF THE INSTALLATION SITE

This document provides sufficient information for SolarRoof™ Adjustable Tilt Legs system installation heights less than 20 meters. If your installation site is more than 20 meters in height, please contact Clenergy to obtain engineering data to support your installation.

5.3.3 DETERMINE THE MAXIMUM RAIL SUPPORT SPACING

Please use the following table to determine the base rail support spacing for sheet metal roof installations.

a) 10 to 15 degree

Installation Height	Region A (mm)	Region B (mm)	Region C (mm)	Region D (mm)
up to 5m	1716	1364	913	561
up to 10m	1560	1240	830	510
up to 20m	1404	1116	747	459

b) 15 to 30 degree

Installation Height	Region A (mm)	Region B (mm)	Region C (mm)	Region D (mm)
up to 5m	1419	1133	913	561
up to 10m	1290	1030	830	510
up to 20m	1161	927	747	459

c) 30 to 60 degree

Installation Height	Region A (mm)	Region B (mm)	Region C (mm)	Region D (mm)
up to 5m	1309	1034	847	561
up to 10m	1190	940	770	510
up to 20m	1071	846	693	459

6.3.1 DETERMINE THE WIND REGION OF YOUR INSTALLATION SITE

- The figures on the opposite page are based on attaching 200 W PV modules (length of 1675 mm, weight of 23 kg) to Solar Roof system. These figures should be sufficient for installing smaller PV modules. Please consult Clenergy for installing PV modules greater than length of 1675 mm and weight of 23 kg.
- Each Fix Foot should be fixed to the purlins under using two 12G X 65* screws through sheet metal roofs with gasket.
- The above spacing applies for fixing through thin sheet purlins (greater than 1mm thickness) or a minimum embedment of 50 mm into timber purlins.

* The length of these screws should be chosen according to the type of tin roof to ensure that the minimum embedment requirement (50 mm into timber purlins).

5.3.4 VERIFY ACCEPTABLE RAIL END OVERHANG

Rail End Overhang must equal 50 percent or less of foot spacing. Thus, if foot spacing is 1200mm, the Rail End Over hang can be up to 600mm. In this case, two feet can support a rail of as much as 2400mm (1200mm between the feet and 600mm of over-hang at each end).

5.3.5 DETERMINE INSTALLATION SLOPE

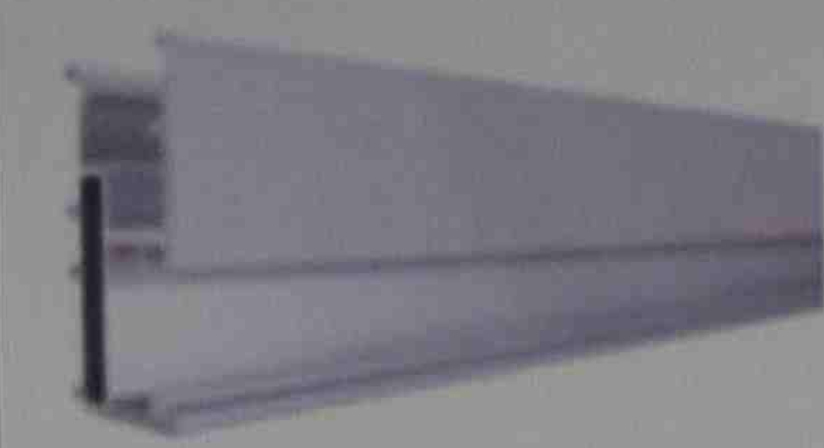
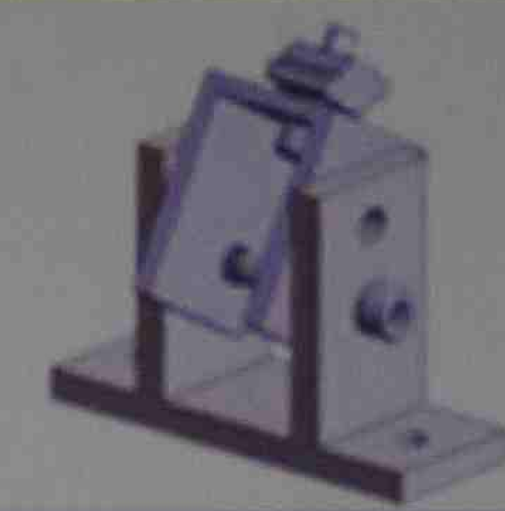
Clenergy SolarRoof™ Adjustable Tilt Legs system can be used for roof slope from -30 to 30 degree.

5.3.6 DETERMINE ROOF INSTALLATION ROOF AREAS

Clenergy Solar Roof Adjustable Tilt Legs can be installed using those spacing every-where on the roof.

5.4 COMPONENTS LIST

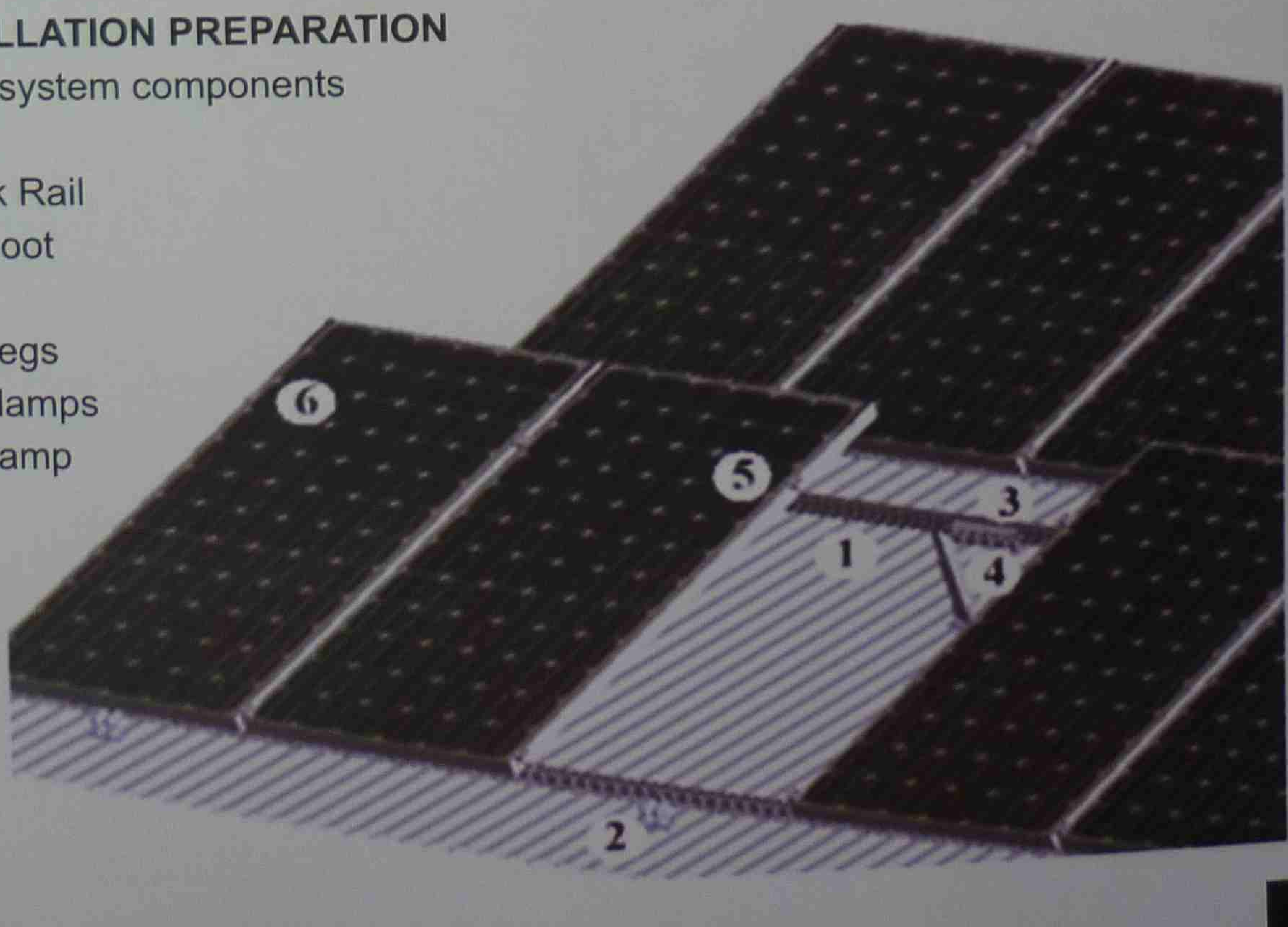
Overview of system components

Part name	Picture	Part name	Picture
ezRack Rail		Front Foot	
Splice		Back Legs	
Inter Clamp		End Clamp	
M8*25 Hex head bolt		Hex head bolt M8*55	
Pan-head Wood Screw 6*90		Set Screw M10*10	

5.4.1 INSTALLATION PREPARATION

Overview of system components

1. EzRack Rail
2. Front Foot
3. Splice
4. Back Legs
5. Inter Clamps
6. End Clamp

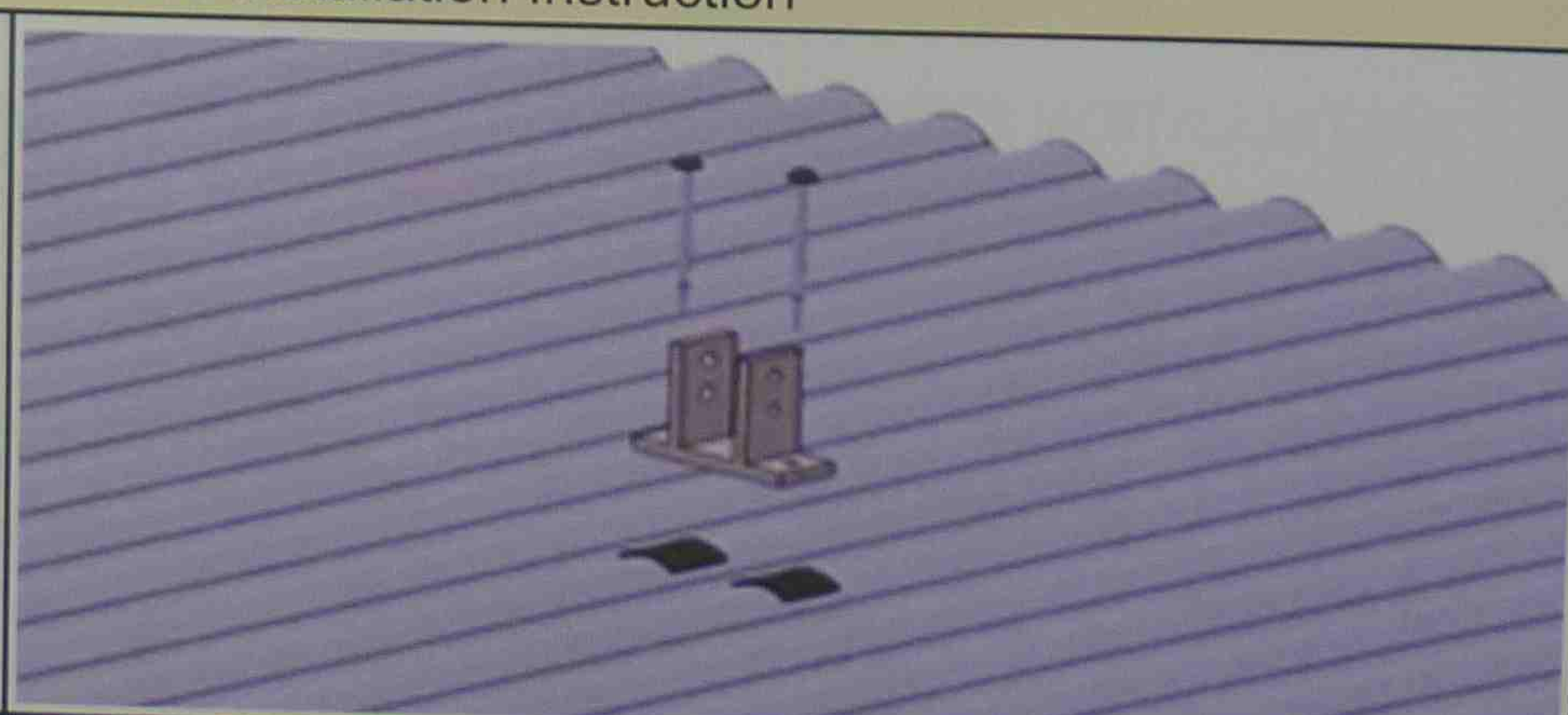
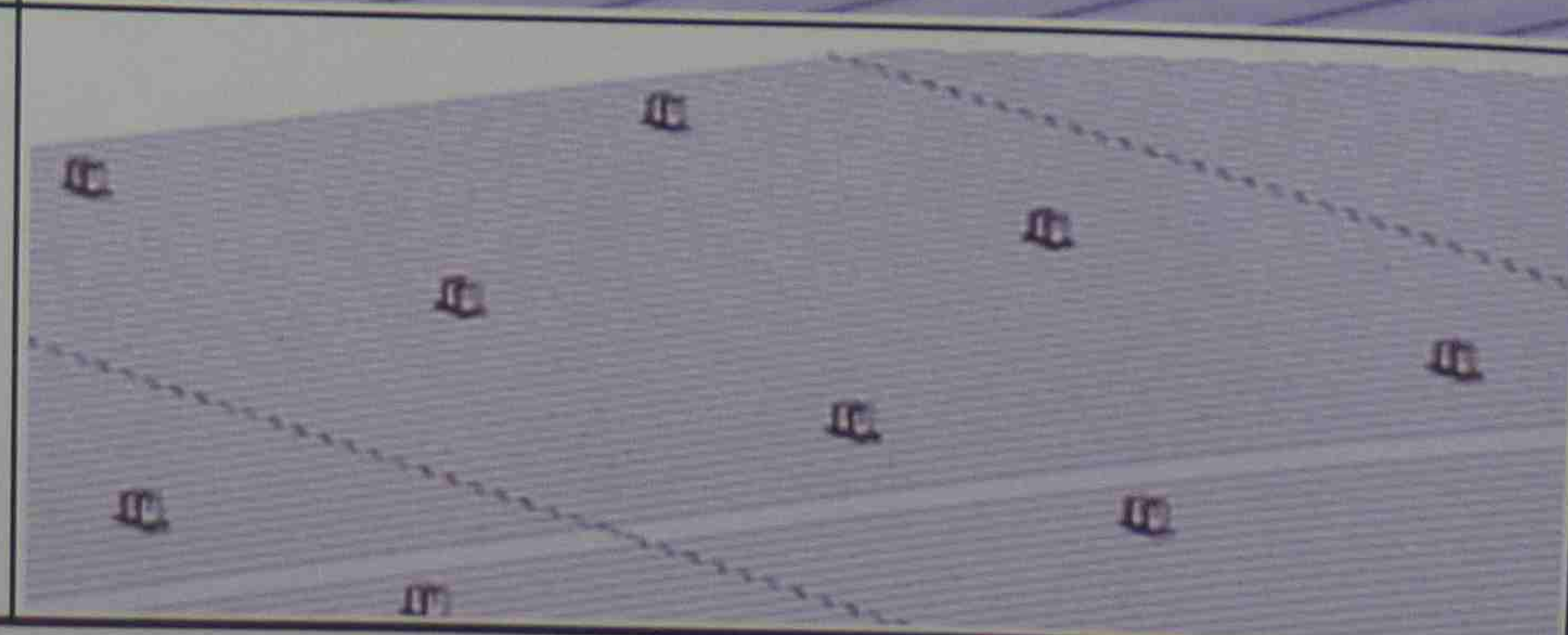


5.4.2 PLANNING THE MODULE AREA

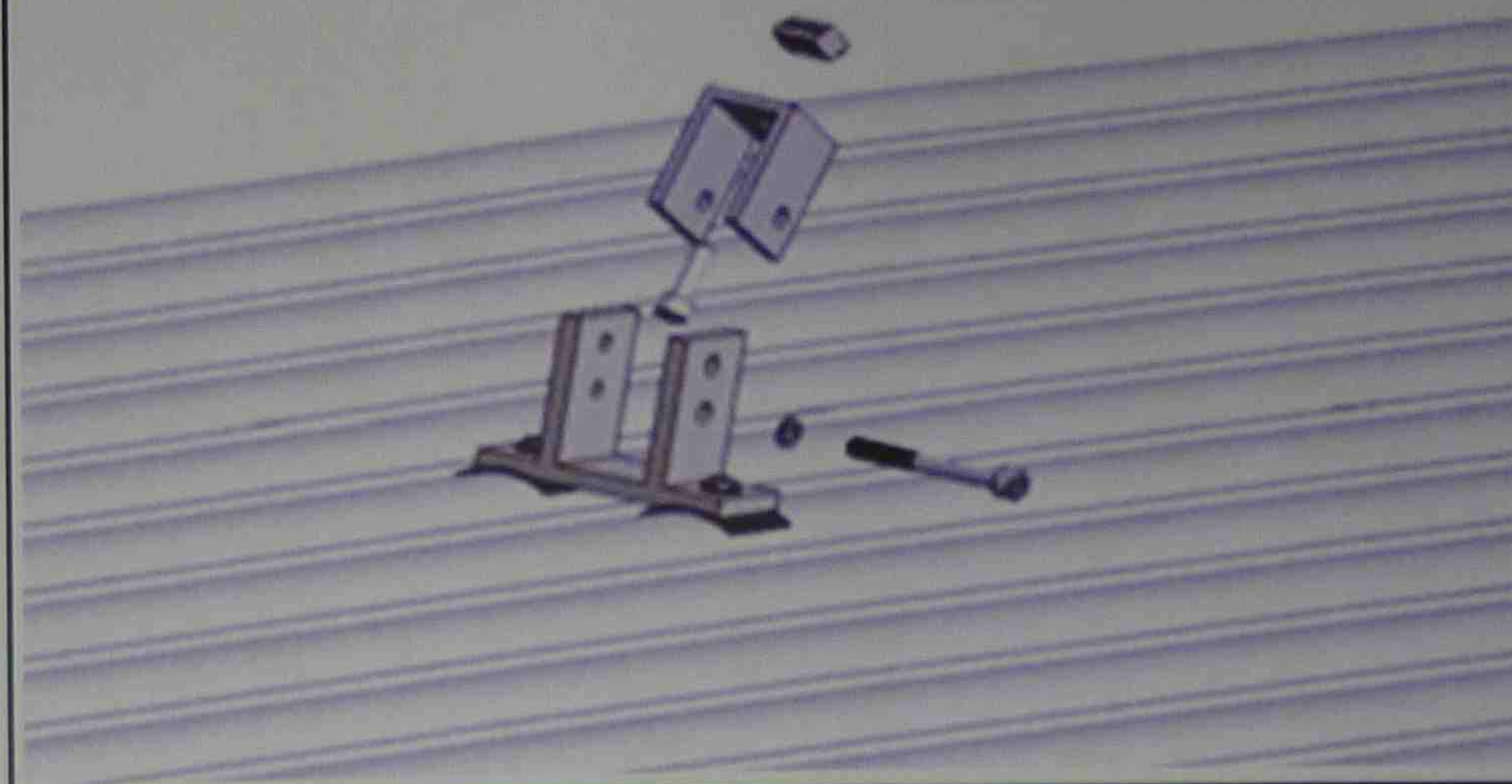
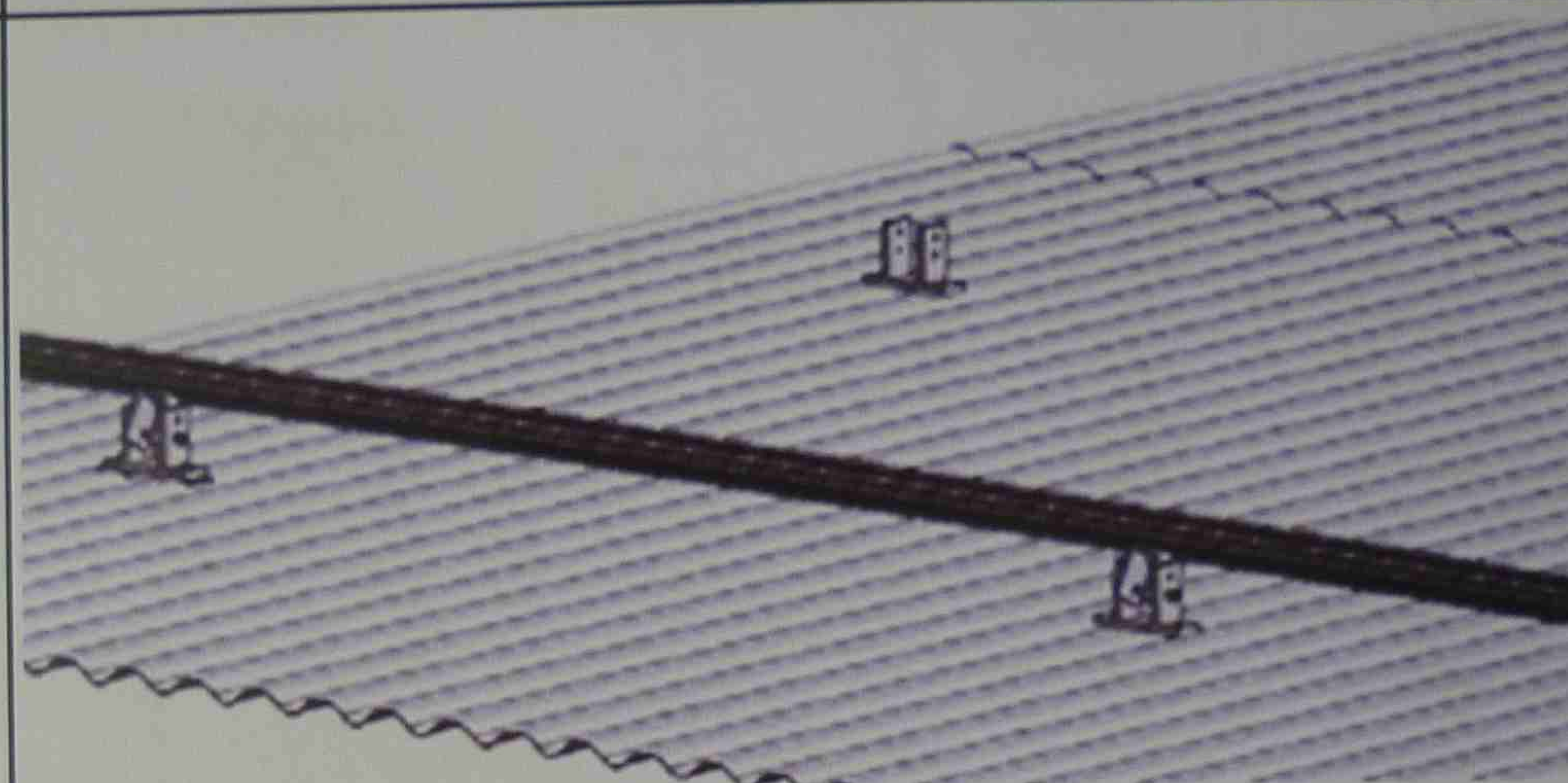
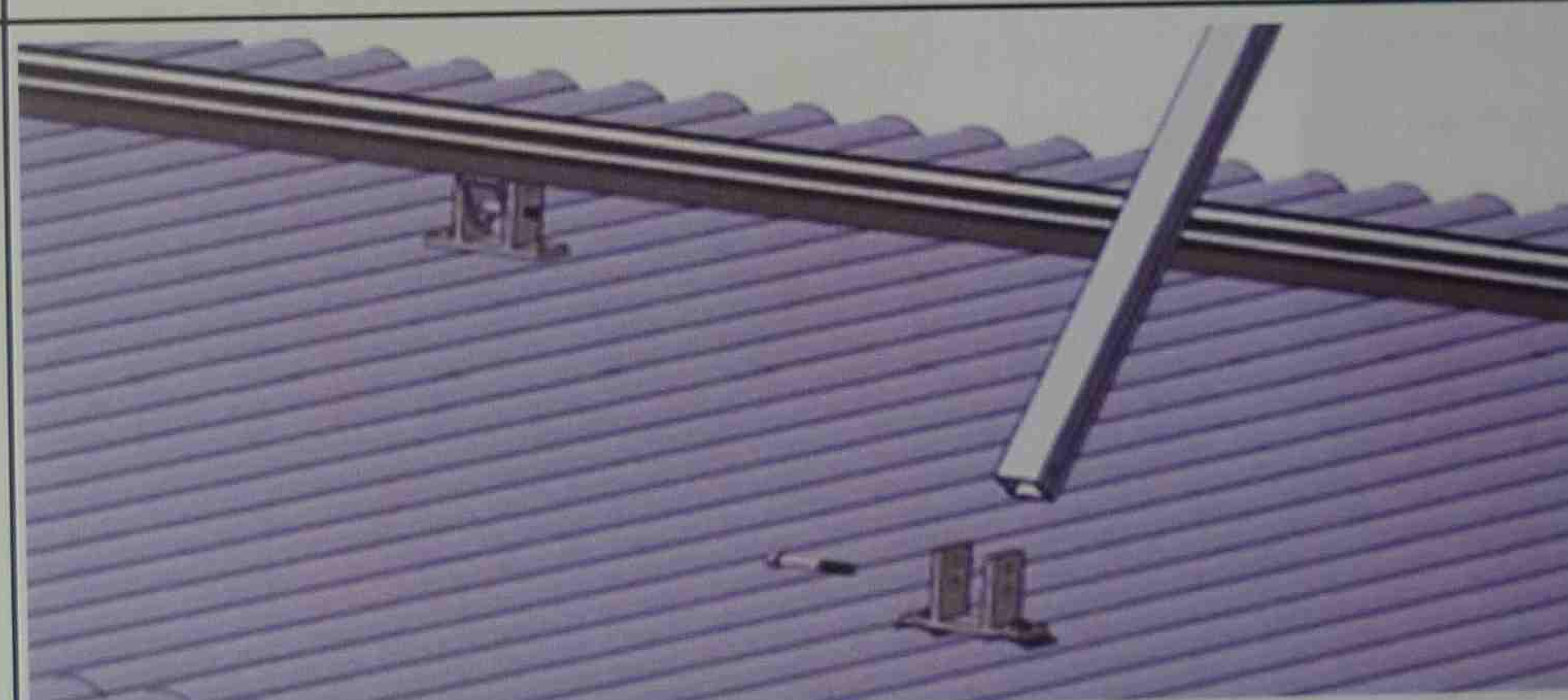
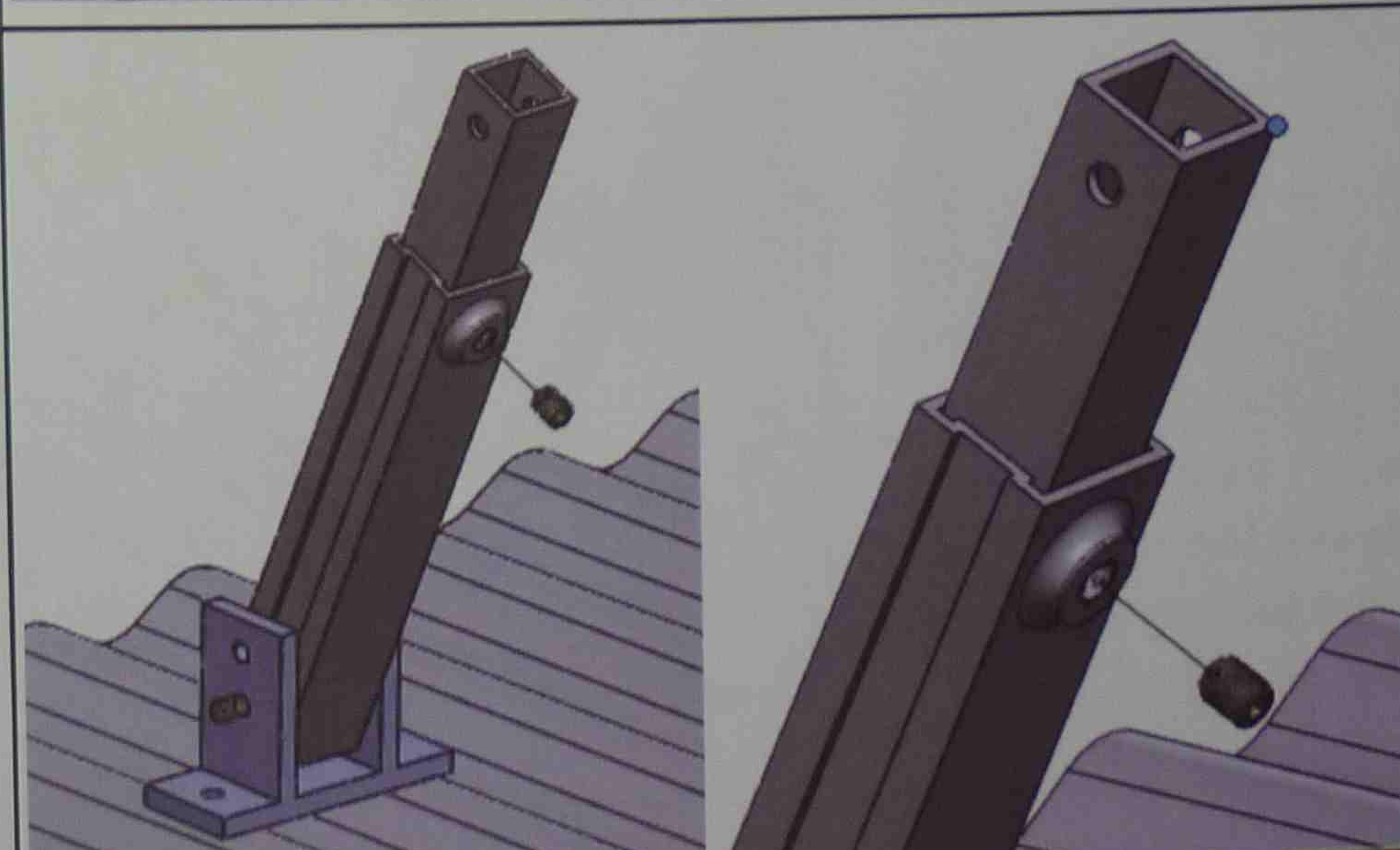
1. Number of modules in the vertical direction x module height (please check also the installation manual of the manufacturer of the solar module)
2. Number of modules in horizontal direction x (module width + 17 mm) + 32 mm
3. Horizontal spacing of the Fix Foot up to 2.0 m*
4. Vertical spacing of the Fix Foot = approx. 1⁄2 to 3⁄4 of module height
5. Distance between the modules: 17mm
6. Distance between 2 strings needs to be calculated based on the location

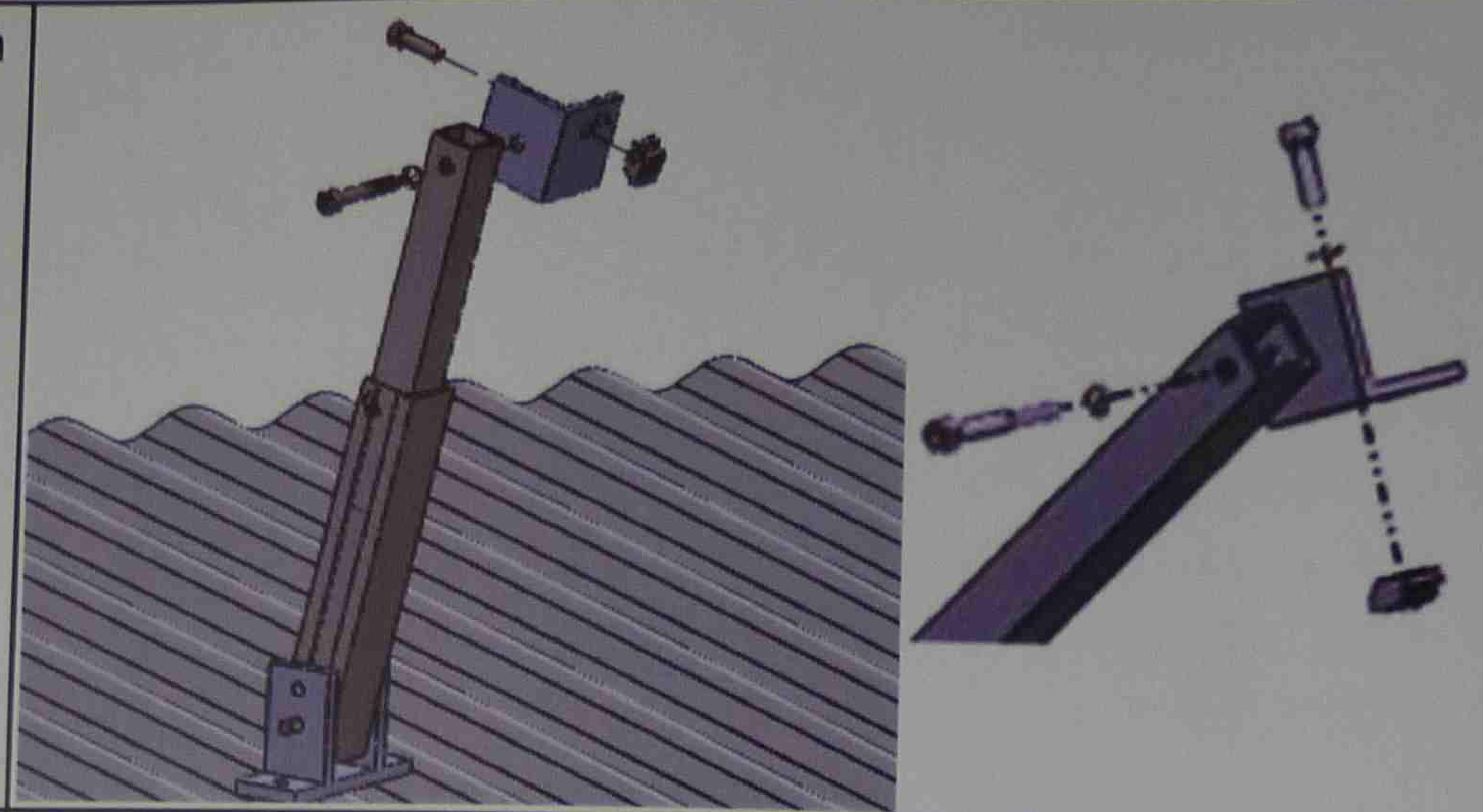
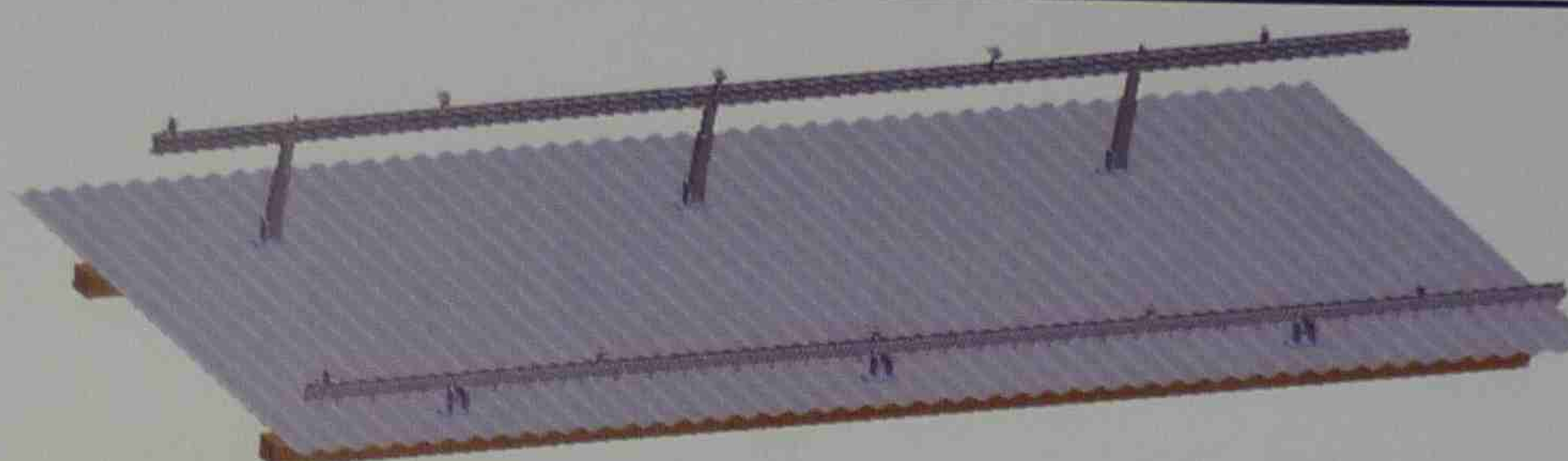
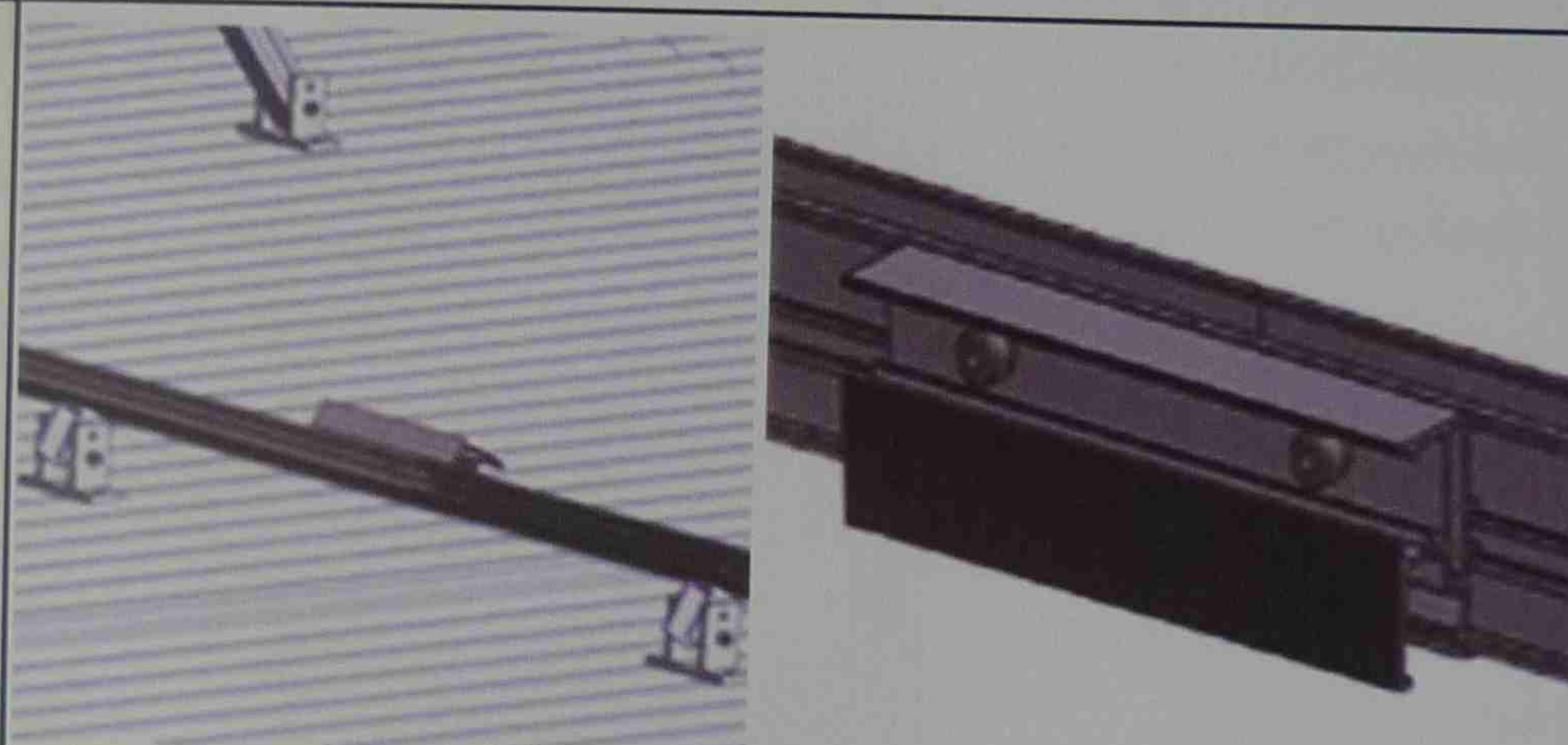
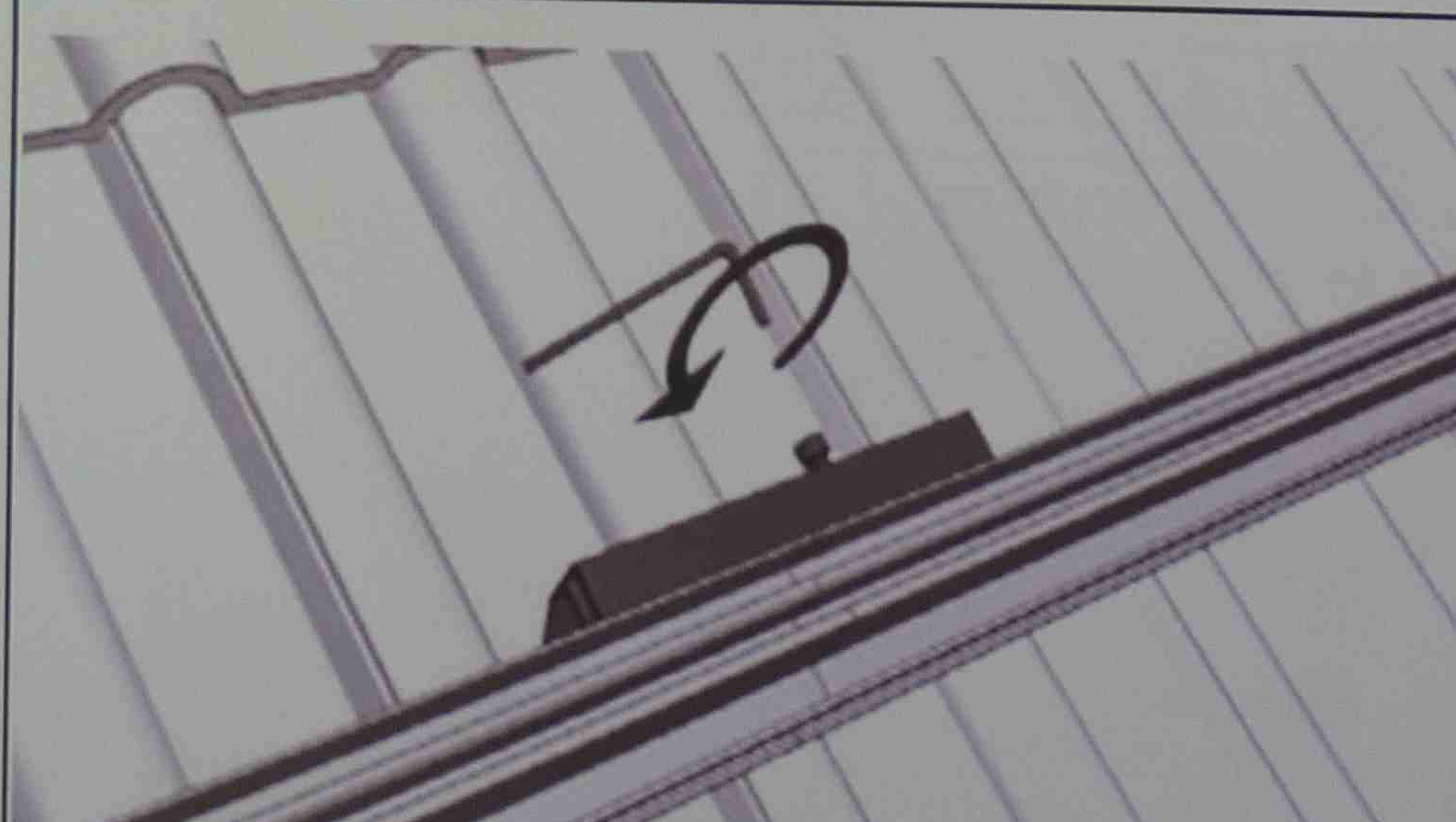
* Caution: Installations that are exposed to the wind or are located on the edge or corners of the roof may make it necessary to leave smaller spaces between modules

5.5 INSTALLATION INSTRUCTION

5.5 Installation Instruction	
1. Determine the positions of the Front Foot according to your plans. Shim the Front Foot with rubber , Fix the Front Foot to the rafter using two 6 x 65 mm wood screws	
2. Fix the Front Foot to the rafter according to your plans.	

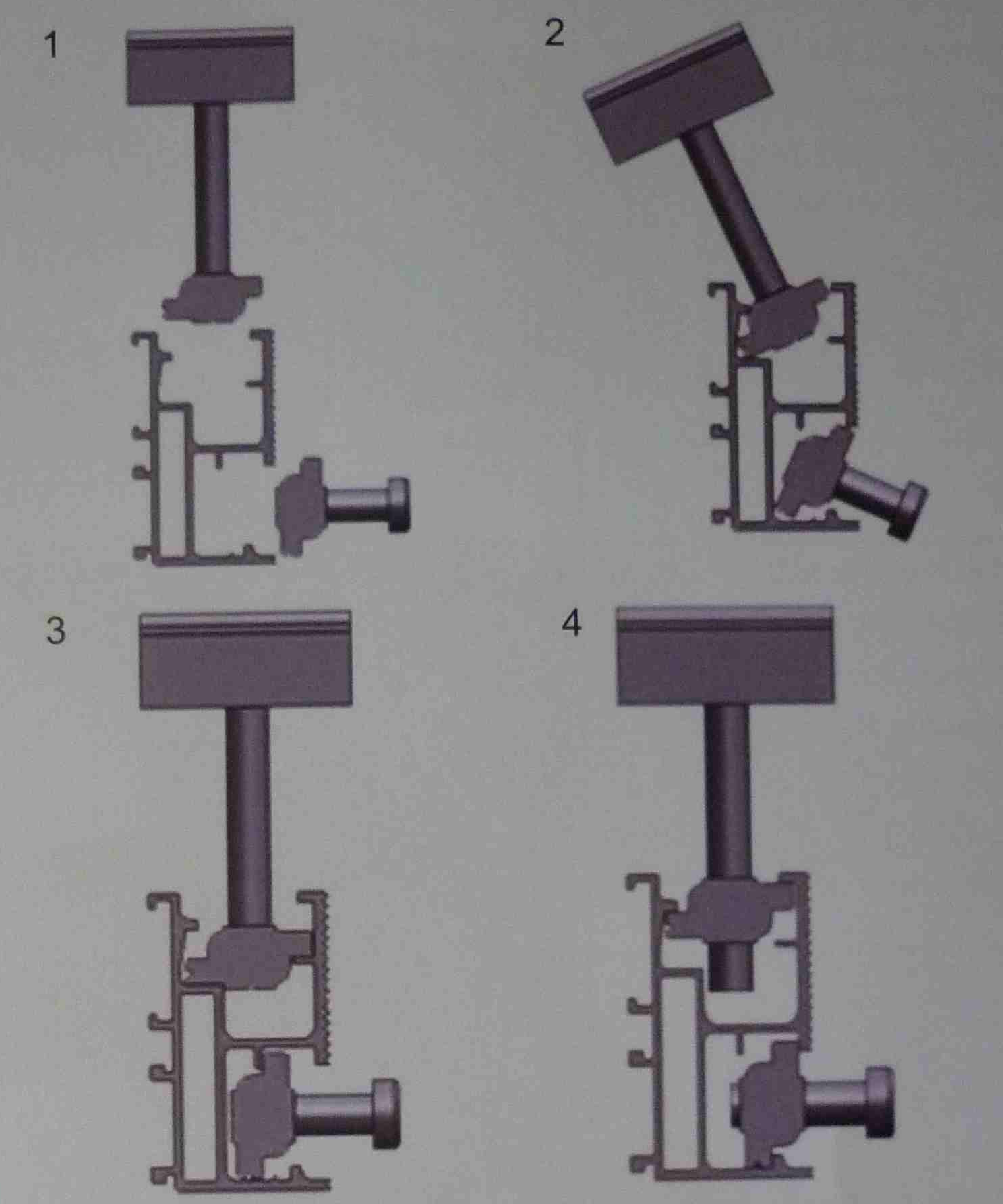
5.5 Installation Instruction (cont'd)

3. Put the U Bracket into the Front foot, It is recommended to mount them just a bit fasten, so it could be adjusted in the mounting and fasten completely. Fix the U Bracket with the Rail by Z module use M8X25mm bolt.	
4. Base rail installation, Position the first frame rails for each row and fasten them temporarily to the roof cladding using a cord. Tighten the Allen bolts on the Z modules that are used to fasten the Front Foot.	
5. Install the Back legs, put the Back Legs into the fix foot and fasten them by M8X55mm bolt.	
6. Adjust the length using 4mm Allen key to fix them by one set screw M8*10mm.	

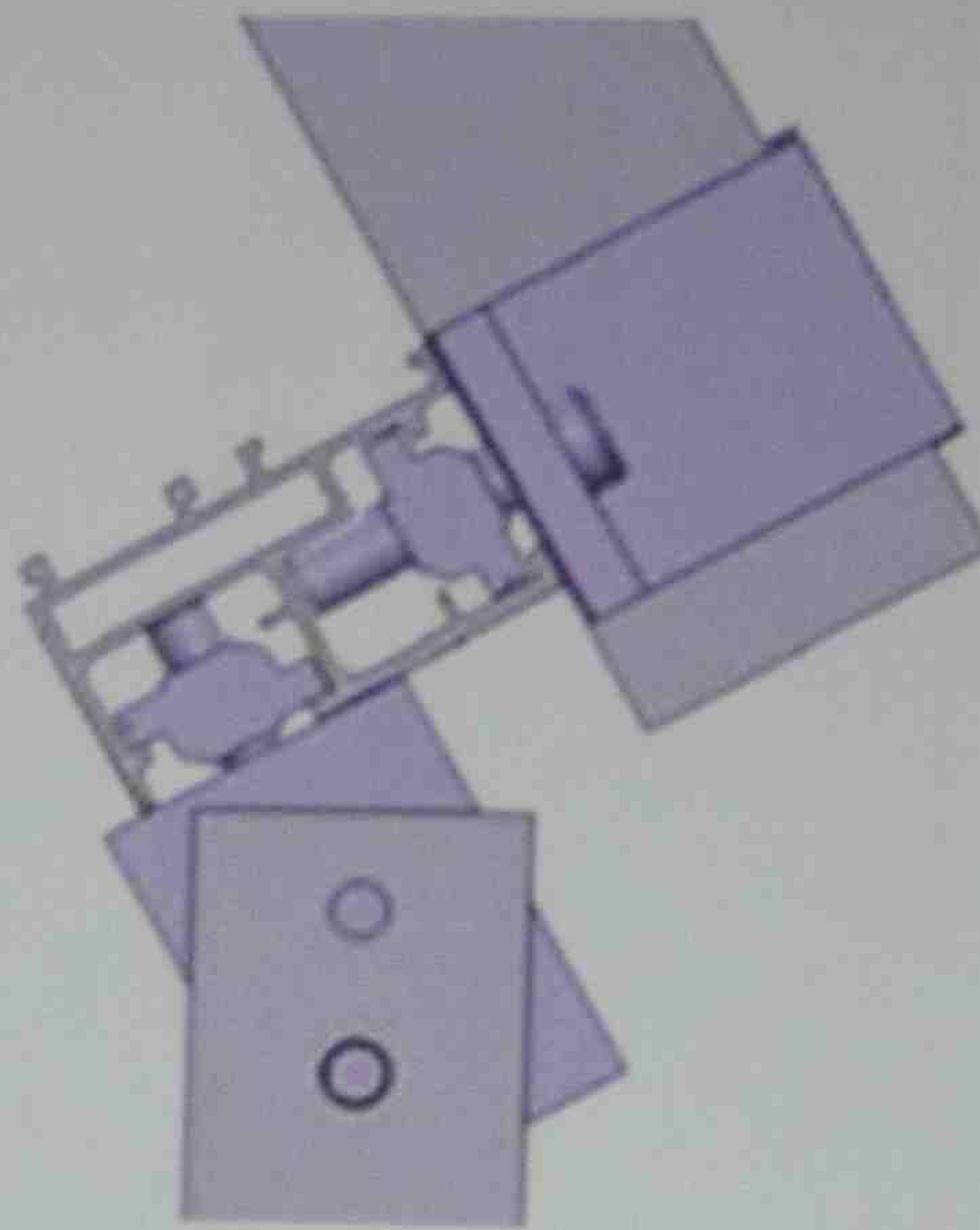
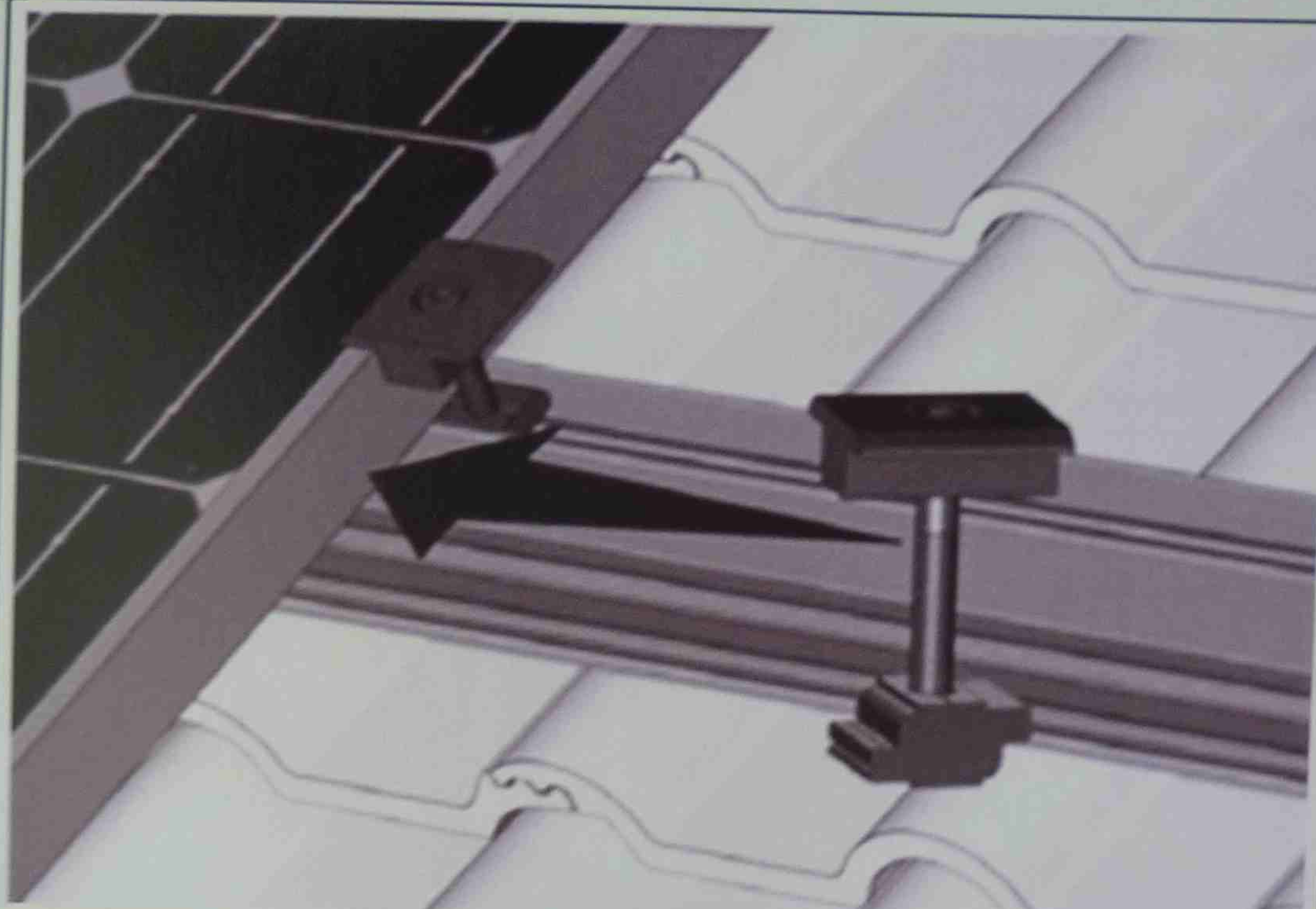
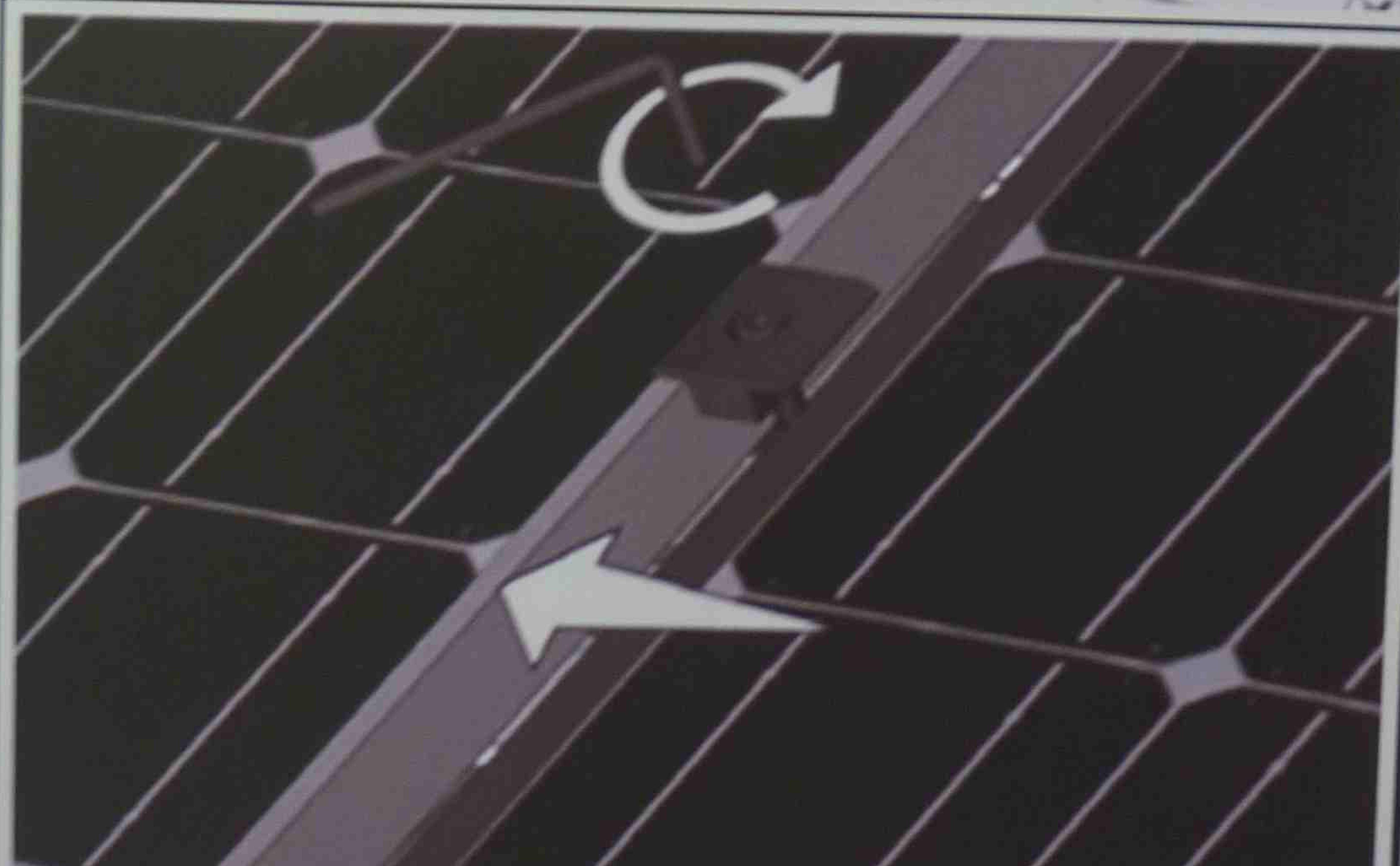
5.5 Installation Instruction (cont'd)	
7. Fix the L Bracket with the Leg tube by using M8X55mm bolt.	
8. Base rail installation, Fix the L Bracket with the base rail by z module use M8x25mm bolt.	
9. To connect multiple rails together, slide the splices on the rear side of the pre-assembled rails halfway to the side. Fasten the first M8 Allen bolt firmly using the Allen key. Now slide the next rail segment into the splice.	
10. Tighten the second M8 Allen bolt using the Allen key. The connection is finished. An expansion gap at the rail joints is recommended. For this purpose, leave a gap about the same width as a finger between the rail joints and then loosely tighten the M8 allen bolt.	

5.5 Installation Instruction (cont'd)

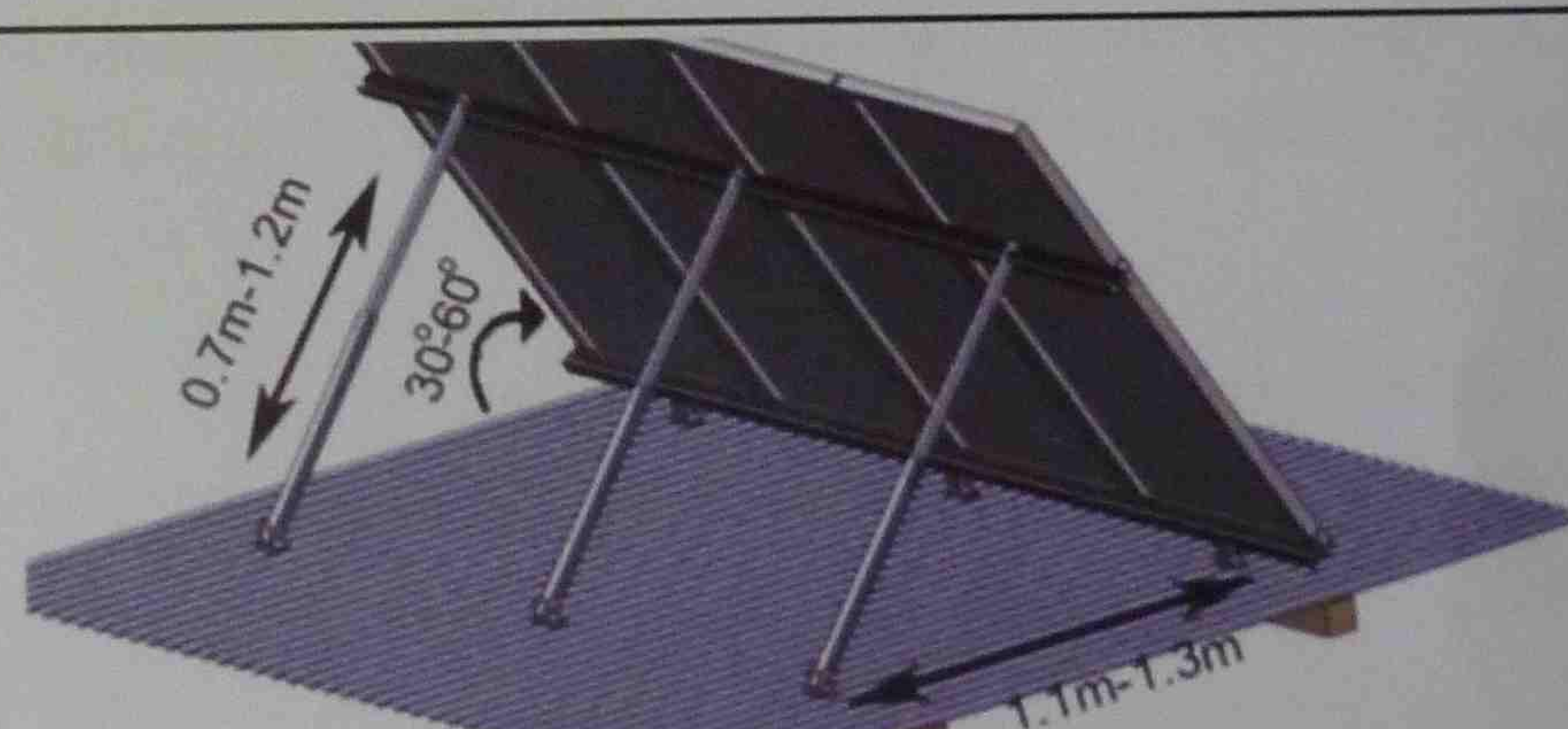
11. For easy use of the Z module, you must make sure that the thread of the screws does not project through the lower side of the Z Module (max. flush). Position the Z Module in the rail channel and fasten it loosely with 2 to 3 turns of the screw. The screws can still be freely moved in the rail channel. Slide the screws to their final position in connection with the inter-module clamp, module end clamp or roof hooks/hanger bolts and fasten firmly (recommended torque is 8 Nm).



12. Slide the module end clamp tightly against the module and fasten tightly using the Allen bolt (recommended torque is 8 Nm). Please take note of Figure 11.

13. Cross-section through the module end clamp when installation step12 has been correctly performed.	
14. Fix the inter-module clamp into the rails from above, place it firmly against the module and fasten loosely (approx. 2 - 3 turns). Please also take note of Figure 11.	
15. Now slide the next module against the previously installed module and tighten the inter-module clamp using the Allen key (recommended torque is 8 Nm). Take care that the anti-slip protection sits in the rail channel of the lowest row of rails.	

5.5 Installation Instruction (cont'd)

10 to 15 degrees.	
15 to 30 degrees.	
30 to 60 degrees.	

5.6 MANUFACTURING AND IMPORTING STANDARDS

Since the advent of the new rebate schemes, the Clean Energy Council has received many enquiries from importers wishing to bring components and entire PV systems into the Country.

There are several requirements to be met:

1. The Australian Standard for Photovoltaic Installations (AS5033)
Currently this Standard states that PV modules shall comply with IEC61215 or IEC61646 and should be should be Class II. Class II is defined in clause 1.4.8. The normative reference to IEC 61829 is for information only.

2. The Australian Standard for Grid-connected Inverters (AS4777)
Grid-connected inverters must comply with AS4777, AS3100 or IEC equivalent and have a current Certificate of Suitability from a state regulator.

3. The Trade Practices Act
We suggest you familiarise yourself with the content of the Trade Practices Act 1974 with regards to importing. Our interpretation includes the need for the importer to provide a warranty as though they were the manufacturer, ensure the goods are of marketable quality and that they are used for the purpose for which they were intended.

Trade Practices Act
http://www.business.gov.au/Business+Entry+Point/Business+TopicsImporting+exporting/

4. The Australian Greenhouse Office requirements for eligibility for rebates.

Each rebate program has its own web pages outlining its requirements in terms of Standards and compliance.

Renewable Remote Power Generation Program (RRPGP)
http://www.greenhouse.gov.au/renewable/rrpgp/

Photovoltaic Power Generation Program .
http://www.greenhouse.gov.au/renewable/pv/index.html

5.7 RELEVANT STANDARDS FOR DESIGN AND INSTALLATION

AS 4509 Stand-alone Power Systems
- part 1 Safety requirements
- part 2 Design guidelines
- part 3 Installation and maintenance

AS 4086 Secondary batteries for SPS
- part 2 Installation and maintenance

AS 5033 Installation of photovoltaic (PV) arrays

If you're a Accredited Installer you MUST have and use a copy of these standards. They can be purchased from www.standards.com.au

Other relevant standards include:
- AS 3000 Electrical Wiring Rules
- AS 1768 Lightning Protection
- ASNZS 1170.2 Wind Loads
- AS 4777 Grid Connections of Energy Systems via Inverters

5.8.1 RELEVANT STANDARDS FOR INSTALLATION

Wiring a grid connected photovoltaic system involves a combination of both a.c. and d.c. so consideration to both the systems will mean that they must comply with the relevant standards AS/NZ 3000, AS/NZ 3008 and AS 5033 Installation of photovoltaic (PV) arrays.

5.8.2 PV CABLES

PV cables should be installed in accordance with the requirements of AS/NZS 3000 and AS 3008. Protection and wiring methods must also comply with the requirements of AS/NZS 5033:2005.

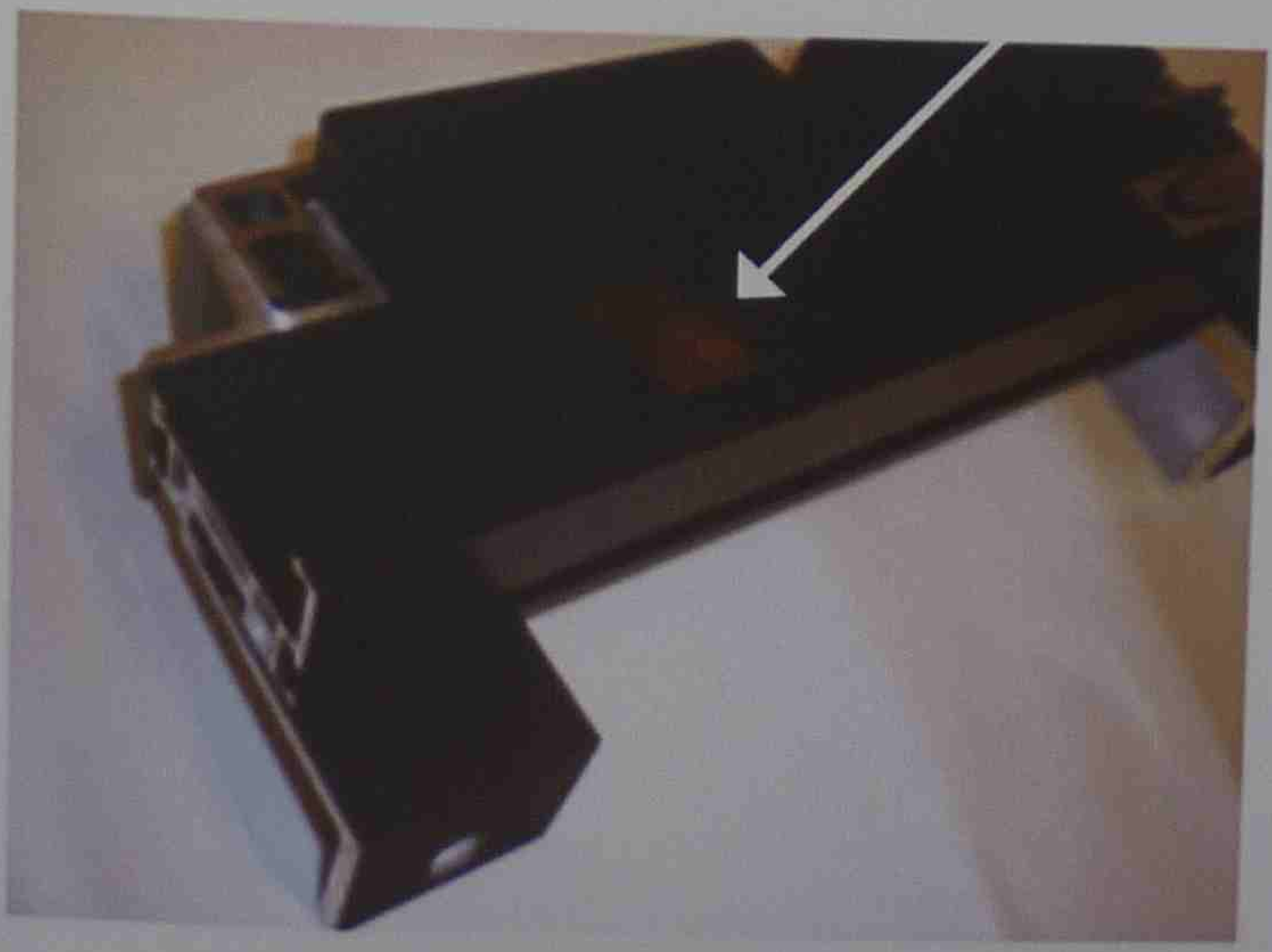
Wiring exposed to weather or those between strings must be enclosed in conduit or be of the sheathed type and have appropriate UV and temperature rating.

The cables used should be those designed for d.c. These cables differ from normal twin insulated in that they are like two double insulated cables joined together by web. This construction allows the cables to be separated without compromise to the double insulation.

This photo shows a d.c. cable separated and the potions of the web still attached to the double insulation.

Where cables are not enclosed and are in a position not likely to be disturbed they should be supported so they do not sag. The use of cable ties is not recommended and a tie which is not affected by ultraviolet and heat should be used.

In the photo below a special built rail is used which has provision for a stainless steel cable clip to be simply clipped into place over the cables.



5.8.3 CONNECTIONS

Connections in d.c. cables should be made with the use of appropriate crimp type terminators. The use of screw type connectors which have the screw bearing down directly on the cables should not be used. When the pressure and the twisting action of the screw are forced down upon the conductors it can alter the crystalline structure of the copper wire and cause a hot spot to occur. This can cause heating of the joint and damage to the cables and conductors. Such a case has the potential to cause serious damage or even fire.

In the photos below such a case has occurred in a very large installation even though double screw connectors were used it still caused thousands of dollars in repairs and down time.

D.C. isolators

Cross hatched is to show where the tile was ground flat to give a flat surface for the back nuts

(B) Entry through a square section tile

Special care must be taken to the technical data application for high rupturing capacity (HRC) fuses with regard to short circuit (SC) faults. Refer to manufacturer's data to ensure that the pre-arcing time does not overlap the arcing time of other fuses in the same circuit.

Care must also be taken when using a combination of HRC fuses and thermal magnetic circuit breakers. The changeover in the time current curves from thermal to magnetic may overlap the curve of the higher rated HRC fuse.

The rating or the circuit protection is that 1.25 x ISC ARRAY is smaller than the trip Rating of the protective device.

For the applications without overcurrent protection refer to table 2.1 AS/NZS 5033:2005.

For location of fault current protection devices refer to table 2.2 AS/NZS 5033:2005

For disconnection device requirements in PV array installations refer AS/NZS5033:2005 table 2.3.

Short circuit protection devices are for the purpose of protecting cables and should be selected in accordance with cables being used.

When protection is used on DC circuits it is important that **the protection devices are rated for DC operation**. It is not appropriate to use AC circuit breakers in the place of DC circuit breakers.

<u>Question 1</u>

A particular module has NOCT 49 Degree C.

(a) What is cell temperature coefficient?

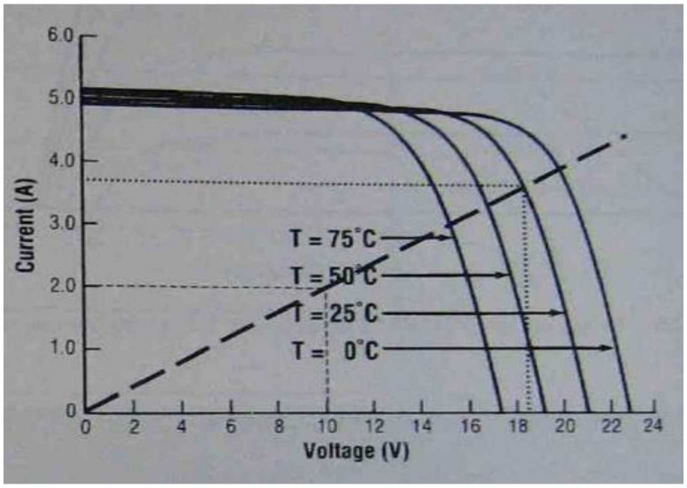
$$k = \frac{NOCT - 20}{800} = \frac{49 - 20}{800} = \frac{29}{800} = 0.03625°C/W - m^2$$

(b) What will be cell temperature if the ambient temperature is 35 Degree C & the irradiance is 65W/m^2

$$Tcell = T_a + \left(\frac{NOCT - 20}{800} \times 65\right) = 35 + \left(\frac{49 - 20}{800} \times 65\right) = 58.8°C$$

Question 2

What would be the output of the module in Figure 27 when connected to the 5.0Ω resistor, if the cell temperature was: 75 °C, 0 °C?



- Temperature 75°C: I_{op}= 3A , V_{op}=15V

$$Power = V_{op} \times I_{op} = 15 \times 3 = 45W$$

- Temperature 0°C: I_{op}= 4A , V_{op}=20V

$$Power = V_{op} \times I_{op} = 20 \times 4 = 80W$$

Question 3

What would be the output current, voltage and power for an SM 55 module connected to a 50 resistance for irradiances of 200W/m^2, 600W/m^2 and 1000W/m^2?

Module/Condition	Voltage	Current	Power
SM55 at 1000W/m2	14	3.35	44.8
SM55 at 600W/m2	14	2	4.2
SM55 at 200W/m2	14	0.65	4.2

Question 4

Find the output of a module operating at its maximum power point given the following data:

- **Typical maximum power at STC=77W**
- **NOCT = 49 °C**
- **Power output coefficient = -0.38%/°C (Note that this value is given a negative sign in most manufacturer's data, with its value as a percentage**
- **Ambient temperature = 35°C**
- **Irradiance = 865W/m^2.**

$$Tcell = T_a + \left(\frac{NOCT - 20}{800} \times G \right) = 35 + \left(\frac{49 - 20}{800} \times 865 \right) = 66.36°C$$

$$P_T = P_{STC} \times (1 - \tau (T_{cell} - T_{STC})) \times \frac{G}{G_{STC}}$$

$$= 77 \times \left[1 - \frac{0.38}{100} (66.36 - 25) \right] \times \frac{865}{1000}$$

$$= 56.1W$$

Question 5

Calculate the daily energy output of a 100W poly-crystalline module operating under the following conditions: maximum power point tracking regulator; ambient day time temperature 25°C; irradiation 5.5kWh/m^2; dusty environment with annual maintenance only. The manufacturer, who tests modules to international standards, guarantees the minimum module power rating to be 95W, and NOCT is 49°C.

$$E_{module} = P_{STC} \times \left[1 - \tau\left(T_{cell} - T_{ref}\right)\right] f_{man} \times f_{dirt} \times H_{daily}$$

P_{STC}=95W, f_{man}=1, f_{dirt}=95%=0.95, H_{daily}=5.5

$$T_{cell} = T_A + k\left(30 H_{daily} + 150\right)$$

$$k = \frac{NOCT - 20}{800} = \frac{49 - 20}{800} = \frac{29}{800} = 0.036$$

$$T_{cell} = 25 + 0.036 \times \left(30 \times 5.5 + 150\right) = 43°C$$

$$E_{module} = P_{STC} \times \left[1 - \tau\left(T_{cell} - T_{ref}\right)\right] f_{man} \times f_{dirt} \times H_{daily}$$

$$= 95 \times \left[1 - \frac{0.05}{100}\left(43 - 35\right) \times 1 \times 0.95 \times 5.5\right]$$

$$= 435 W - hr$$

Question 6

a) **What is the average daily radiation (MJ/m^2) on a north facing collector tilted at the angle of latitude for Brisbane in May?**

Using the table 1, the average daily radiation on a north facing collector tilted at the angle of latitude for Brisbane in May is: 15.9MJ/m^2.

BRISBANE

Latitude: 27 degrees 25 minutes South Longitude: 153 degrees 05 minutes East

Elevation: 6 metres

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
5	3										7	8	2
6	58	18	6	2				1	10	34	75	61	21
7	184	155	116	48	24	15	18	39	152	224	248	222	120
8	368	354	348	314	261	240	235	325	398	421	437	413	343
9	536	538	504	521	455	438	424	526	617	575	576	554	522
10	686	662	631	653	610	587	577	690	772	703	697	688	663
11	785	763	735	711	699	667	654	767	841	784	745	781	742
12	832	808	776	733	670	665	669	797	866	783	774	811	765
13	825	808	794	699	601	632	624	752	823	738	725	779	733
14	754	714	731	616	506	549	539	652	732	640	614	688	645
15	618	587	563	472	387	414	418	504	532	487	460	525	499
16	419	415	379	284	209	224	288	315	351	311	309	341	317
17	223	221	178	65	22	17	29	50	91	129	147	183	113
18	58	50	22	4				2	6	10	26	44	19
19	8	4										6	1
20													
Daily	22.8	22.0	20.8	18.4	15.9	16.0	16.0	19.5	22.4	21.0	21.0	22.0	19.8

Extracted from the Australian Solar Radiation Data Handbook, Table 4.3 for Brisbane.

Table 1 Average total hourly irradiance (W/m^2) and daily total irradiation (MJ/m^2) on a *north facing plane tilted at latitude angle* for each month for Brisbane.

(Source: Lee et al)

b) What is the hourly irradiance at 9am, 12 noon and 3pm in August?

The hourly irradiance at 9am in August is: 526MJ/m^2
The hourly irradiance at 12 noon in August is: 797MJ/m^2
The hourly irradiance at 3pm in August is: 504MJ/m^2

c) What do you notice about the irradiation levels before 8am and after 4pm in all months?

The irradiation levels in this period of time are the lowest values during the day. Between 8am and 4pm are the crucial hours for solar access as the majority of irradiation is received between these hours.

BRISBANE

Latitude 27 degrees 25 minutes South Longitude [illegible] degrees [illegible] minutes East

Elevation [illegible] metres

Plane Azimuth (Degrees)	Plane Inclination (degrees) 0	10	20	30	40	50	60	70	80	90
0	24.1	24.1	23.5	22.4	20.7	18.6	16.0	13.3	10.3	7.6
10	24.1	24.1	23.5	22.4	20.7	18.5	16.1	13.4	10.6	7.9
20	24.1	24.1	23.5	22.4	20.7	18.7	16.3	13.8	11.2	8.8
30	24.1	24.1	23.5	22.4	20.8	18.9	16.7	14.3	11.9	9.7
40	24.1	24.1	23.5	22.8	21.0	19.1	17.1	14.9	12.7	10.6
50	24.1	24.1	23.5	22.5	21.1	19.4	17.4	15.4	13.4	11.5
60	24.1	24.1	23.5	22.5	21.1	19.6	17.8	15.8	13.9	12.0
70	24.1	24.1	23.5	22.5	22.2	19.7	18.0	16.2	14.2	12.4
80	24.1	24.1	23.5	22.5	21.3	19.7	18.1	16.5	14.5	12.7
90	24.1	24.1	23.5	22.5	21.2	19.7	18.1	16.6	14.5	12.7
100	24.1	24.1	23.5	22.5	21.2	19.6	18.0	16.2	14.4	12.6
110	24.1	24.1	23.5	22.4	21.0	19.4	17.7	15.9	14.2	12.4
120	24.1	24.1	23.5	22.3	20.9	19.2	17.3	15.5	13.7	12.0
130	24.1	24.1	23.5	22.3	20.7	18.9	16.9	14.9	13.1	11.4
140	24.1	24.1	23.5	22.3	20.7	18.6	16.4	14.2	12.5	10.7
150	24.1	24.1	23.5	22.3	20.6	18.5	16.0	13.5	11.4	9.8
160	24.1	24.1	23.5	22.3	20.7	18.5	15.9	12.9	10.4	8.9
170	24.1	24.1	23.5	22.4	20.7	18.5	15.9	13.0	9.8	8.0
180	24.1	24.1	23.5	22.4	20.7	18.5	15.9	13.0	9.8	7.6
190	24.1	24.1	23.5	22.4	20.7	18.5	16.0	13.0	9.8	8.0
200	24.1	24.1	23.5	22.4	20.7	18.6	16.0	13.0	10.3	8.9
210	24.1	24.1	23.5	22.4	20.7	18.6	16.3	13.6	11.5	9.8
220	24.1	24.1	23.5	22.4	20.8	18.8	16.6	14.4	12.4	10.7
230	24.1	24.1	23.6	22.5	20.9	19.1	17.1	15.1	13.2	11.3
240	24.1	24.1	23.6	22.5	21.1	19.4	17.6	15.7	13.9	12.1
250	24.1	24.1	23.6	22.6	21.3	19.7	18.0	16.2	14.4	12.6
260	24.1	24.1	23.6	22.7	21.5	20.0	18.3	16.5	14.7	12.8
270	24.1	24.1	23.6	22.7	21.5	20.1	18.4	16.7	14.8	12.9
280	24.1	24.1	23.6	22.7	21.6	20.1	18.4	16.7	14.8	12.8
290	24.1	24.1	23.6	22.7	21.5	20.0	18.3	16.5	14.5	12.5
300	24.1	24.1	23.6	22.7	21.5	19.9	18.1	16.2	14.1	12.1
310	24.1	24.1	23.6	22.7	21.3	19.7	17.8	15.7	13.6	11.5
320	24.1	24.1	23.6	22.6	21.1	19.4	17.4	15.2	12.9	10.8
330	24.1	24.1	23.6	22.5	21.0	19.1	17.0	14.6	12.2	9.9
340	24.1	24.1	23.5	22.4	20.8	18.9	16.5	14.0	11.4	8.9
350	24.1	24.1	23.5	22.4	20.7	18.7	16.2	13.5	10.7	8.0

Extracted from the Australian Solar Radiation Data Handbook, Table 5.1 for Brisbane

Table 2 Average total daily irradiation (MJ/m^2) on an inclined plane during January for Brisbane (Source Lee et al)

BRISBANE

Latitude 27 degrees 25 minutes South Longitude 153 degrees 05 minutes East

Elevation 8 metres

Plane Azimuth (Degrees)	Plane Inclination (degrees)									
	0	10	20	30	40	50	60	70	80	90
0	11.2	13.3	15.6	16.4	17.3	17.8	17.8	17.3	16.4	15.1
10	11.2	13.3	15.0	16.4	17.3	17.7	17.7	17.3	16.4	15.0
20	11.2	13.2	14.9	16.1	17.0	17.4	17.4	16.9	16.0	14.6
30	11.2	13.1	14.6	15.8	16.5	16.8	16.7	16.2	15.2	13.9
40	11.2	12.9	14.3	15.2	15.8	16.0	15.8	15.2	14.3	13.0
50	11.2	12.7	13.8	14.5	15.0	15.1	14.8	14.2	13.2	12.0
60	11.2	12.4	13.3	13.8	14.1	14.0	13.6	13.0	12.1	11.0
70	11.2	12.1	12.7	13.0	13.1	12.9	12.5	11.8	11.0	10.0
80	11.2	11.8	12.0	12.1	12.0	11.8	11.2	10.6	9.8	8.9
90	11.2	11.4	11.4	11.2	11.0	10.5	10.0	9.3	8.6	7.7
100	11.2	11.3	10.7	10.3	9.9	9.3	8.7	8.1	7.4	6.7
110	11.2	10.7	10.1	9.4	8.7	8.2	7.5	6.9	6.3	5.6
120	11.2	10.4	9.5	8.6	7.7	7.0	6.3	5.8	5.3	4.8
130	11.2	10.1	8.9	7.7	6.7	5.9	5.3	4.8	4.4	4.0
140	11.2	9.9	8.4	7.0	5.8	4.9	4.4	4.0	3.8	3.5
150	11.2	9.7	7.9	6.3	4.9	4.0	3.7	3.6	3.4	3.3
160	11.2	9.5	7.6	5.7	4.2	3.5	3.5	3.5	3.4	3.2
170	11.2	9.4	7.3	5.3	3.6	3.5	3.5	3.3	3.4	3.2
180	11.2	9.5	7.2	5.1	3.4	3.5	3.5	3.5	3.4	3.2
190	11.2	9.5	7.3	5.2	3.6	3.5	3.5	3.5	3.4	3.2
200	11.2	9.4	7.5	5.6	4.1	3.5	3.5	3.5	3.4	3.2
210	11.2	9.6	7.8	6.1	4.7	4.0	3.6	3.5	3.4	3.3
220	11.2	9.7	8.2	6.7	5.5	4.7	4.2	3.9	3.7	3.4
230	11.2	10.3	8.6	7.4	6.4	5.6	5.0	4.6	4.2	3.9
240	11.2	10.2	9.2	8.2	7.3	6.6	5.9	5.4	5.0	4.5
250	11.2	10.5	9.8	9.0	8.2	7.6	7.0	6.4	5.9	5.3
260	11.2	10.9	10.4	9.8	9.3	8.7	8.1	7.5	6.9	6.2
270	11.2	11.2	11.0	10.7	10.3	9.8	9.3	8.6	8.0	7.1
280	11.2	11.6	11.7	11.6	11.4	11.0	10.5	9.8	9.0	8.2
290	11.2	11.9	12.3	12.5	12.4	12.2	11.7	11.0	10.2	9.1
300	11.2	12.2	12.9	13.3	13.5	13.3	12.9	12.2	11.3	10.2
310	11.2	12.5	13.5	14.3	14.4	14.4	14.1	13.4	12.4	11.2
320	11.2	12.8	14.0	14.9	15.3	15.4	15.2	14.5	13.5	12.2
330	11.2	13.0	14.4	15.5	16.1	16.4	16.2	15.6	14.6	13.3
340	11.2	13.1	14.7	15.9	16.7	17.1	17.0	16.5	15.5	14.2
350	11.2	13.3	14.9	16.2	17.1	17.6	17.6	17.1	16.2	14.8

Extracted from the Australian Solar Radiation Data Handbook, Table 5.7 for Brisbane

Table 3 Average daily total irradiation (MJ/m²) on an inclined plane in Brisbane during July

Question 7

From the radiation tables for Brisbane, determine the average total daily irradiation received on a collector for the months of January and July if the collector has the following orientations:

a) **Azimuth 45° degrees, tilt angle 20° degrees**

January: Using Table 2, the average total daily irradiation for January is 23.5MJ/m^2.

July: Using Table 3

For azimuth 40° = 14.3MJ/m^2

For azimuth 50° =13.8MJ/m^2

By interpolation, the average total daily irradiation for July is calculated by

$$14.3 - \left[\frac{45-40}{50-40} \times (14.3 - 13.8) \right] = 14.05 MJ/m^2$$

b) Azimuth 270° degrees, tilt angle 40° degrees

January: Using Table 2, the average total daily irradiation for January is 21.5MJ/m^2.

July: Using Table 3, the average total daily irradiation for July is 10.3MJ/m^2.

c) Azimuth 270° degrees, tilt angle 25° degrees

January: Using Table 2

For tilt 20° = 23.6MJ/m^2

For Tilt 30° = 22.7MJ/m^2

By interpolation, the average total daily irradiation for January is calculated by

$$23.6 - \left[\frac{25 - 20}{30 - 20} \times (23.6 - 22.7) \right] = 23.15 MJ / m^2$$

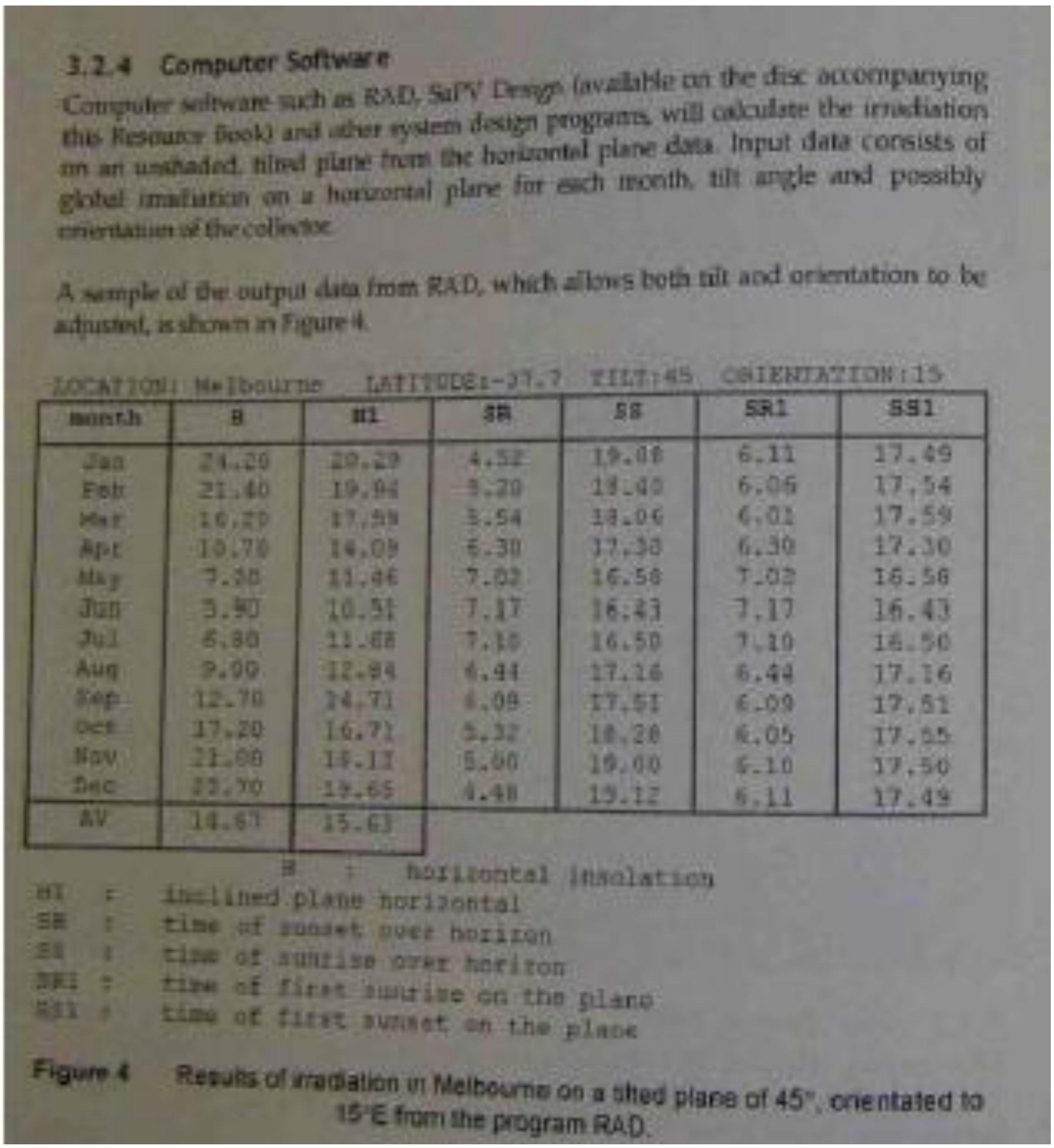
July: Using Table 3

For tilt 20° = 11.0MJ/m^2

For Tilt 30° = 10.7MJ/m^2

By interpolation, the average total daily irradiation for July is calculated by

$$11.0 - \left[\frac{25-20}{30-20} \times (11.0 - 10.7) \right] = 10.85\, MJ/m^2$$



3.2.4 Computer Software

Computer software such as RAD, SaPV Design (available on the disc accompanying this Resource Book) and other system design programs, will calculate the irradiation on an unshaded, tilted plane from the horizontal plane data. Input data consists of global irradiation on a horizontal plane for each month, tilt angle and possibly orientation of the collector.

A sample of the output data from RAD, which allows both tilt and orientation to be adjusted, is shown in Figure 4.

LOCATION: Melbourne LATITUDE:-37.7 TILT:45 ORIENTATION:15

month	H	HI	SR	SS	SR1	SS1
Jan	24.20	20.29	4.52	19.08	6.11	17.49
Feb	21.40	19.94	5.20	18.40	6.06	17.54
Mar	16.20	17.59	5.54	18.06	6.01	17.59
Apr	10.70	14.09	6.30	17.30	6.30	17.30
May	7.30	11.46	7.02	16.58	7.02	16.58
Jun	5.90	10.51	7.17	16.43	7.17	16.43
Jul	6.80	11.68	7.10	16.50	7.10	16.50
Aug	9.00	12.84	6.44	17.16	6.44	17.16
Sep	12.70	14.71	6.09	17.51	6.09	17.51
Oct	17.20	16.71	5.32	18.28	6.05	17.55
Nov	21.00	18.13	5.00	19.00	6.10	17.50
Dec	22.70	19.65	4.48	19.12	6.11	17.49
AV	14.67	15.63				

H : horizontal insolation
HI : inclined plane horizontal
SR : time of sunset over horizon
SS : time of sunrise over horizon
SR1 : time of first sunrise on the plane
SS1 : time of first sunset on the plane

Figure 4 Results of irradiation in Melbourne on a tilted plane of 45°, orientated to 15°E from the program RAD.

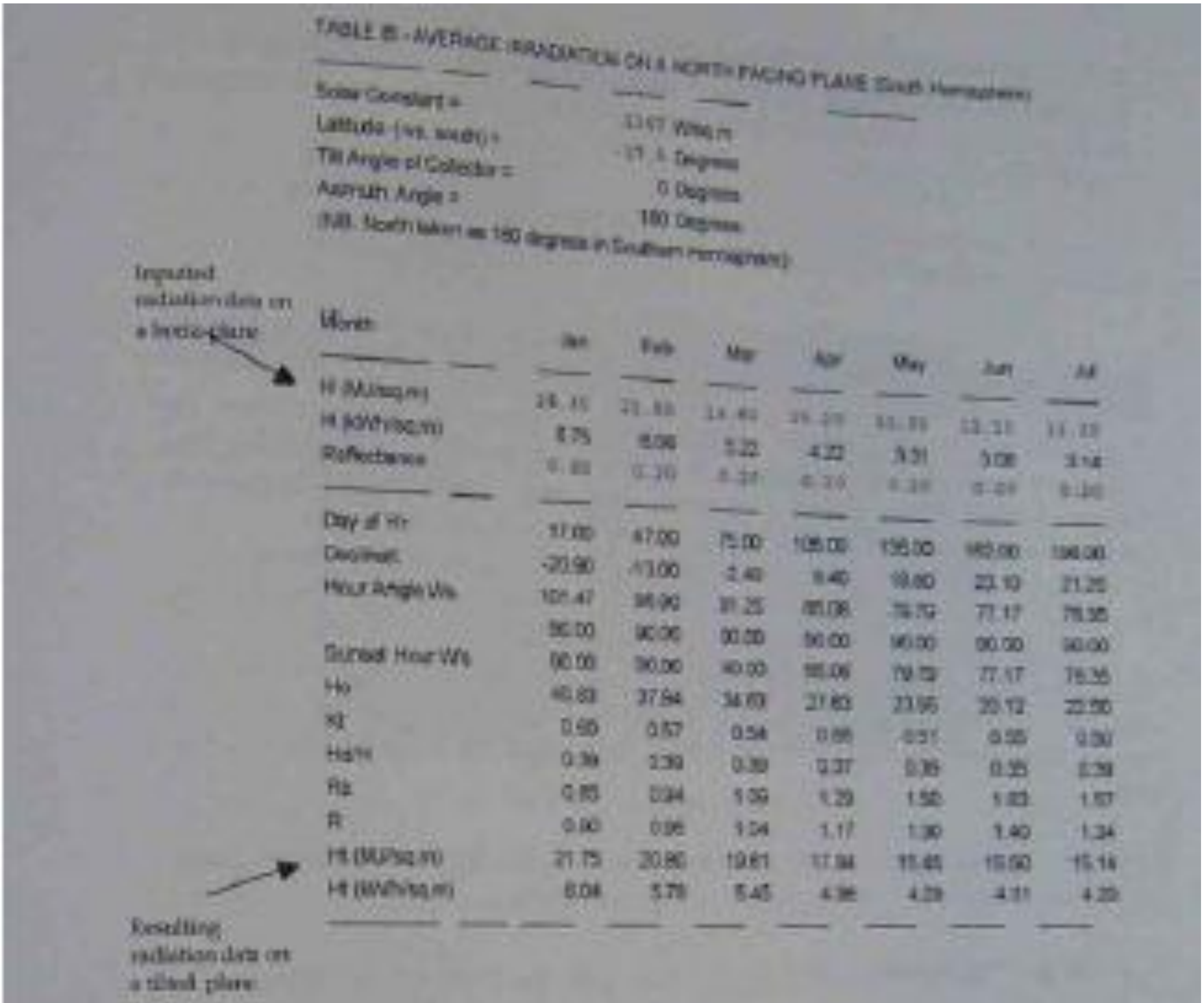


TABLE B - AVERAGE IRRADIATION ON A NORTH FACING PLANE (South Hemisphere)

Solar Constant =
Latitude (-ve. south) = 1367 W/sq.m
Tilt Angle of Collector = -27.5 Degrees
Azimuth Angle = 0 Degrees
(NB. North taken as 180 degrees in Southern Hemisphere) 180 Degrees

Month	Jan	Feb	Mar	Apr	May	Jun	Jul
H (MJ/sq.m)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
H (kWh/sq.m)	8.75	6.06	5.22	4.22	3.31	3.08	3.14
Reflectance	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Day of Yr	17.00	47.00	75.00	105.00	135.00	162.00	198.00
Declinat.	-20.90	-13.00	-2.40	9.40	18.80	23.10	21.25
Hour Angle Ws	101.47	96.90	91.25	85.08	79.79	77.17	78.35
	90.00	90.00	90.00	90.00	90.00	90.00	90.00
Sunset Hour Ws	90.00	90.00	90.00	85.08	79.79	77.17	78.35
Ho	40.83	37.94	34.69	27.83	23.95	20.12	22.50
Kt	0.55	0.57	0.54	0.55	0.51	0.55	0.50
Hd/H	0.34	0.39	0.39	0.37	0.38	0.35	0.39
Rb	0.85	0.94	1.09	1.29	1.50	1.63	1.57
R	0.90	0.96	1.04	1.17	1.30	1.40	1.34
Ht (MJ/sq.m)	21.75	20.80	19.61	17.94	15.45	15.50	15.14
Ht (kWh/sq.m)	6.04	5.78	5.45	4.98	4.29	4.31	4.20

Figure 5 Spreadsheet calculations of irradiation data on an Equatorial Facing Plane tilted at the latitude angle of 27.5° (Source: SOLWATT software)

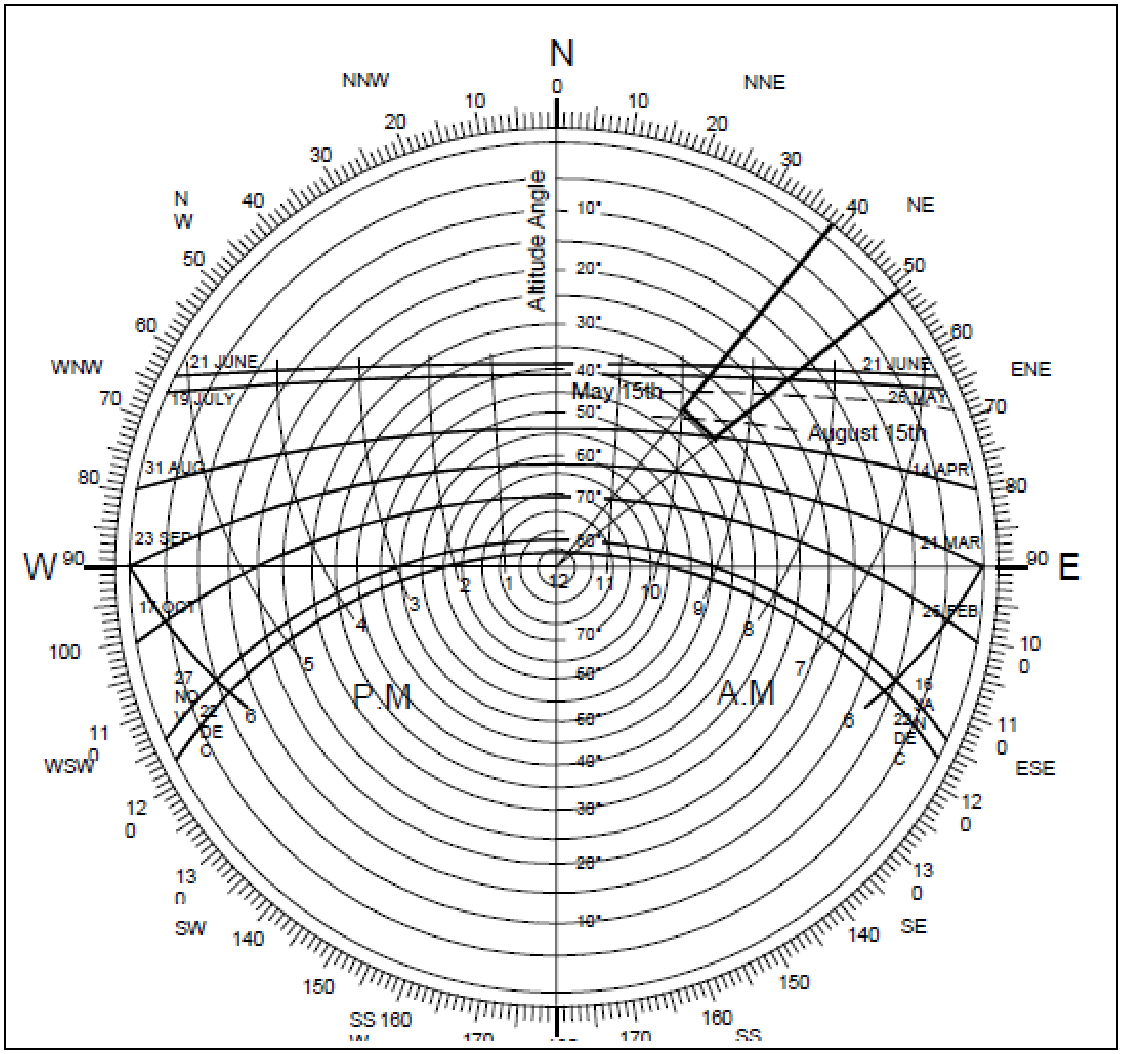


Figure A1.3.11 – Sun path diagram for Brisbane with shading from a tree shown

Question 8

Calculate the solar power arriving on 10 square meters of root area if the irradiance perpendicular to the roof is 1000W/m^2

$$P = G \times A = 1000 \times 10 = 10000W = 10kW$$

Question 9

Calculate the daily solar energy received by a standard hot water collector of dimensions 1m by 2m, in a location which receives 24MJ/m^2 day.

To determine the total solar energy received by an area over a period of time.

$$E = H \times A$$

$$E = a \times A \times t$$

E = Energy received by the collector area (J)
H = Irradiation (J/m^2)
a = Irradiance (W/m^2)
A = collector Area (m^2)
t = The period of time over which energy is received

$$E = H \times A = 24 \times 2 \times 1 = 48mJ$$

Question 10

Calculate the solar energy received by a standard hot water collector of dimensions 1m by 2m, over one hour at round noon, if the irradiance stays fairly constant at about 800W/m^2

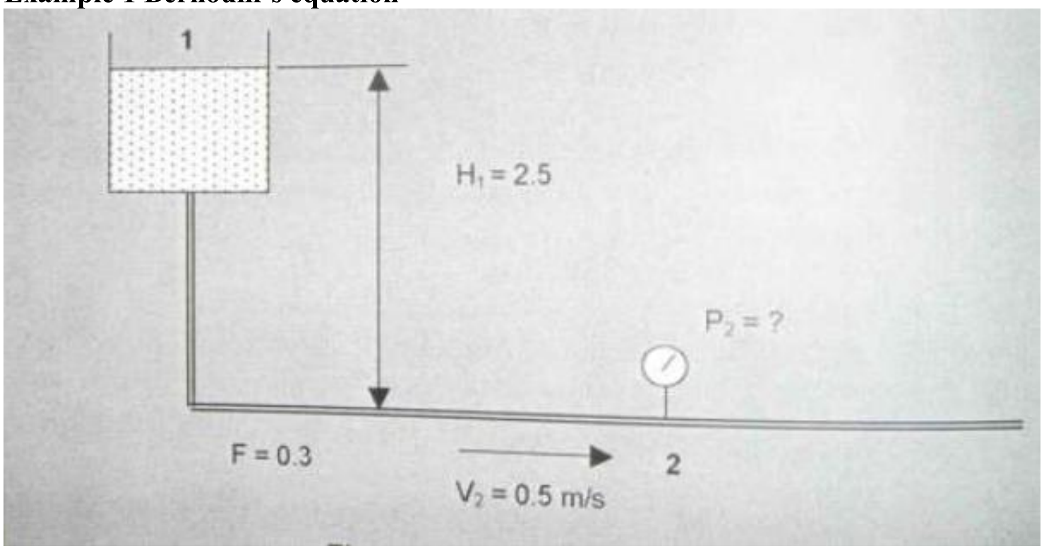
$$E = a \times A \times t$$
$$= 800 \times 1 \times 2 \times 3600$$
$$= 5760000J$$
$$= 5.76mJ$$

Question 11

Losses due to friction can be allowed for by adding a term

$$H_2 + \frac{V_2^2}{2g} + \frac{P_2}{\rho g} + F = H_1 + \frac{V_1^2}{2g} + \frac{P_1}{\rho g}$$

Example 1 Bernoulli's equation



$$H_1 + \frac{V_1^2}{2g} + \frac{P_1}{\rho g} = H_2 + \frac{V_2^2}{2g} + \frac{P_2}{\rho g} + F$$

$$2.5 + \frac{0^2}{2g} + \frac{0}{\rho g} = 0 + \frac{0.5^2}{2g} + \frac{P_2}{\rho g} + 0.3$$

$$2.5 = \frac{0.25}{2 \times 9.81} + \frac{P_2}{1 \times 9.81} + 0.3$$

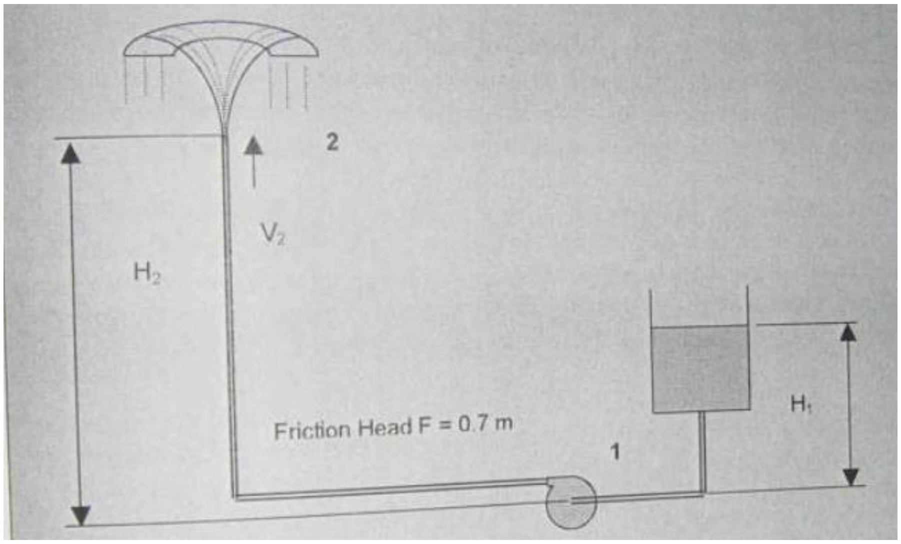
$$2.5 = 0.0127 + 0.3 + \frac{P_2}{9.81}$$

$$2.1873 = \frac{P_2}{9.81}$$

$$P_2 = 21.45 kPa$$

Question 12

Example 2 Pumping Head



Calculate Pumping Head P_1

$$H_1 + \frac{V_1^{\,2}}{2g} + \frac{P_1}{\rho g} = H_2 + \frac{V_2^{\,2}}{2g} + \frac{P_2}{\rho g} + F$$

$$0.5 + \frac{0^2}{2g} + \frac{P_1}{1 \times 9.81} = 3 + \frac{2^2}{2 \times 9.81} + \frac{0}{\rho g} + 0.7$$

$$0.5 + \frac{P_1}{9.81} = 3 + \frac{4}{2 \times 9.81} + 0.7$$

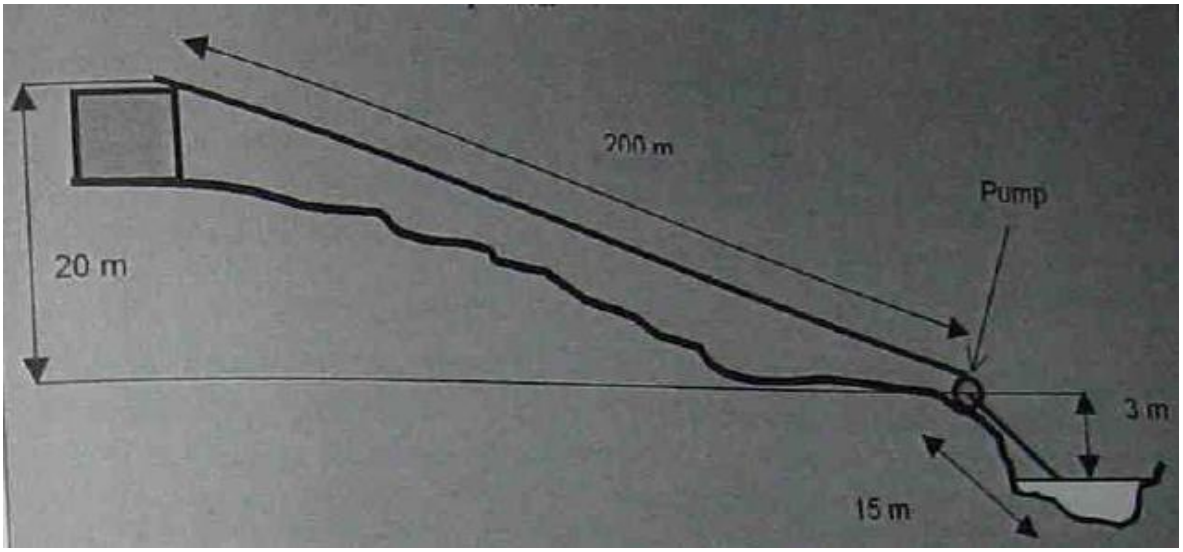
$$\frac{P_1}{9.81} = 3 + \frac{4}{2 \times 9.81} + 0.7 - 0.5$$

$$P_2 = 9.81 \times 3.4 = 33.35 kPa$$

<u>Question 13</u>

Example 4 Total Head

The pump shown in Figure 5 below is lifting water from a dam at a rate of 3600L/hr to a storage tank 200m away. Select a suitable pipe size and determine the total head against which the pump must operate.



From friction loss table
Flow rate/m/s
Pipe diameter 50mm
Velocity =0,6m/s
Friction loss=1m/100
For (200+15)=215m, V_1=0.6m/s

$$flow = 3600L/hr = \frac{3600}{3600} L/s = 1L/s$$

$$\frac{\pi D^2}{4} \times V = Q(L/s)$$

$$\frac{\pi D^2}{4} \times V = 1$$

$$H_1 + \frac{V_1^2}{2g} + \frac{P_1}{\rho g} = H_2 + \frac{V_2^2}{2g} + \frac{P_2}{\rho g} = Total\ Head$$

$$\therefore Friction\,Loss = 2.2m$$

$$H_1 = 20m + 3m = 23m$$

$$\therefore Velocity\ Head = \frac{V_1^2}{2g} = \frac{0.6^2}{2 \times 9.81} = 0.02m$$

$$\therefore Total\ Head = 2.2 + 23 + 0.02 = 25.22m$$

Question 14

A solar module has NOCT of 49 C. What is cell temperature coefficient? What will be it's cell temperature if ambient temperature is 45 C and irradiance 75W/m^2.

$$T_{cell} = T_a + k \times G$$

T_{cell} = The cell temperature for the module (C)
T_a= The ambient air temperature (C)
K = cell temperature coefficient (C/W-m^2)
G = Irradiance (W/m^2)

$$k = \frac{T_{cell} - T_a}{G} = \frac{49 - 45}{75} = 0.053\ °C/W - m^2$$

Question 15

What are electrical, mechanical and thermal requirement of solar cell

(a) Electrical. Test for

- Isolation/ isolation rating
- I-V performance curve

(b) Mechanical. Tests are carried out to determine

- Resistance to impact
- Robustness of electrical terminals
- Rigidity of frame (twisting/bending)
- Wind loading (in excess of 200 km/hr)

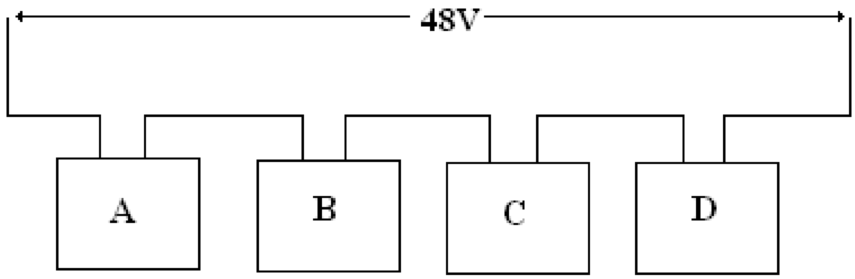
(c) Thermal. Test for

- Hot spot endurance test (to determine the effect of shading & cell overheating)
- NOCT determination

Question 16

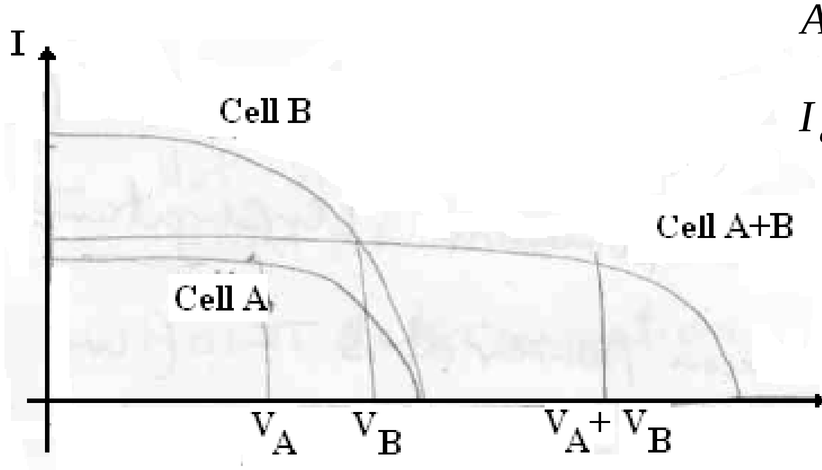
Sketch the interconnection diagram of solar modules and explain the mismatch losses. How can it be avoided?

- **Interconnection of modules**



Average Operating Current

$$I_{co} = \frac{I_{ao} + I_{bo}}{2}$$



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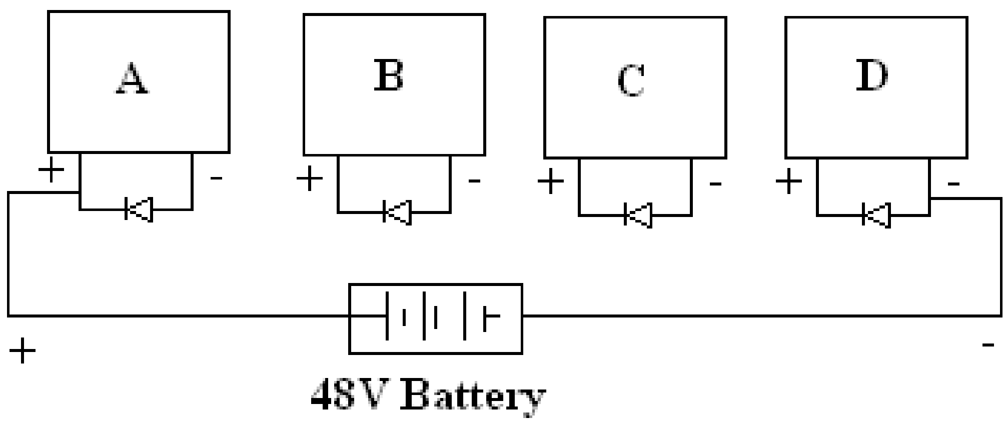
- **Mismatch Losses**

  The output of each series string of cells or modules is limited to the weakest one.

- **Shading & power dissipation**

  When part of a group of series connected modules is shaded, the unshaded cells in each of the modules will be trying to develop higher current than the shaded cells are able to develop. To avoid over loading, shunt connected diode is applied.



Question 17

Find the output power of a module operating maximum power point giving the followings that

- **typical maximum power at STC=87W**
- **NOCT -49°C**
- **Power output coefficient =-0.38%**
- **Ambient temperature =35°C**
- **Irradiance =865 w/m^2**

$$P_{STC} = 77W \quad \gamma = -0.38\%$$

$$T_A = 35°C \quad a = 865W/m^2$$

$$G_{STC} = 1000\,W/m^2 \quad T_{STC} = 25°C$$

$$P_T = 77 \times (1 - 0.38(T_{Cell} - 25)) \times \frac{865}{1000}$$

$$T_{Cell} = T_A + \frac{NOCT - 20}{800} \times G$$

$$= 35 + \frac{49 - 20}{800} \times 865$$

$$= 66.36$$

$$P_T = 77 \times (1 - 0.38(66.36 - 25)) \times \frac{865}{1000}$$

$$= 56.1W$$

Question 18

Calculate the daily energy output of a 100W poly crystalline module operating under the following conditions. Maximum power point tracking regulator MPPT, ambient temperature =25°C, Irradiation = 5.5kWH/m^2. The manufacturer who test the modules to international standard guarantees that the maximum module power rating to be 95W and NOCT=49°C and y=0.5%

$$E_{module} = P_{STC} \times \left[1 - \tau \left(T_{cell} - T_{ref}\right)\right] f_{man} \times f_{dirt} \times H_{daily}$$

P_{STC}=95W, f_{man}=1, f_{dirt}=95%=0.95, H_{daily}=5.5

$$T_{cell} = T_A + k\left(30 H_{daily} + 150\right)$$

$$k = \frac{NOCT - 20}{800} = \frac{49 - 20}{800} = \frac{29}{800} = 0.036$$

$$T_{cell} = 25 + 0.036 \times \left(30 \times 5.5 + 150\right) = 43°C$$

$$E_{module} = P_{STC} \times \left[1 - \tau \left(T_{cell} - T_{ref}\right)\right] f_{man} \times f_{dirt} \times H_{daily}$$

$$= 95 \times \left[1 - \frac{0.05}{100}\left(43 - 35\right) \times 1 \times 0.95 \times 5.5\right]$$

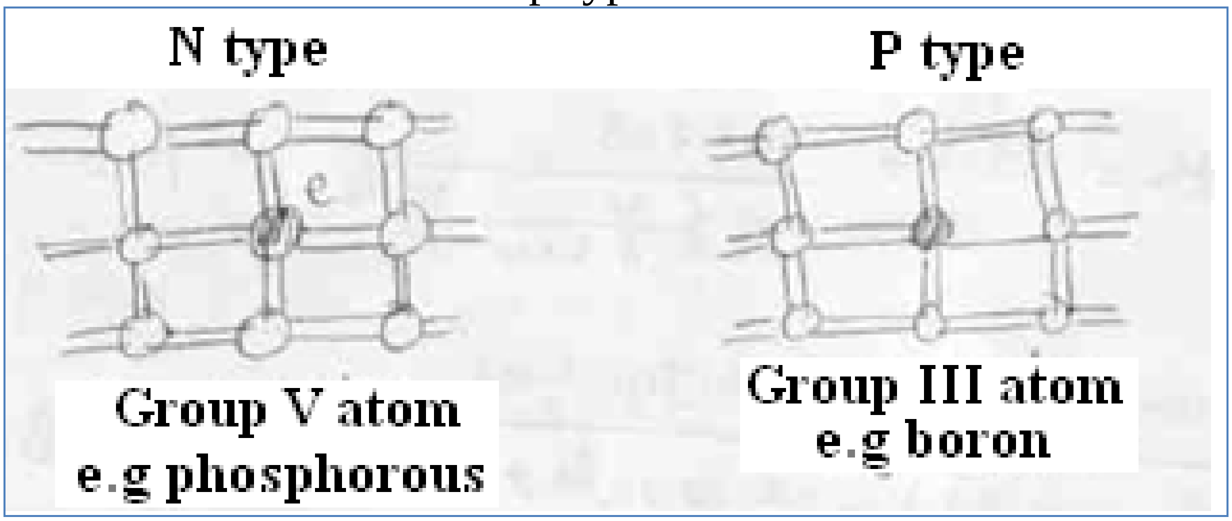
$$= 435W - hr$$

Question 19

Explain the followings

(i) Doping.

It is possible to shift the balance of electrons and holes in a silicon crystal lattice by doping it with other atoms. Atoms with one more valance electron than silicon an used to produce n type semiconductor material. Atom with one less valance electron result in p-type material.



(ii) Crystalline Silicon.

Ordered crystal structure

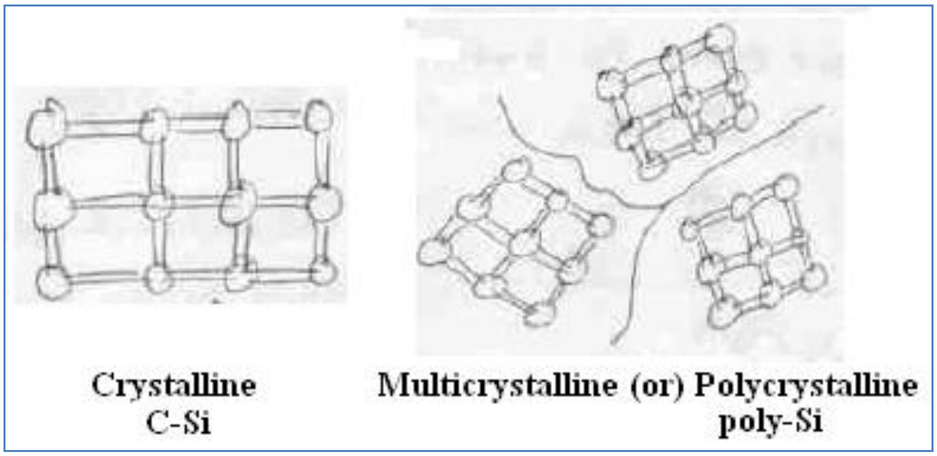
Each atom ideally lying in a pre-ordained position

Predictable and uniform behaviour

Most expensive type

Careful and slow manufacturing process required

(iii) Polycrystalline Silicon



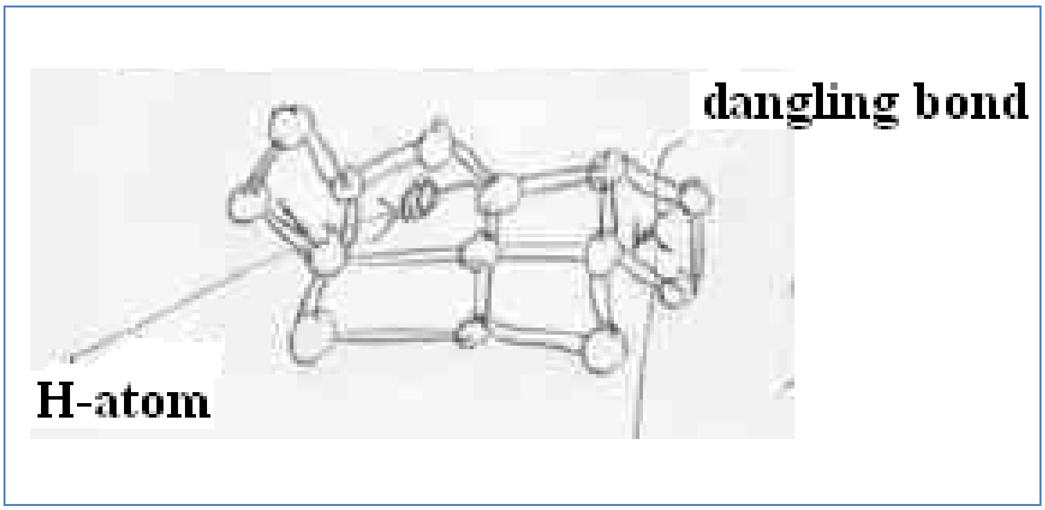
Regions of crystalline Si separated by grain boundaries where bonding is irregular

(iv) Amorphous

Like a liquid with less regular arrangement of atoms leading to internal dangling bonds.

Extra energy level with the forbidden gap

Making it impossible to dope the semiconductor when pure or to obtain reasonable carrier flow in a solar cell configuration.



Question 20

Express the equation for

(a) Dark characteristics

$$I_0 = A\left[\frac{qD_e n_1^1}{L_e N_A} + \frac{qD_h n_1^2}{L_h N_D}\right]$$

q = charge
L_h = difussion density
L_e = exposed length
A = crossectional area of diode
N_A = No. of acceptor electron
N_D = No. of donor electron

(b) Illuminated characteristics

$$I_L = qAG(L_e + W + L_h)$$

W= plate separation

A = crossectional area of diode

q = charge

G = Irradiance

Question 21

Explain the followings

(a) Solar irradiance

The rate at which solar energy strikes a surface. Intensity or the solar power (the power per unit area). On a clear day, around noon, the solar irradiance on a surface facing the sun will be about $1000W/m^2$ (or) $1kW/m^2$.

(b) Solar irradiation (Industry term – insolation)

The solar energy which strikes a surface over a period of time. In most places in Australia, for any month of the year the average daily irradiation on a horizontal surface will be between about $3kWh/m^2$ and $6kWh/m^2$.

(c) Black body

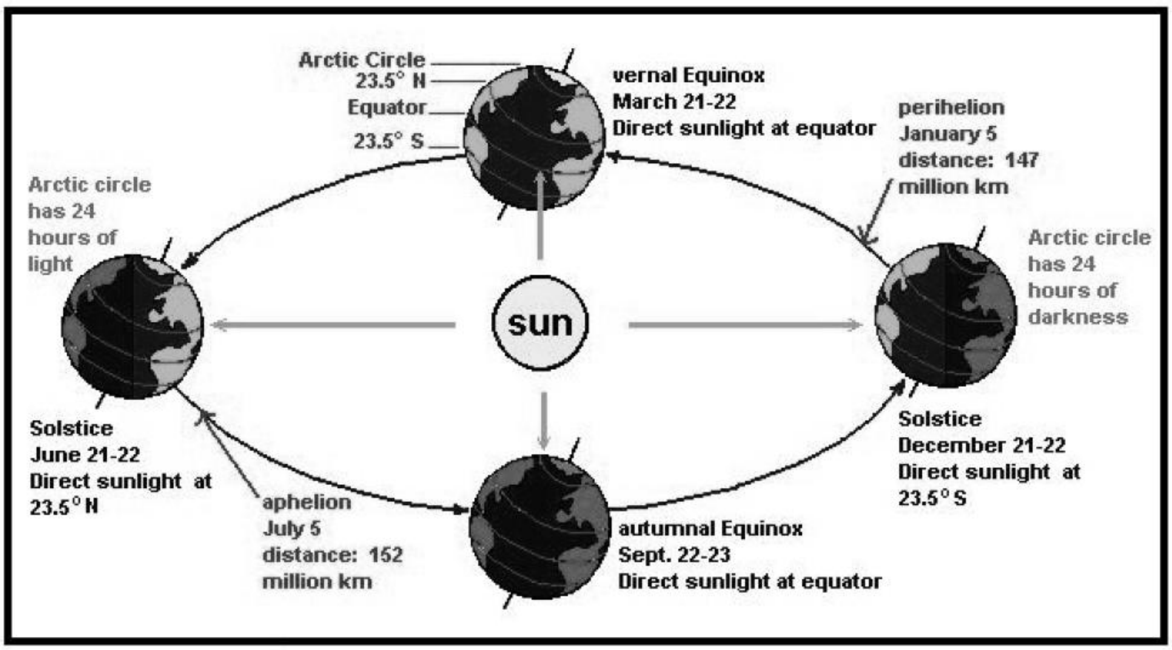
A black body is an ideal absorber, and emitter of radiation. As it is heated, it starts to glow, that is, to emit electromagnetic radiation.

Question 22

Sketch the solar geometry diagram for Australia

<u>Australia</u>

March 2/ Equinox
June 22 Winter
September 23 – Spring Equinox
December 21 – Summer Solstice



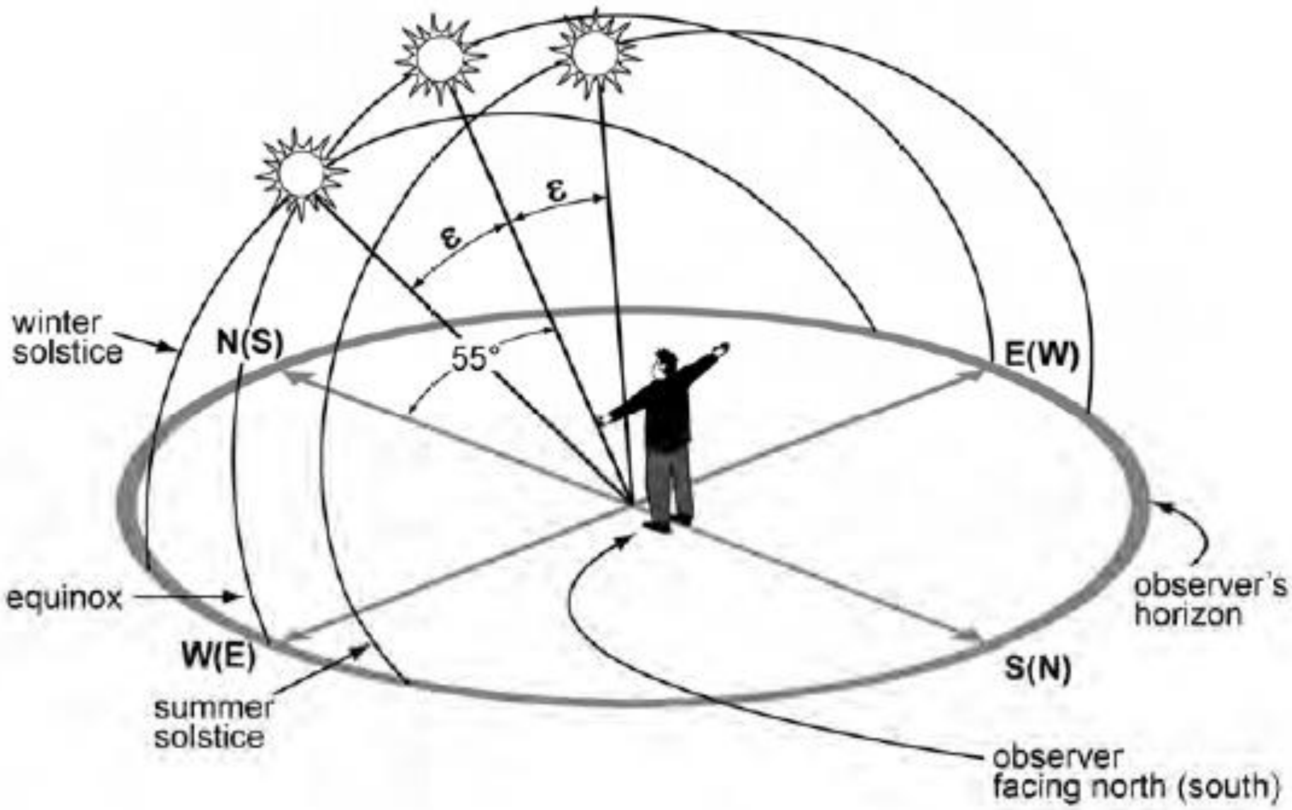


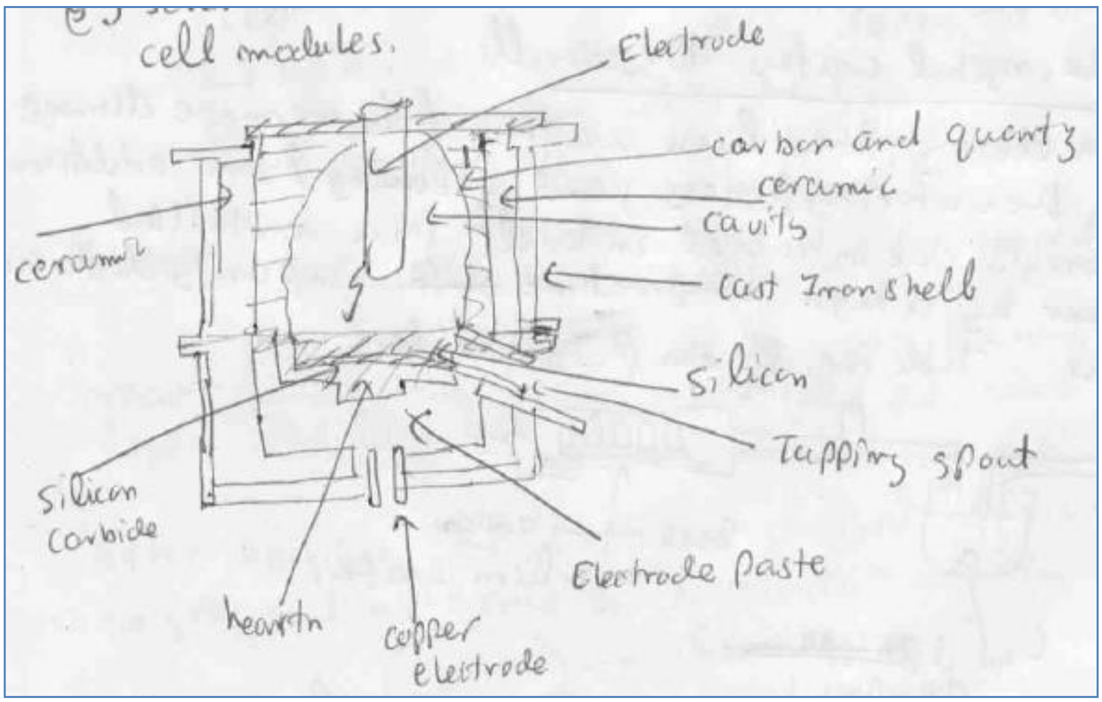
Figure 1.10. Apparent motion of the sun for an observer at 35°S (or N), where ε is the inclination of the earth's axis of rotation relative to its plane of revolution about the sun (= 23°27' = 23.45°).

Question 23

Describe the process to manufacture the solar cell

Standard Technology for making cells

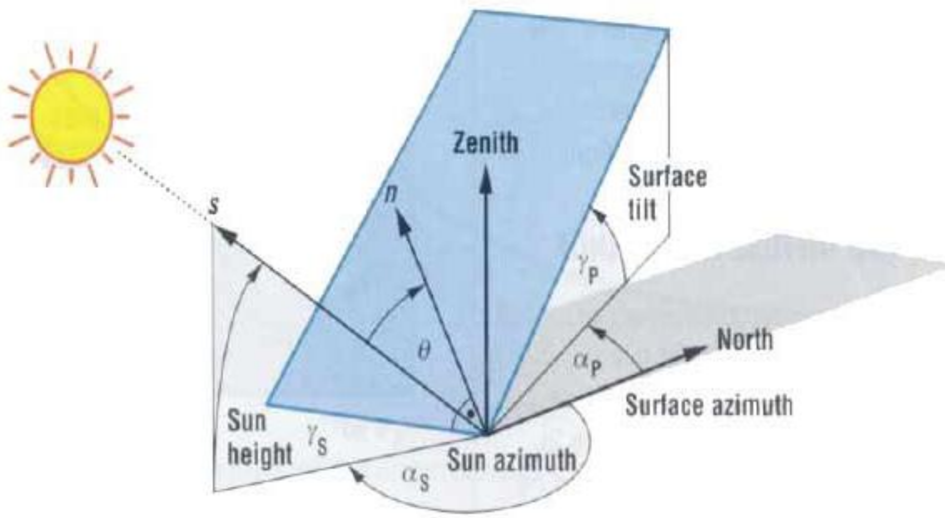
1) Reduction of sand to metallurgical grade silicon
2) Purification of metallurgical grade silicon to semiconductor grade silicon
3) Conversion of semiconductor grade silicon to single crystal silicon waters.
4) Processing of single crystal silicon waters in to solar cells.
5) Solar cell encapsulation into weather proof solar cell modules



Question 24

Locate the followings in the diagram

(a) Zenith (b) Angle of tilt plane (c) Incidence angle for tilted surface (d) Azimuth angle of sun (e) Orientation angle of tilted plane (f) Altitude angle of sun



$\beta = Tilt\ angle\ of\ solar\ plane$

$\gamma_Z = Azimuth\ angle\ of\ the\ sun$

$\gamma = Orientation\ angle\ of\ tilted\ plane$

$\theta_Z = Incidence\ angle\ for\ tilted\ surface$

$\alpha_r = Altitude\ angle\ for\ sun$

Question 25

What are the steps to be done in manual shading assessment?

Manual Shading Assessment using sun path diagram and hourly Irradiance

- Plotting the obstacles causing shading on to the sun path diagram to determine the likely day times and months of the year when the shading will occur.
- Then use the irradiation data table for hourly irradiance.
- The shaded amount of irradiation is estimated and deducted from the daily total irradiation.

Question 26

Calculate monthly daily average total irradiation on horizontal surface for January in Brisbane a=0.42, b=0.22 n=7.5 δ=20.9 ϕ= 27.5 n=17 (day number)

$$W = \cos^{-1}\left(-\tan\phi\tan\delta\right)$$

$$= \cos^{-1}(-\tan(-27.5)\tan(-20.9))$$

$$= 101.47$$

$$\bar{H}_a = \frac{24\times3600\times G_{sc}}{\pi\times10^6}\left[1+0.33\cos(\frac{360n}{365})\times\left(\cos\phi\cos\delta\sin\varpi\right)+\left(\frac{2\pi\varpi_s}{360}\right)\sin\phi\sin\delta\right]$$

$$= \frac{24\times3600\times1367}{\pi\times100}\left[1+0.33\cos\left(\frac{360\times17}{365}\right)\times\left(\cos(-27.5)\cos(-20.9)\sin(101.47)\right)+\left(\frac{2\pi\times101.47}{360}\right)\sin(-27.5)\sin(-20.9)\right]$$

$$\bar{H}_a = 42.81mJ/m^2$$

$$\bar{N} = \frac{2}{15}\cos^{-1}(-\tan\phi\tan\delta)$$

$$= \frac{2}{15}\cos^{-1}(-\tan(-27.5)\tan(-20.9))$$

$$= 13.3$$

$$\frac{\bar{H}}{\bar{H}_a} = \left(a + b\frac{\bar{n}}{\bar{N}}\right)$$

$$\frac{\bar{H}}{42.81} = \left(0.42 + 0.22\times\frac{7.5}{13.3}\right)$$

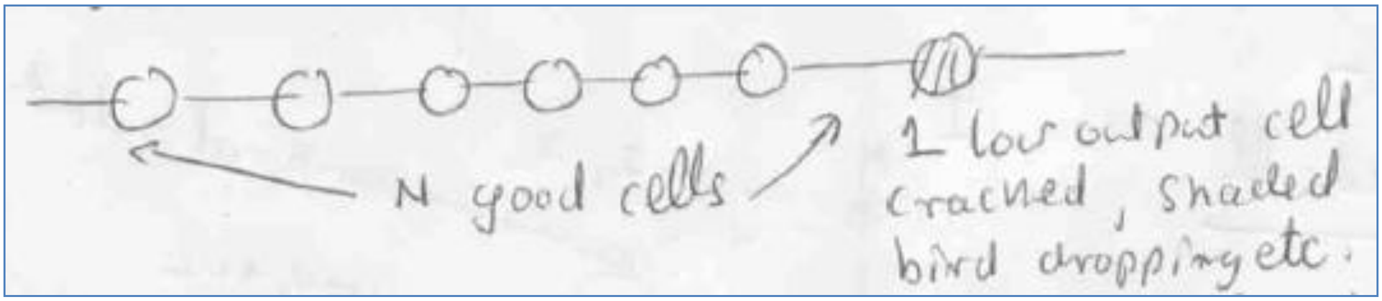
$$\bar{H} = 23.3mJ/m^2$$

Question 27

Explain the followings

(a) Hot spot heating

Mismatched cell within a module can result in some cells generating and some dissipating power. In the worst case the whole output of good cells can be dissipated in the bad cell on short circuit.



Dissipation of power in poor cells leads in breakdown in localised regions of the cell p-n junction. Enormous power dissipation can occur in a small area leading to load overheating or hot spots which in turn leads to destructive effects such as cell or glass cracking or melting of solder

(b) Efficiency limit for black body cell

Blackbody solar cell in equilibrium emits photons. For photons of energy larger than band gap, the source of these photons is predominantly radiative recombination events in semiconductors. In thermal equilibrium these events will be balanced by an equal generation rate.

Silicon – minimum value of Io – max Voc=850mV

(c) Effect of temperature on solar cell

The short circuit current of solar cell is not strongly temperature dependant. The relation between short circuit current and open circuit voltage.

$$I_{SC} = I_0\left(e^{\frac{qV_{oc}}{KT}} - 1\right)$$

Ego=zero temperature bond gap of semiconductor making up cell

$$I_0 = AT^{\gamma}e^{-E_{go}/KT}$$

A=Independent of temperature

T=Temperature

γ=Temperature dependencies in determining Io

$$I_{SC} = AT^{\gamma}e^{-E_{go}/KT} \times e^{qV_{oc}/KT}$$

$$\frac{dV_{oc}}{dt} = \frac{V_{go} - V_{oc} + \gamma(KT/q)}{T}$$

For silicon V_{go}=1.2V, T=300K, V_{oc}=0.6V, =3, k/q=6.23x10^{-6}

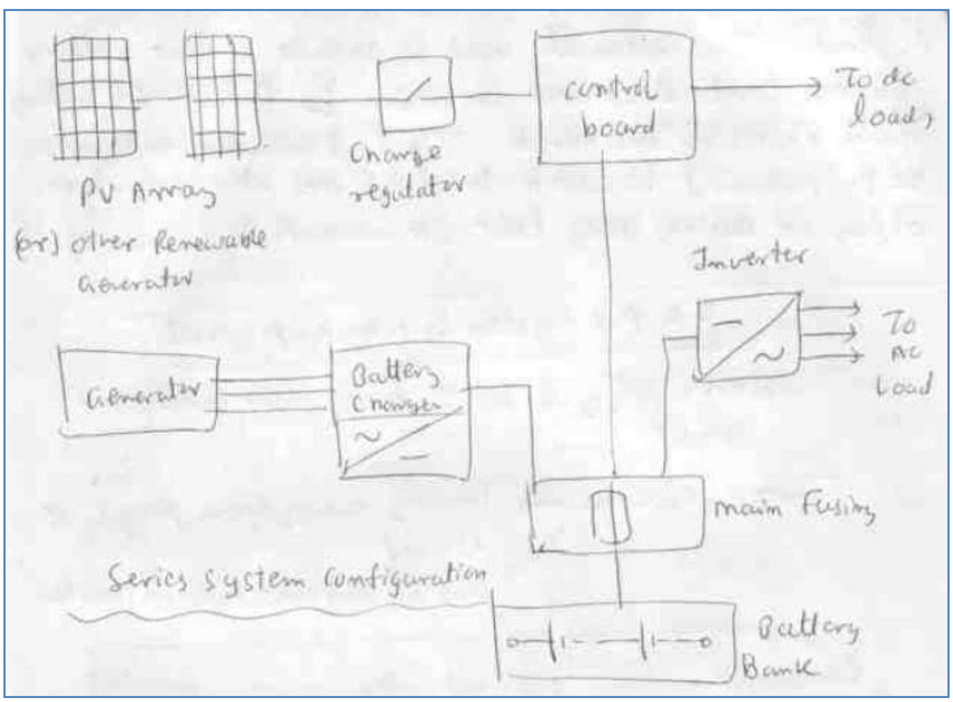
$$\frac{dV_{oc}}{dt} = \frac{1.2 - 0.6 + 3\left(300 \times 6.23 \times 10^{-6}\right)}{300} = \frac{1.2 - 0.6 + 0.078}{300} = 2.3mV/°C$$

Question 28

Sketch the followings

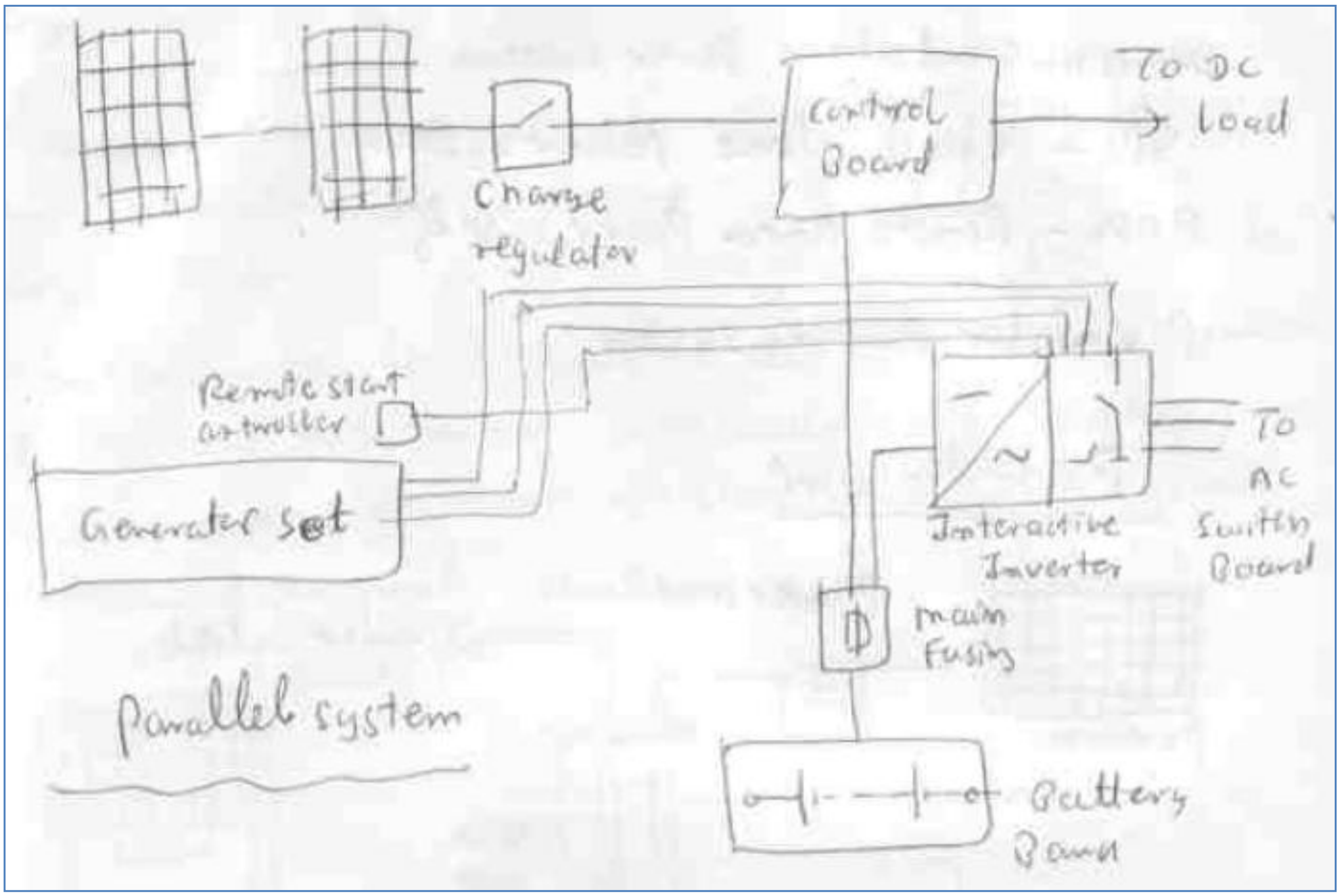
(a) Series system

- All of the supplementary energy input from the generator is fed into battery via battery charger.
- All of the supplementary energy provided by the generator passes through both the battery charger and the battery.
- For dc loads trough the inverter as well.
- The efficiency of use of gen set output is low.



(b) Parallel system

- Special inverter interactive/bidirectional inverter is used.
- Two type of inverter can charge the batteries as well as connected the generator supply to ac loads while the generator is running.



Question 29

Sketch the followings

(a) Grid connected PV system

An alternative to stand alone PV is to source supplementary energy from the electricity grid. This eliminates the need for energy storage since power can be drawn from the grid at times when the PV system cannot meet demand and excess power not immediately needed by the loud is supplied to the grid.

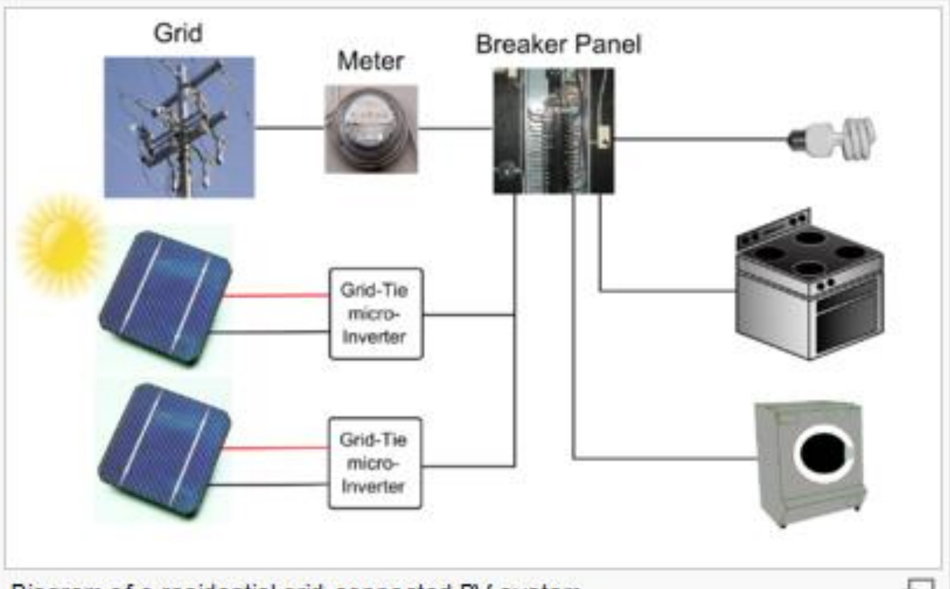
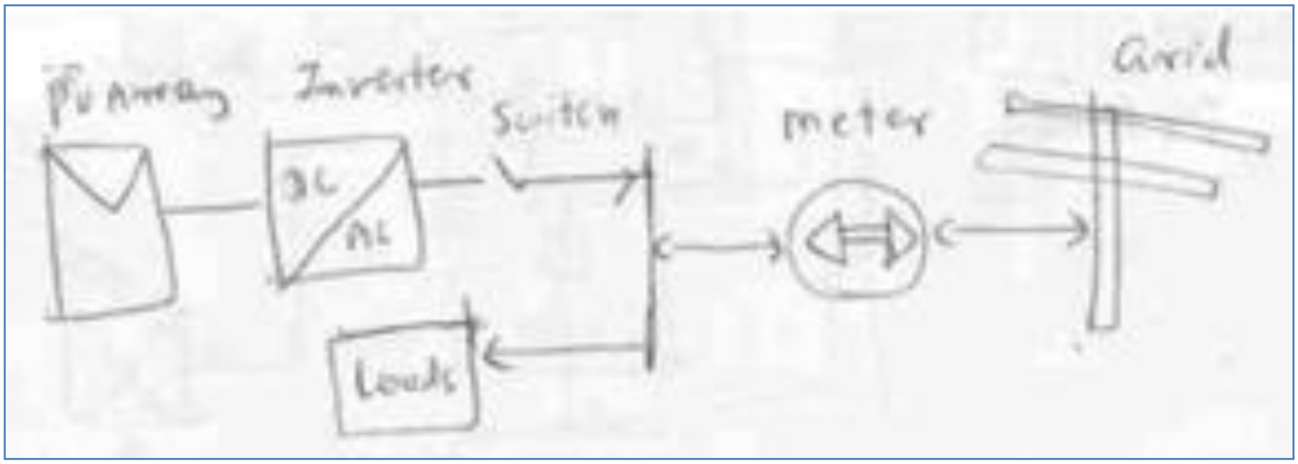
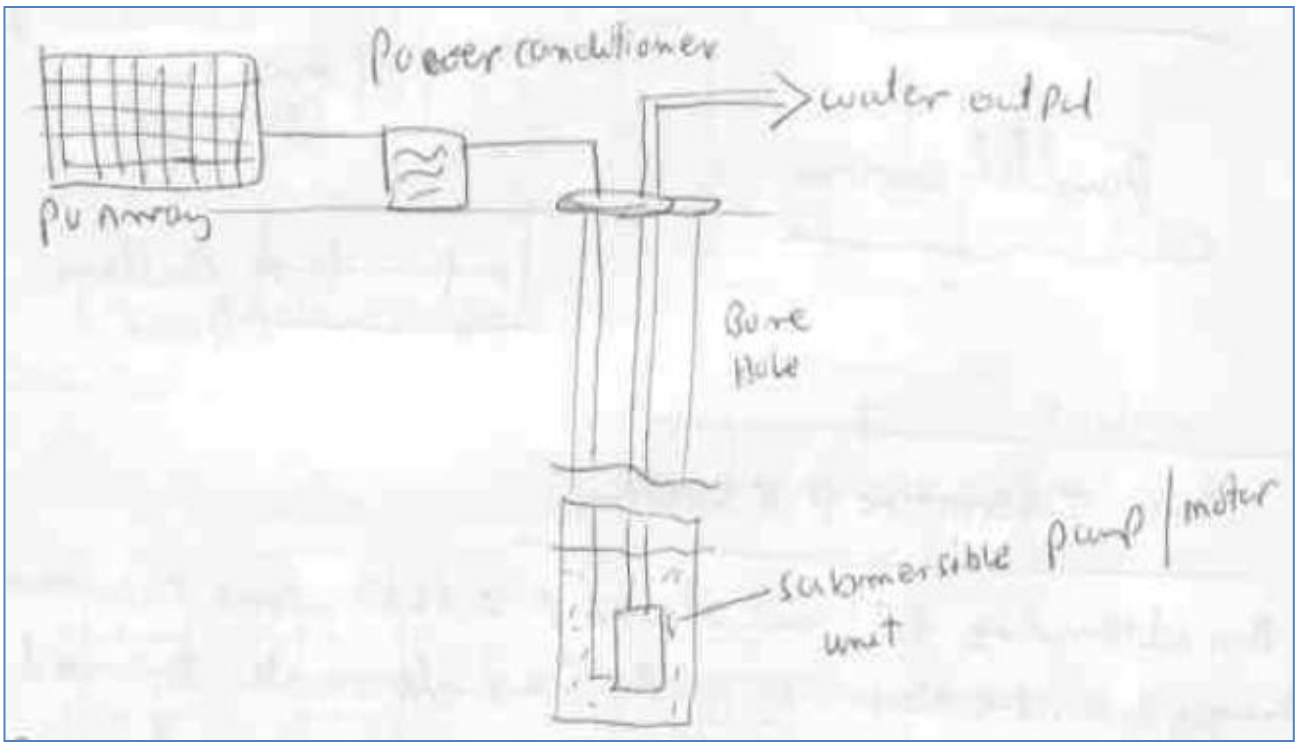


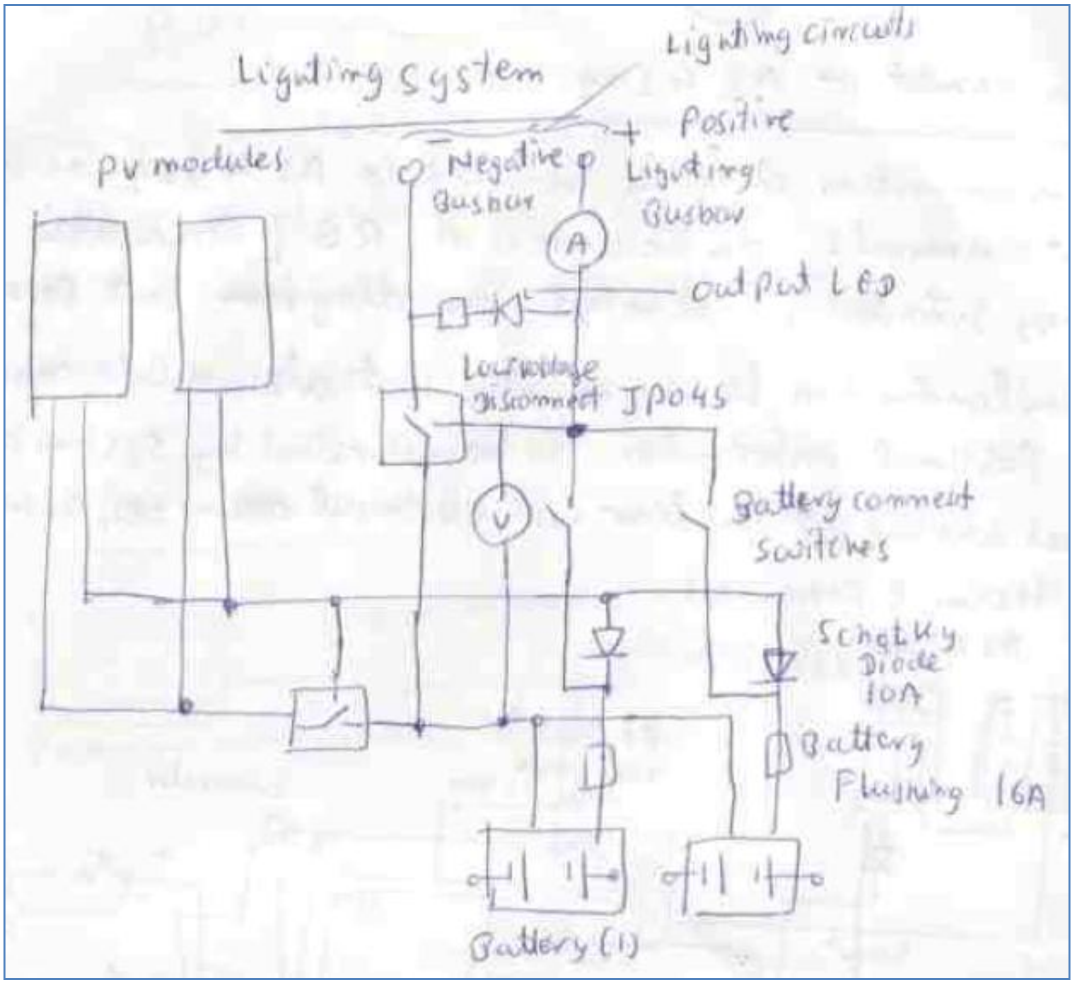
Diagram of a residential grid-connected PV system



PV water pumping system



(b) PV lighting system



Question 30

What are the steps to design the PV water pumping system?

- Determine the volume of water to be pumped each day and at what head
- Calculate the pump rate from the number of sun light hours.
- Select the pump type
- From the torque speed characteristic of the pump select a motor with a compatible torque-speed characteristics.
- Select appropriate solar panels

Direct Couple System

The direct coupled system is not suitable for the following situations

(a) When pumping heads are too large to be able to use a centrifugal pump with reasonable efficiency.
(b) When suitable dc motors are not available, such as with some large systems (>10HP) where little noise exists or when a submersible motor is

necessary and no brushless dc motors are available at a suitable price.

(c) When the pumping rate in bright sunshine exceeds the water source replenishment rates.

(d) When it is essential batteries to be used for energy storage (i.e. where availability of pumped water must be very high and tank storage) e.g. portable units.

(e) Locations characteristic by excessive cloudy weather making the poor part-loud efficiencies of directly coupled system unacceptable.

<u>Consideration</u>

- Volume of water to be pumped
- Pumping head and seasonal variations
- Water storage and consumer’s need
- Insolation data
- Select the pump to suit starting torque requirement
- Select a motor with a torque (speed characteristics compatible with that of the pump.

$$V_m = k\phi H + I_a R_a$$

m = motor, a= Armature, N=speed

ϕ = flux, k = motor constant, R_a = resistance of armature, I_n=motor current

Question 31

Why energy efficiency is important in solving the problem of Global warming?

Most of our energy comes from fossil fuels, and burning these fuels causes environmental problems, and in particular, the global warming problem. Global warming raises the sea level; brings drought in tropical regions near the equator; increases hurricanes, tornadoes, and floods; and causes the spread of diseases. Various measures to solve or mitigate the global warming problem have been proposed. Power electronics will play a very important role in clean energy generation, bulk storage of electricity, and efficient energy utilization, and eventually, it will be a key element in the energy policies of nations. It has been estimated that the widespread energy efficiency improvement by power electronics and other methods with the existing technologies can save 20% of the global energy demand, and another 20% can be saved by preventing waste, i.e., by various conservation methods.

Question 32

Present a typical Stand Alone Power System. The submission must include

(a) Construction diagram (b) Technical Data (c) Apparatus used

The design of stand-alone PV-based power system is determined by the location, climate, site characteristics and equipment used. Figure 6.2 shows a schematic of a typical PV-based stand-alone power system.

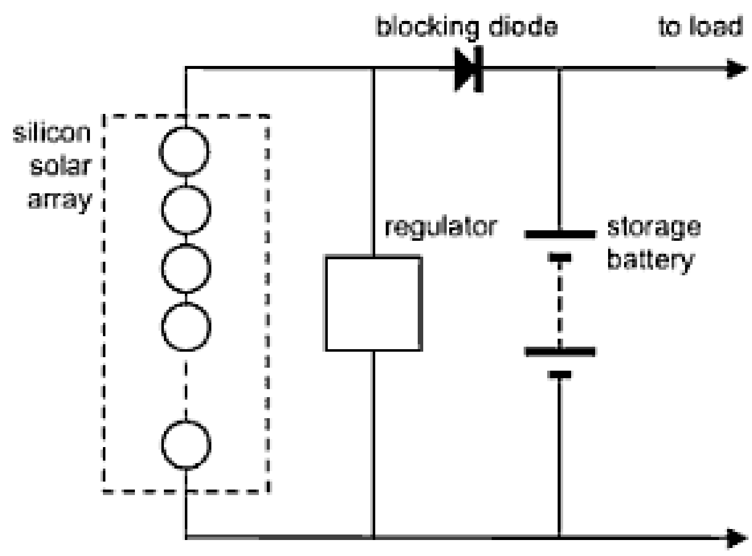


Figure 6.2. Simplified stand-alone PV power system (Mack, 1979, reprinted with permission of the Telecommunication Society of Australia).

Design Procedures

1. **Load determination** - To specify the load as accurately as possible, and hence achieve a system design that optimises components and costs, the following information is need:
   - Nominal system voltage
   - Range of voltages able to be tolerated by load
   - Average load per day
   - Load profile throughout the year

   For a microwave repeater station, for example, the voltage may be 24+/-5V, the average load 100W (current=4.17A), and the required storage 15 days.
2. **Select battery capacity** – For telecommunications loads, the design approach is quite conservative, allowing for 15 days of battery storage to give very high availabilities. For the example given above, this would be 4.17A x 24h x 15 days = 1500Ah.

3. **First approximation of tilt angle** – This is based on site information and usually involves selecting a tilt angle 20° greater than the latitude. For example, for Melbourne, which is at latitude 37.8S, the first approximation for tilt angle is 37.8 + 20 = 57.8°

4. **Insolation** – From the available site insolation data, the actual insolation falling on the array at the selected tilt angle can be estimated. An example of typical insolation data throughout the year falling on a horizontal plane in Melbourne. Using this insolation data, sample calculations are provided for determining the actual corresponding amount of insolation that will fall on the photovoltaic array when tilted at an angle of 57.8°. An assumption made in these calculations is that the diffuse component of the insolation data is independent of tilt angle. This is a reasonable approximation, provided the tilt angle is not too great.
5. **First approximation of array size** – As a rule of thumb, the initial array size in peak amps (1kW/m2) is selected to be five times the average load current. This figure is large because:
   - The sun does not shine at night
   - There is reduced light intensity during mornings, afternoons and periods of cloudy weather.
   - The batteries have a limited charging efficiency

- There is some self-discharge of the batteries
- Dust often partly obscures light penetration

Using the initial array size and the modified insolation data from (4), the ampere-hours generated throughout the year can be calculated. In these calculations, allowance needs to be made for loss owing to dust coverage, assumed to be in the vicinity of 10% although this may be an overestimation for the impact of dust. An Arizona study (Hammond, 1997) found that for modules at normal incidence to the sun, soiling causes a maximum of 3% loss between periods of rain but that the loss increased with incidence angle, to 4.7% and 8% at 58. Bird droppings, however, can have a more serious impact.

The electricity generated can then be compared to the amount consumed by the load throughout the year. When calculating the load consumption, allowance needs to be made for self-discharge of the battery, usually set at about 3% of the battery charge per month.
Assuming the batteries are at a full state of charge in summer, the state of charge of the batteries throughout the year can be determined.

6. **Optimising array tilt angle** – Retaining the same array size, the above procedures can be repeated with small variations in the array tilt angle until the depth-of-discharge of the batteries is minimised. This represents the optimal tilt angle.

7. **Optimising array size-** Using the optimal tilt angle, the array size can be optimised, in conjunction with the depth-of-discharge of the batteries, by using successive approximations of array size in conjunction with the above procedures.
8. **Summarise the design.**

In a stand-alone system, solar modules are usually used to charge a battery. A typical 36 cell module, based on screen-printed or buried-contact silicon cell technology, has the cells series connected to suit of a 12V battery. Typical characteristics for each (screen printed) cell would be:

$$V_{oc} = 600mV(25°C)$$

$$I_{sc} = 3.0A$$

$$FF = 75\%$$

$$V_{n\psi} = 500mV(25°C)$$

$$I_{n\psi} = 2.7A$$

$$Area = 100cm^2$$

Therefore, 36 cells in series give:

$$V_{oc} = 21.6V(25°C)$$

$$I_{sc} = 3.0A$$

$$FF = 75\%$$

$$V_{n\psi} = 18V(25°C)$$

$$I_{n\psi} = 2.7A$$

Question 33

Estimate total electrical energy used in your home and calculate the size of solar panel to supply the electrical load. Also include the appropriate size of the battery. Use the following solar irradiation data a=0.42, b=0.22, n=7.5 δ=20.9 n= 17 (day number). You need to find latitude angle ϕ of Sydney

Sydney Latitude =-33.867

The daily average total irradiation on horizontal surface is calculated as follows

$$\begin{aligned} \varpi &= \cos^{-1}(-\tan\phi\tan\delta) \\ &= \cos^{-1}(-\tan(-33.86)\tan(-20.9)) \\ &= -104.76 \end{aligned}$$

$$\begin{aligned} H_a &= \frac{24\times 3600\times G_{SC}}{\pi\times 10^6}\left[1+0.33\cos\left(\frac{360\times n}{365}\right)\times[\cos\phi\cos\delta\sin\varpi_s] + \frac{2\pi\varpi_s}{300}\sin\phi\sin\delta\right] \\ &= \frac{24\times 3600\times 1367}{\pi\times 10^6}\left[1+0.33\cos\left(\frac{360\times 17}{365}\right)\times[\cos(-33.86)\cos(-20.9)\sin(104.76)] + \frac{2\pi\times 104.76}{360}\sin(-33.86)\sin(-20.9)\right] \\ &= 60.08 mJ/m^2 \end{aligned}$$

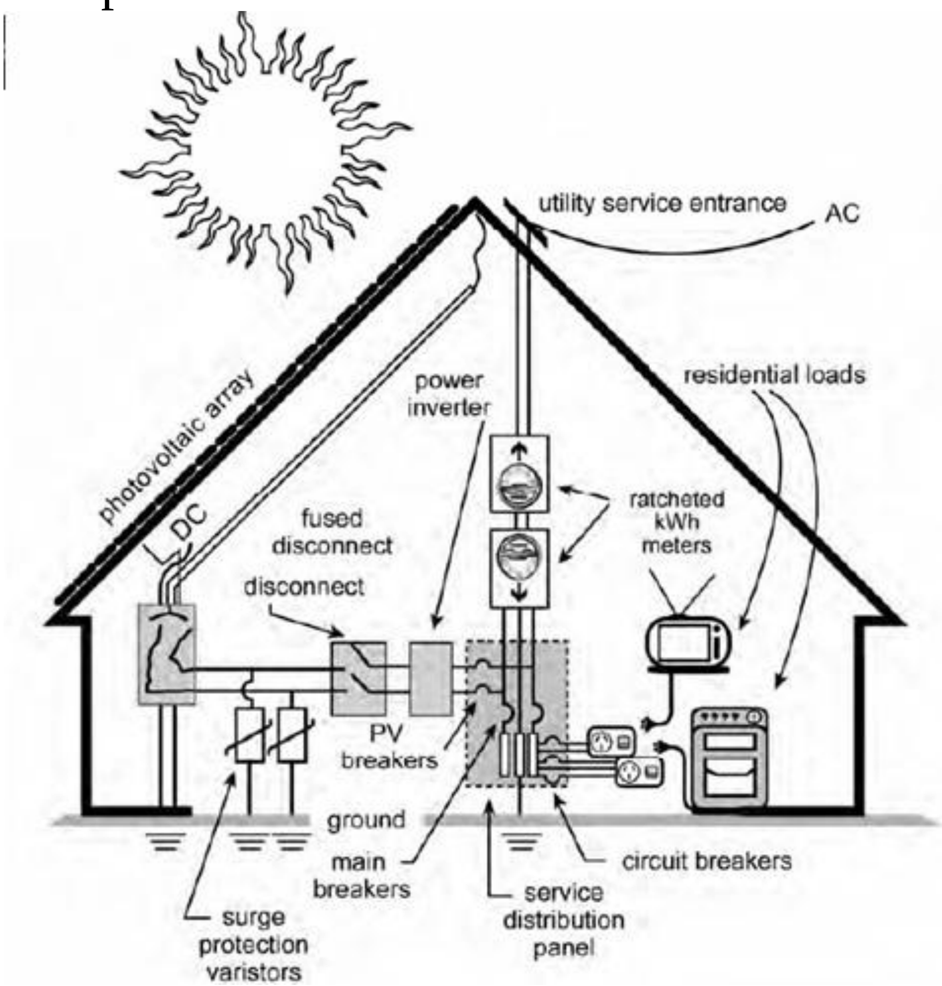
$$\begin{aligned} \bar{N} &= \frac{2}{15}\cos^{-1}(-\tan\phi\tan\delta) \\ &= \frac{2}{15}\cos^{-1}(-\tan(-33.86)\tan(-20.9)) \\ &= 13.96 \end{aligned}$$

$$\frac{\bar{H}}{\bar{H}_a} = \left\{ a + b \frac{\bar{n}}{\bar{N}} \right\}$$

$$\frac{\bar{H}}{60.08} = \left\{ 0.42 + 0.22 \times \frac{7.5}{13.96} \right\}$$

$$\bar{H} = 32.33 mJ/m^2$$

For household systems, modules can be mounted on array frames next to the house, in a position where no shading from buildings or trees would occur. However in many cases, rooftop mounted offers the best aspect and the safest and most economical option.



To make much impact on typical household electricity use, a photovoltaic system of about 2kWp or 20m^2 would be needed. A system rate at 3-4kWp would supply most household needs.
Example:

A house has the following electrical appliance usage:

- One 18 watt fluorescent lamp with electronic ballast used 4 hours per day
- One 60 watt fan used for 2 hours per day
- Size the PV panel
- One 75 watt refrigerator that runs 24 hours per day with compressor run 12 hours and off 12 hours.

The system will be powered by 12 Vdc, 110Wp PV module.

1. **Determine power consumption demands**

Total appliance use = (18W x 4 hours) + (60W x 2 hours) + (75W x 24 x 0.5 hours)

=1,092 Wh/day

Total PV panels energy needed = 1,092x1.3

=1,419.6 Wh/day

1.1 Total Wp of PV panel capacity needed = 1,419.6/3.4

= 413.9Wp

1.2 Number of PV panels needed =413.9/110

=3.76 modules

Actual requirement = 4 modules

So this system should be powered by at least 4 modules of 110 Wp PV module.

2. **Inverter sizing**

Total Watt of all appliances = 18 + 60 +75 = 153 W

For safety, the inverter should be considered 25-30% bigger size.

The inverter size should be about 190 W or greater

3. **Battery sizing**

Total appliances use = (18 W x 4 hours) + (60 W x 2 hours) + (75 W x 12 hours)

Nominal battery voltage = 12V

Days of autonomy = 3 days

$$Battery\ capacity = \frac{[(18W \times 4hours) + (60W \times 2hours) + (75W \times 12hours)] \times 3}{0.85 \times 0.6 \times 12}$$

$$Total\ \ Ampere - hours\ required\ 535.29\,Ah$$

So the battery should be rated 12V 600Ah for 3 day autonomy.

4. **Solar charge controller sizing**

PV module specification

Pm = 110Wp

Vm = 16.7Vdc

Im = 6.6A

Voc = 20.7A

Isc = 7.5A

Solar charge controller rating = (4 strings x 7.5A) x 1.3 = 39A
So the solar charge controller should be rated 40 A at 12 V or greater.

can still exert some influence the fountain performance. The fact is that the purer water enables more efficient pumping. The tap water which seems to be quite pure can also produce some minerals from the water in the pump. To prevent this, the distilled water can be used, which however would cost more. On the other hand, you can also change the water more frequently and pay more attention of the water cleaning.

Q58.What are typical characteristics of PV module?

A **photovoltaic system** (or **PV system**) is a system which uses one or more solar panels to convert sunlight into electricity. It consists of multiple components, including the photovoltaic modules, mechanical and electrical connections and mountings and means of regulating and/or modifying the electrical output.

Due to the low voltage of an individual solar cell (typically ca. 0.5V), several cells are wired in series in the manufacture of a "laminate". The laminate is assembled into a protective weatherproof enclosure, thus making a photovoltaic module or solar panel. Modules may then be strung together into a photovoltaic array. The electricity generated can be either stored, used directly (island/standalone plant)or fed into a large electricity grid powered by central generation plants (grid-connected/grid-tied plant) or combined with one or many domestic electricity generators to feed into a small grid (hybrid plant). Depending on the type of application, the rest of the system ("balance of system" or "BOS") consists of different components. The BOS depends on the load profile and the system type. Systems are generally designed in order to ensure the highest energy yield for a given investment.

Q65.Write equation for overall efficiency of solar water system.

To calculate BTUNeed, use the following formula:

BTUNeed = 8.34 X Gallons X (122 – Coldtemp) X Standby loss factor

ULTIMO COLLEGE OF TAFE

Course name : Advance Diploma in Electrical engineering

Course no. : 17794

Student name : THI TRUONG

Student number : 210182527

SUBJECT : ASSIGNMENT KO35

DESIGN GRID CONNECTED POWER SUPPLY SYSTEMS

TEACHER'S NAME : KYAW NAING

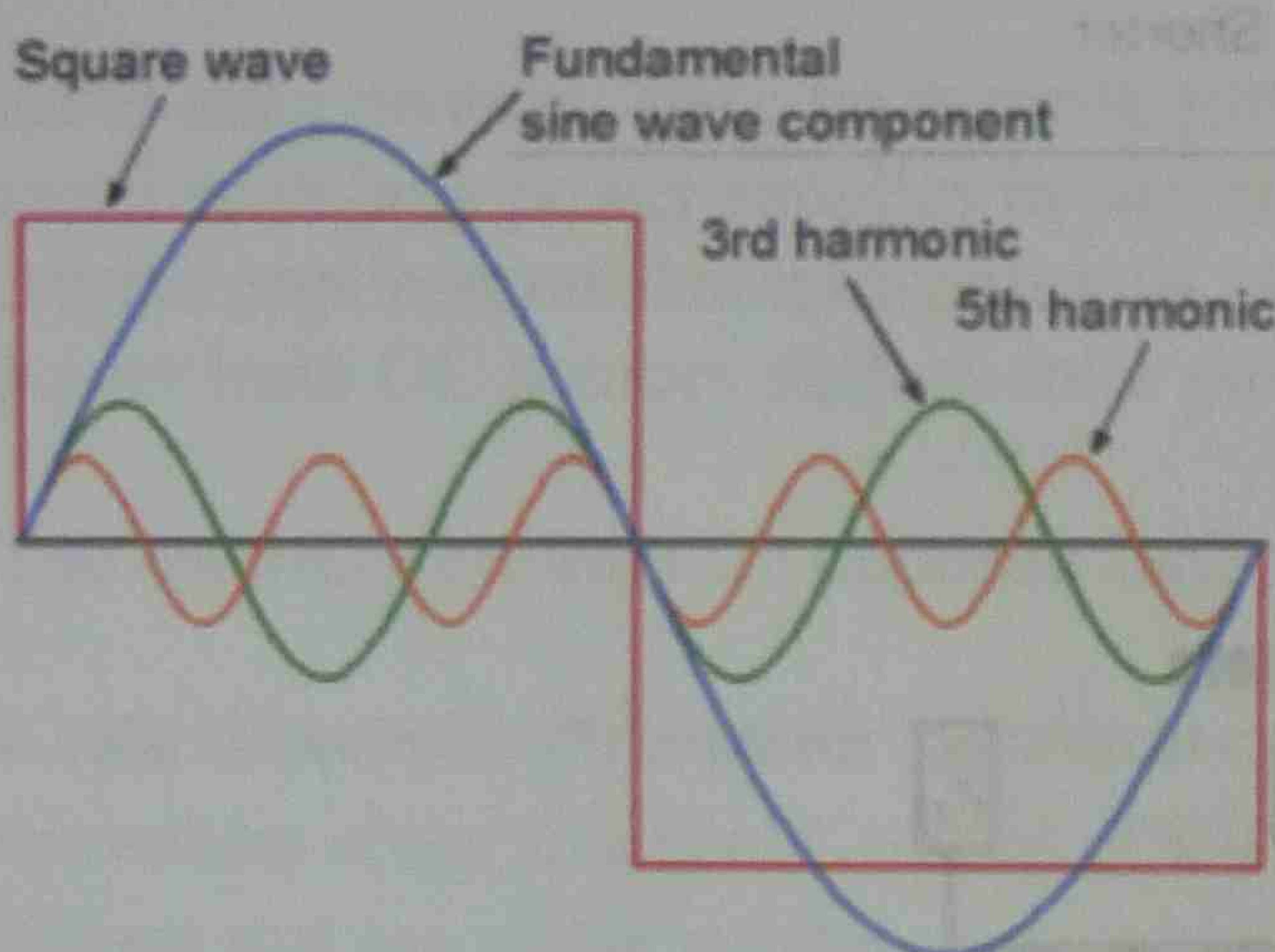
ASSIGNMENT K035

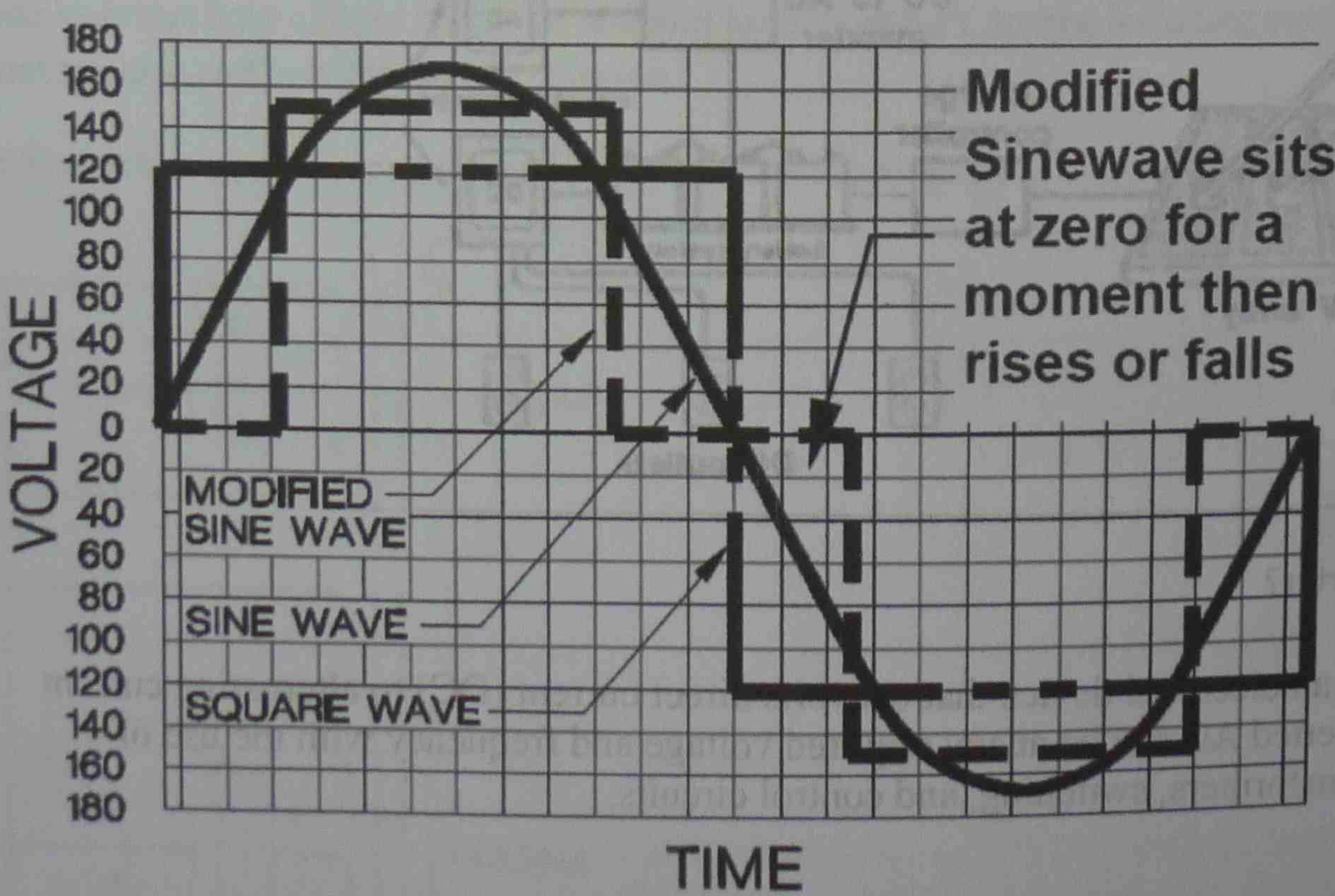
Q1.Sketch the waveforms for (a) DC to pulsating AC inverter (b) Modified sine wave , step sine wave inverter (c) PWM inverter.

An **inverter** is an electrical device that converts direct current (DC) to alternating current (AC) the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits.

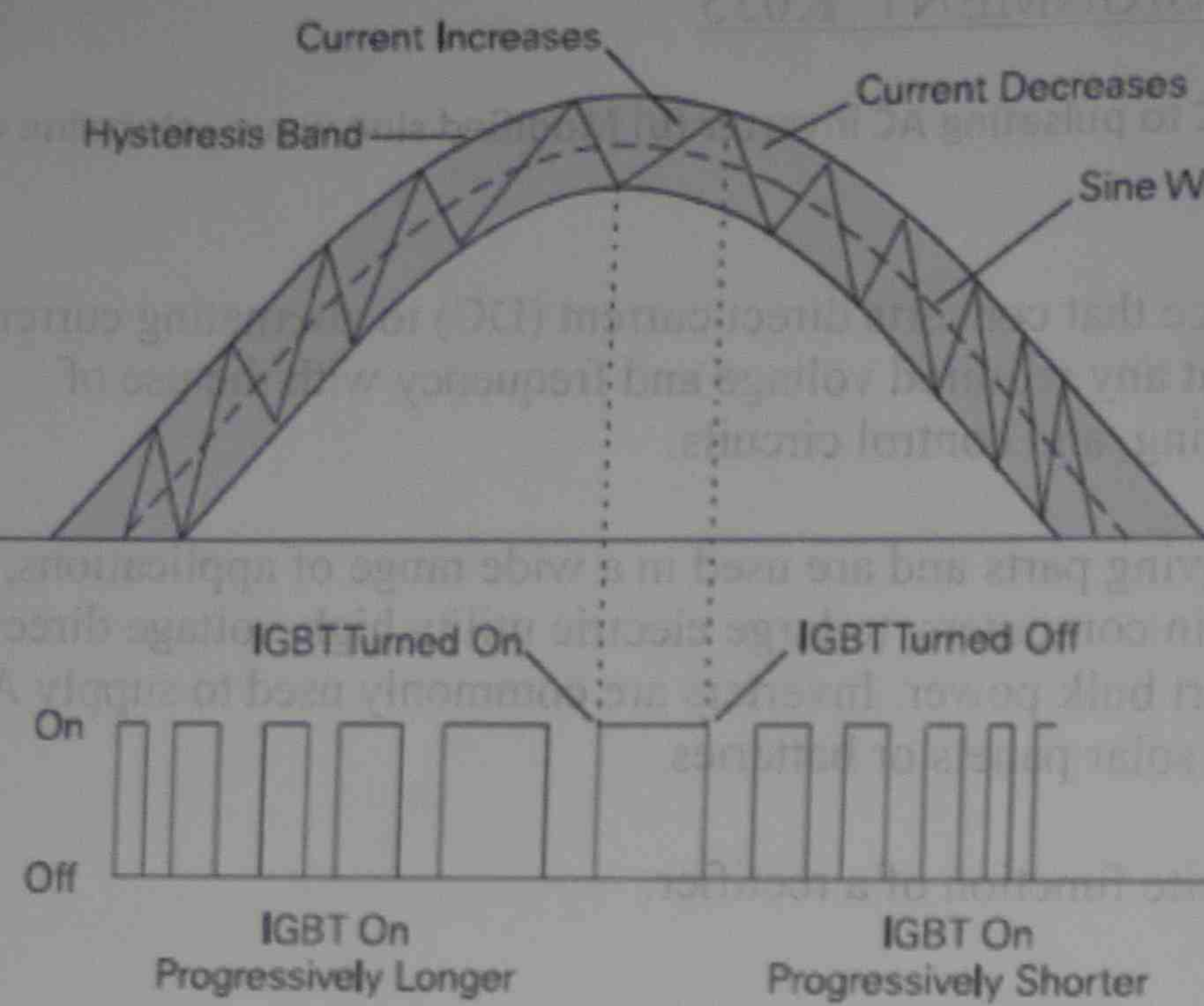
Solid-state inverters have no moving parts and are used in a wide range of applications, from small switching power supplies in computers, to large electric utility high-voltage direct current applications that transport bulk power. Inverters are commonly used to supply AC power from DC sources such as solar panels or batteries.

The inverter performs the opposite function of a rectifier.



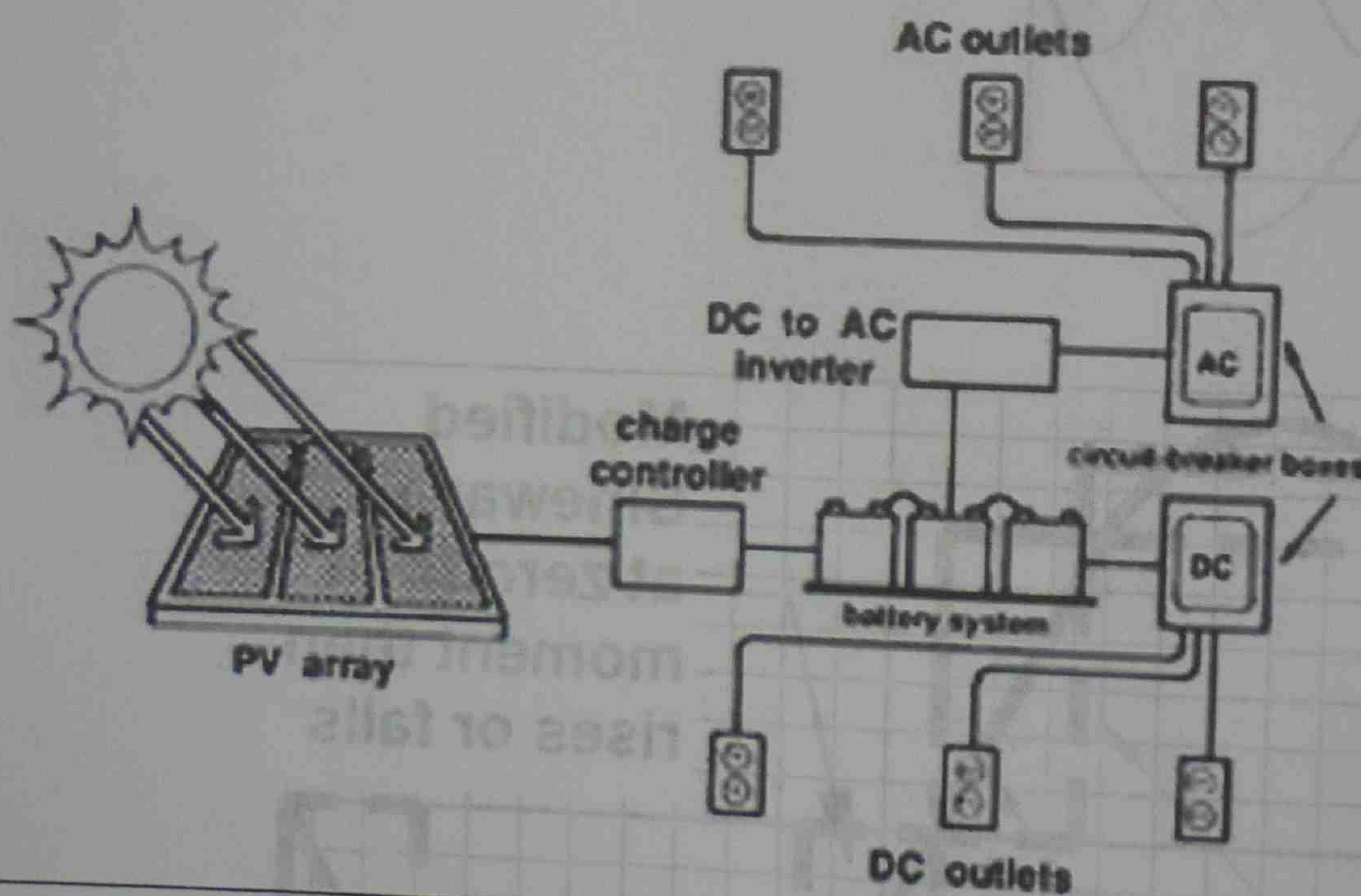


Square, Modified, and Pure Sine Wave



PWM inverter

Q2.Sketch the block diagram for stand alone PV system.



Q3.What is inverter?

An **inverter** is an electrical device that converts direct current (DC) to alternating current (AC) the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits.

Q4.What is grid tie inverter?

A grid-tie inverter (GTI) is a special type of inverter that converts direct current(DC) electricity into alternating current(AC) electricity and feeds it into an existing electrical grid. GTIs are often used to convert direct current produced by many renewable energy sources, such as solar panels or small wind turbines, into the alternating current used to power homes and businesses. The technical name for a grid-tie inverter is "grid-interactive inverter". They may also be called synchronous inverters. Grid-interactive inverters typically cannot be used in standalone applications where utility power is not available.

Q5.What are the applications of inverter?

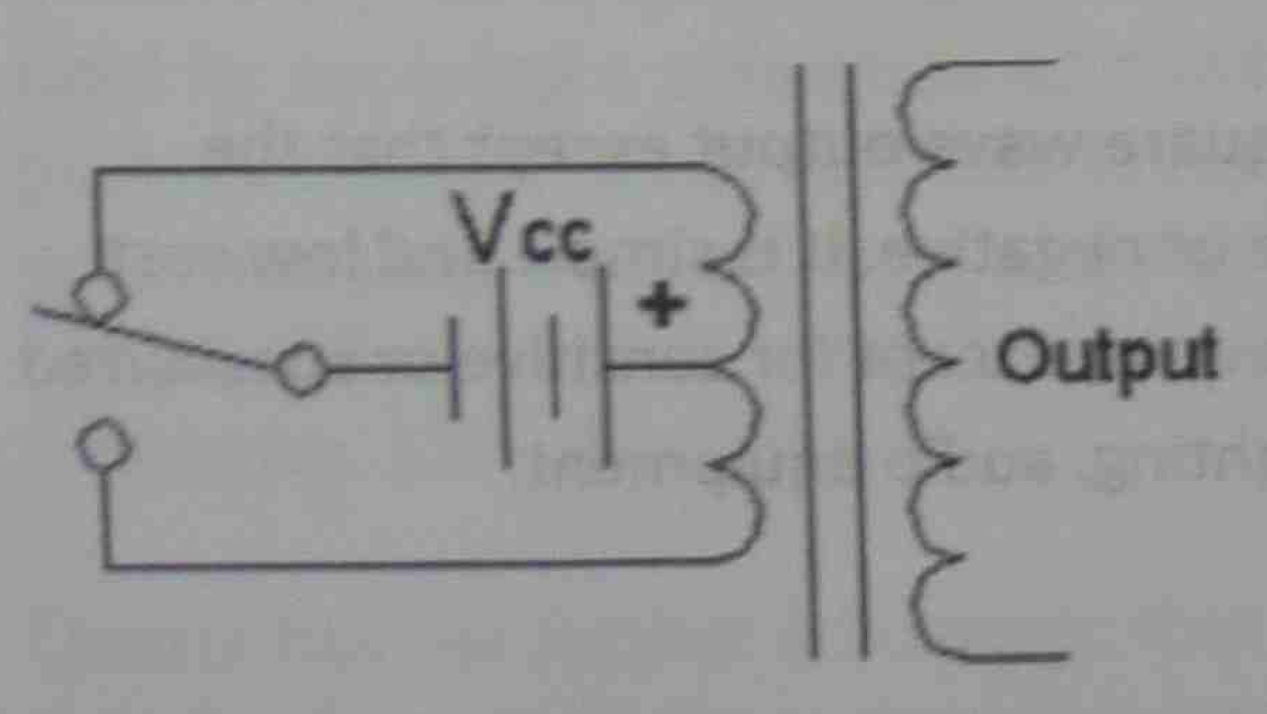
An **inverter** is an electrical device that converts direct current (DC) to alternating current (AC) the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits.

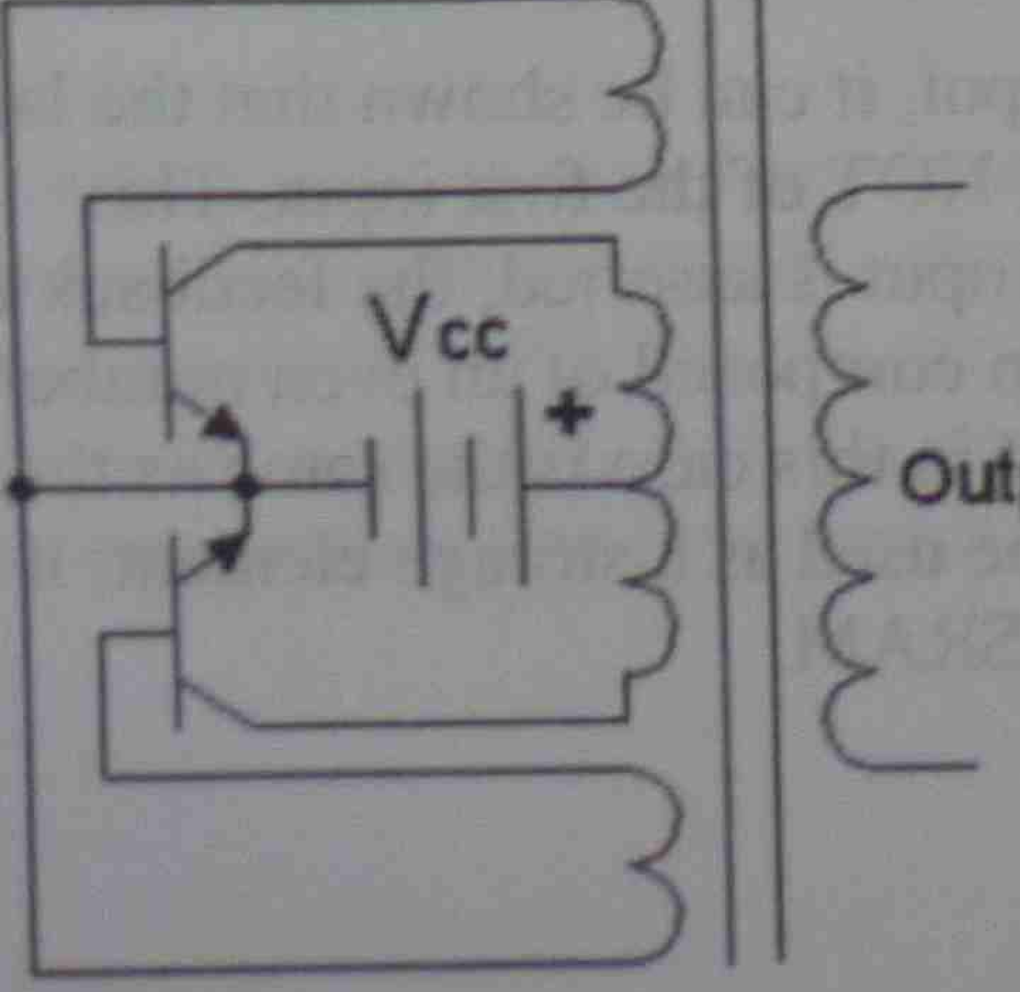
Solid-state inverters have no moving parts and are used in a wide range of applications, from small switching power supplies in computers, to large electric utility high-voltage direct current applications that transport bulk power. Inverters are commonly used to supply AC power from DC sources such as solar panels or batteries.

The inverter performs the opposite function of a rectifier.

A **solar inverter** or **PV inverter** is a critical component in a solar energy system. It performs the conversion of the variable DC output of the Photovoltaic (PV) modules into a utility frequency AC current that can be fed into the commercial electrical grid or used by a local, off-grid electrical network. An inverter allows use of ordinary mains-operated appliances on a direct current system. Solar inverters have special functions adapted for use with PV arrays, including maximum power point tracking and anti-islanding protection.

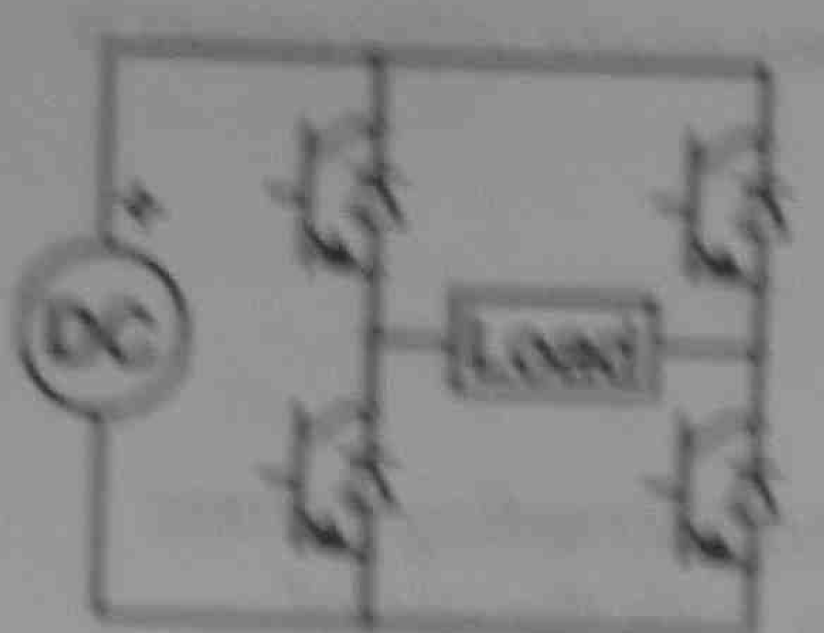
Q6.Sketch basic inverter principle circuit and operating principle.



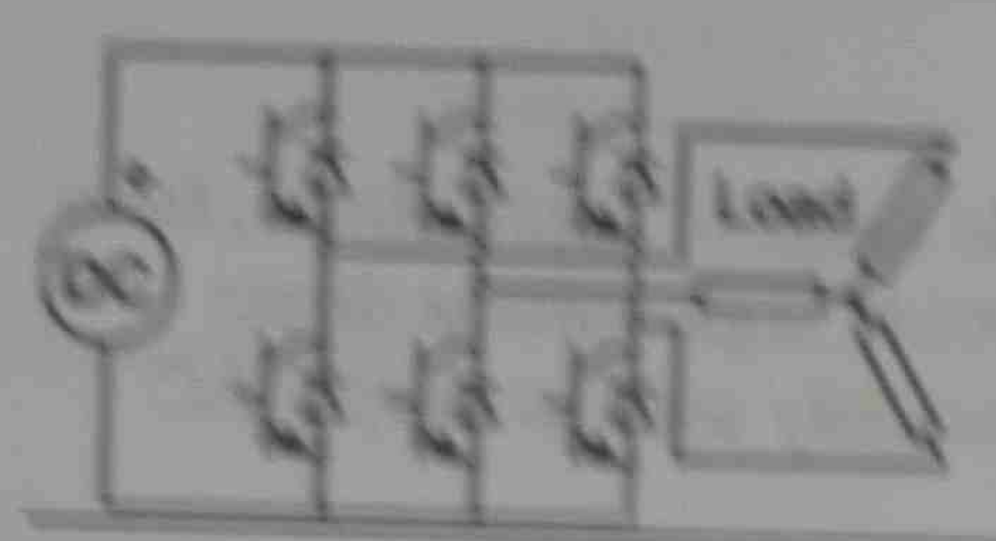


In one simple inverter circuit, DC power is connected to a transformer through the centre tap of the primary winding. A switch is rapidly switched back and forth to allow current to flow back to the DC source following two alternate paths through one end of the primary winding and then the other. The alternation of the direction of current in the primary winding of the transformer produces alternating current (AC) in the secondary circuit.

Q7.Sketch (a) H bridge inverter (b) Three phase inverter.



H bridge inverter,



Three phase inverter

Q8.Explain PWM technology and inverter circuit used with PWM technology.

PWM or **Pulse Width Modulation** is the technology to generate a steady output voltage from inverters. When compared to the conventional **Semi Sine wave** and **Pure sine wave** inverters, PWM Inverter offers superior quality. PWM Inverters use **MOSFET** technology at the output stage, so that any type of loads can be connected to the inverter. These inverters also have voltage control and load protection circuits.

Q9.Explain modified sine wave inverter.

The output of a **modified sine wave** inverter is similar to a square wave output except that the output goes to zero volts for a time before switching positive or negative. It is simple and low cost (~$0.10USD/Watt) and is compatible with most electronic devices, except for sensitive or specialized equipment, for example certain laser printers, fluorescent lighting, audio equipment.

Q10.Explain the oscillator for inverter circuit.

Because a single inverter computes the logical NOT of its input, it can be shown that the last output of a chain of an odd number of inverters is the logical NOT of the first input. This final output is asserted a finite amount of time after the first input is asserted; the feedback of this last output to the input causes oscillation.A circular chain composed of an even number of inverters cannot be used as a ring oscillator; the last output in this case is the same as the input. However, this configuration of inverter feedback can be used as a storage element; it is the basic building block of static random access memory, or SRAM.

A real ring oscillator only requires power to operate; above a certain threshold voltage, oscillations begin spontaneously. To increase the frequency of oscillation, two methods may be used. Firstly, the applied voltage may be increased; this increases both the frequency of the oscillation and the power consumed, which is dissipated as heat. The heat dissipated limits the speed of a given oscillator. Secondly, a smaller ring oscillator may be fabricated; this results in a higher frequency of oscillation given a certain power consumption.

Q11.A crystal oscillator has the following parameters C_p =50PF C_o = 10PF R = 100Ω at 10MHZ for a CMOS inverter with an open loop gain a =200 calculate the value of feedback resistor.

Q12.Explain the operational requirement of crystal oscillator for inverter.

A **crystal oscillator** is an electronic oscillator circuit that uses the mechanical resonance of a vibrating crystal of piezoelectric material to create an electrical signal with a very precise frequency. This frequency is commonly used to keep track of time (as in quartz wristwatches), to provide a stable clock signal for digital integrated circuits, and to stabilize frequencies for radio transmitters and receivers. The most common type of piezoelectric resonator used is the quartz crystal, so oscillator circuits designed around them became known as "crystal oscillators."

A crystal is a solid in which the constituent atoms, molecules, or ions are packed in a regularly ordered, repeating pattern extending in all three spatial dimensions.

Almost any object made of an elastic material could be used like a crystal, with appropriate transducers, since all objects have natural resonant frequencies of vibration. For example, steel is very elastic and has a high speed of sound. It was often used in mechanical filters before quartz. The resonant frequency depends on size, shape, elasticity, and the speed of sound in the material. High-frequency crystals are typically cut in the shape of a simple, rectangular plate. Low-frequency crystals, such as those used in digital watches, are typically cut in the shape of a tuning fork. For applications not needing very precise timing, a low-cost ceramic resonator is often used in place of a quartz crystal.

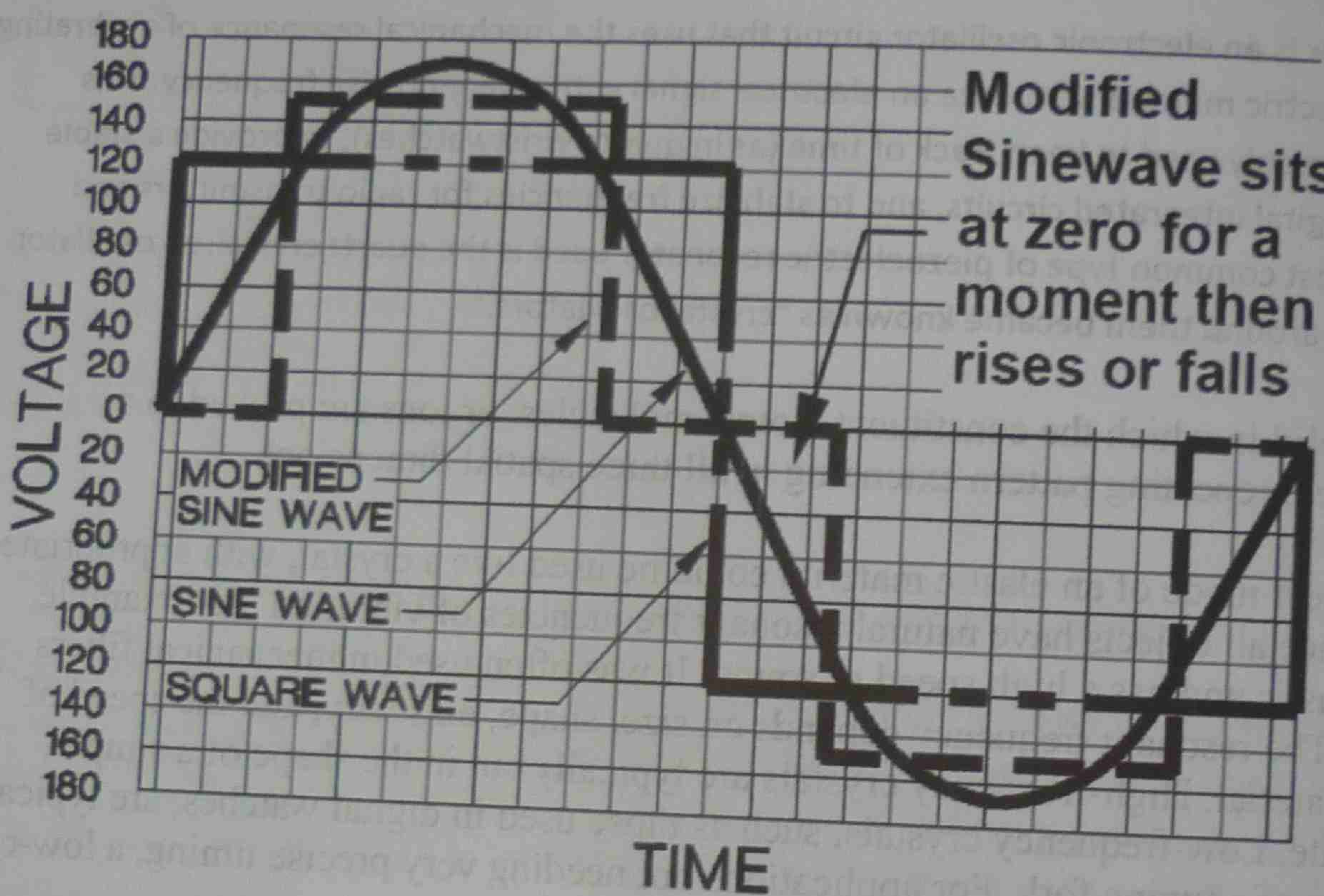
When a crystal of quartz is properly cut and mounted, it can be made to distort in an electric field by applying a voltage to an electrode near or on the crystal. This property is known as piezoelectricity. When the field is removed, the quartz will generate an electric field as it returns to its previous shape, and this can generate a voltage. The result is that a quartz crystal behaves like a circuit composed of an inductor, capacitor and resistor, with a precise resonant frequency. (See RLC circuit.)

Quartz has the further advantage that its elastic constants and its size change in such a way that the frequency dependence on temperature can be very low. The specific characteristics will depend on the mode of vibration and the angle at which the quartz is cut (relative to its crystallographic axes). Therefore, the resonant frequency of the plate, which depends on its size, will not change much, either. This means that a quartz clock, filter or oscillator will remain accurate. For critical applications the quartz oscillator is mounted in a temperature-controlled container, called a crystal oven, and can also be mounted on shock absorbers to prevent perturbation by external mechanical vibrations.

Q13.Explain the basic principle of sine wave inverter.

A **pure sine wave** inverter produces a nearly perfect sine wave output (<3% total harmonic distortion) that is essentially the same as utility-supplied grid power. Thus it is compatible with all AC electronic devices. This is the type used in grid-tie inverters. Its design is more complex, and costs more per unit power. The electrical inverter is a high-power electronic oscillator. It is so named because early mechanical AC to DC converters were made to work in reverse, and thus were "inverted", to convert DC to AC.

Q14.Sketch the graphs for square wave , modified sine wave & pure sine wave.



Q15.Explain pulse width modulation.

Pulse-width modulation (PWM), or **pulse-duration modulation (PDM)**, is a commonly used technique for controlling power to inertial electrical devices, made practical by modern electronic power switches.

The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast pace. The longer the switch is on compared to the off periods, the higher the power supplied to the load is.

The PWM switching frequency has to be much faster than what would affect the load, which is to say the device that uses the power. Typically switchings have to be done several times a minute in an electric stove, 120 Hz in a lamp dimmer, from few kilohertz (kHz) to tens of kHz for a motor drive and well into the tens or hundreds of kHz in audio amplifiers and computer power supplies.

The term duty cycle describes the proportion of 'on' time to the regular interval or 'period' of time; a low duty cycle corresponds to low power, because the power is off for most of the time. Duty cycle is expressed in percent, 100% being fully on.

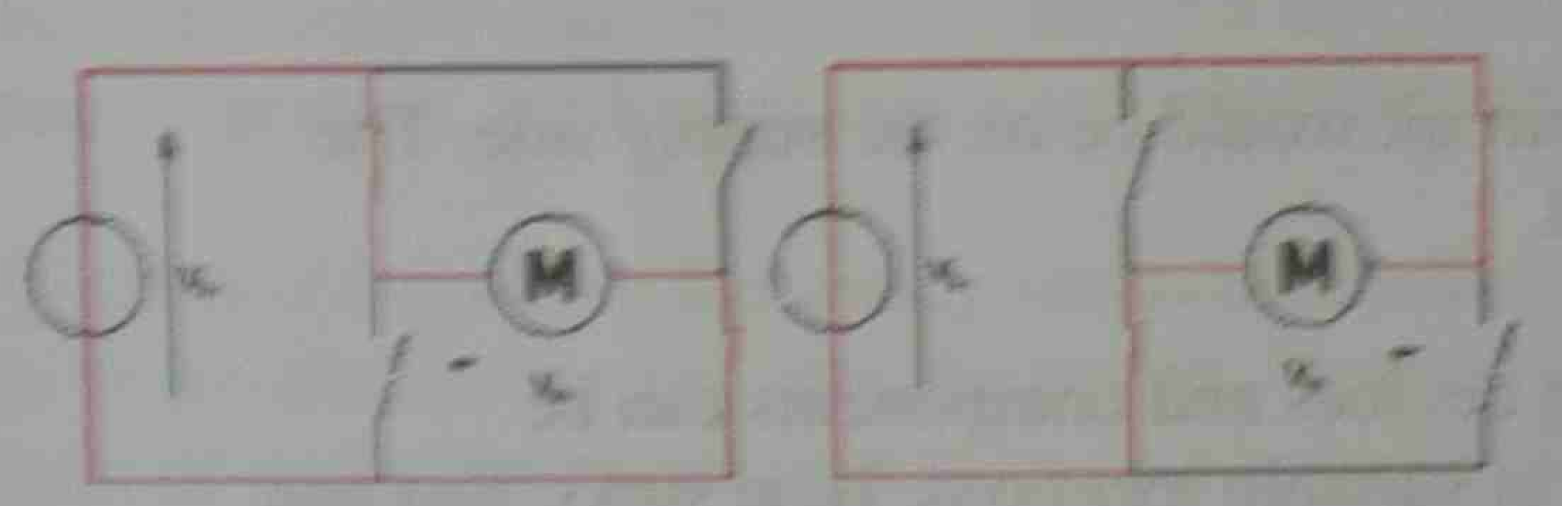
The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically no current, and when it is on, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases close to zero. PWM also works well with digital controls, which, because of their on/off nature, can easily set the needed duty cycle.

Q16.Explain the operation of Bubba oscillator.

The design starts with a DC voltage input that powers all circuits. From here, our circuit is broken into three sequential phases. In the first phase we use a loop of operational amplifiers to generate a perfect sine wave called the "Bubba Oscillator." We also tweak the elements of this oscillator so that the sinusoidal wave travels at 60 Hz or approximately what is coming out of a wall outlet. We tap this circuit at two points to obtain two complementary sine waves. We are not using these voltages to power anything; they are used as what are called "reference voltages" or voltages that guide the operation of another part of the circuit. Because we cannot allow our circuit to use a negative rail (only have one power source), at this stage, our sine wave clips, and we have only the top half of both a sine wave and a –sine wave.

Q17.Sketch H bridge construction & operation table.

Operation

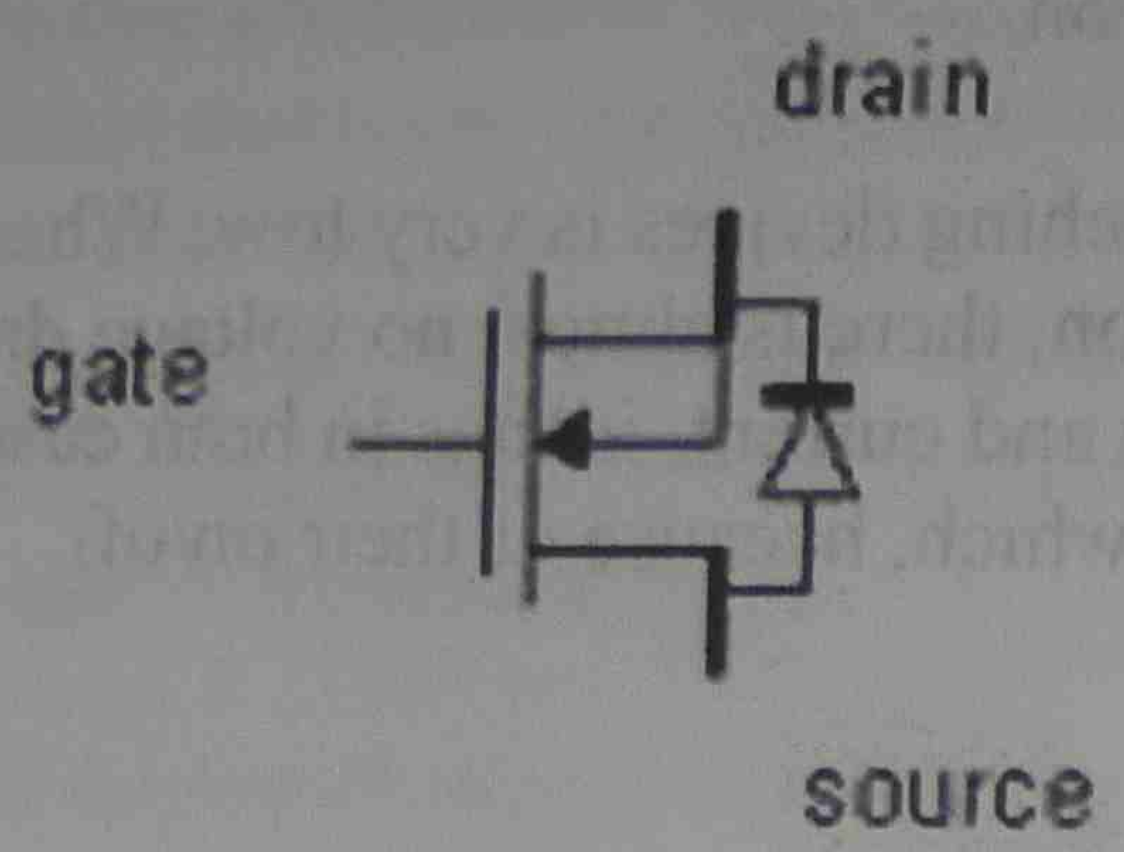


The two basic states of an H bridge

The H-bridge arrangement is generally used to reverse the polarity of the motor, but can also be used to 'brake' the motor, where the motor comes to a sudden stop, as the motor's terminals are shorted, or to let the motor 'free run' to a stop, as the motor is effectively disconnected from the circuit. The following table summarises operation, with S1-S4 corresponding to the diagram above.

S1	S2	S3	S4	Result
1	0	0	1	Motor moves right
0	1	1	0	Motor moves left
0	0	0	0	Motor free runs
0	1	0	1	Motor brakes
1	0	1	0	Motor brakes

Q18.Explain MOSFET driver with sketch.



The source terminal is normally the negative one, and the drain is the positive one (the names refer to the source and drain of electrons). The diagram above shows a diode connected across the MOSFET. This diode is called the "intrinsic diode", because it is built into the silicon structure of the MOSFET. It is a consequence of the way power MOSFETs are created in the layers of silicon, and can be very useful. In most MOSFET architectures, it is rated at the same current as the MOSFET itself.

The power handling of the package without an extra heatsink is very small. On some MOSFETs, the metal tab is connected internally to one of the MOSFETs terminals - usually the drain. This is a disadvantage as it means that you cannot fit more than one MOSFET to a heatsink without electrically isolating the MOSFET package from the metal heatsink. This can be done with thin mica sheets placed between the package and the heatsink. Some MOSFETs have the package isolated from the terminals.

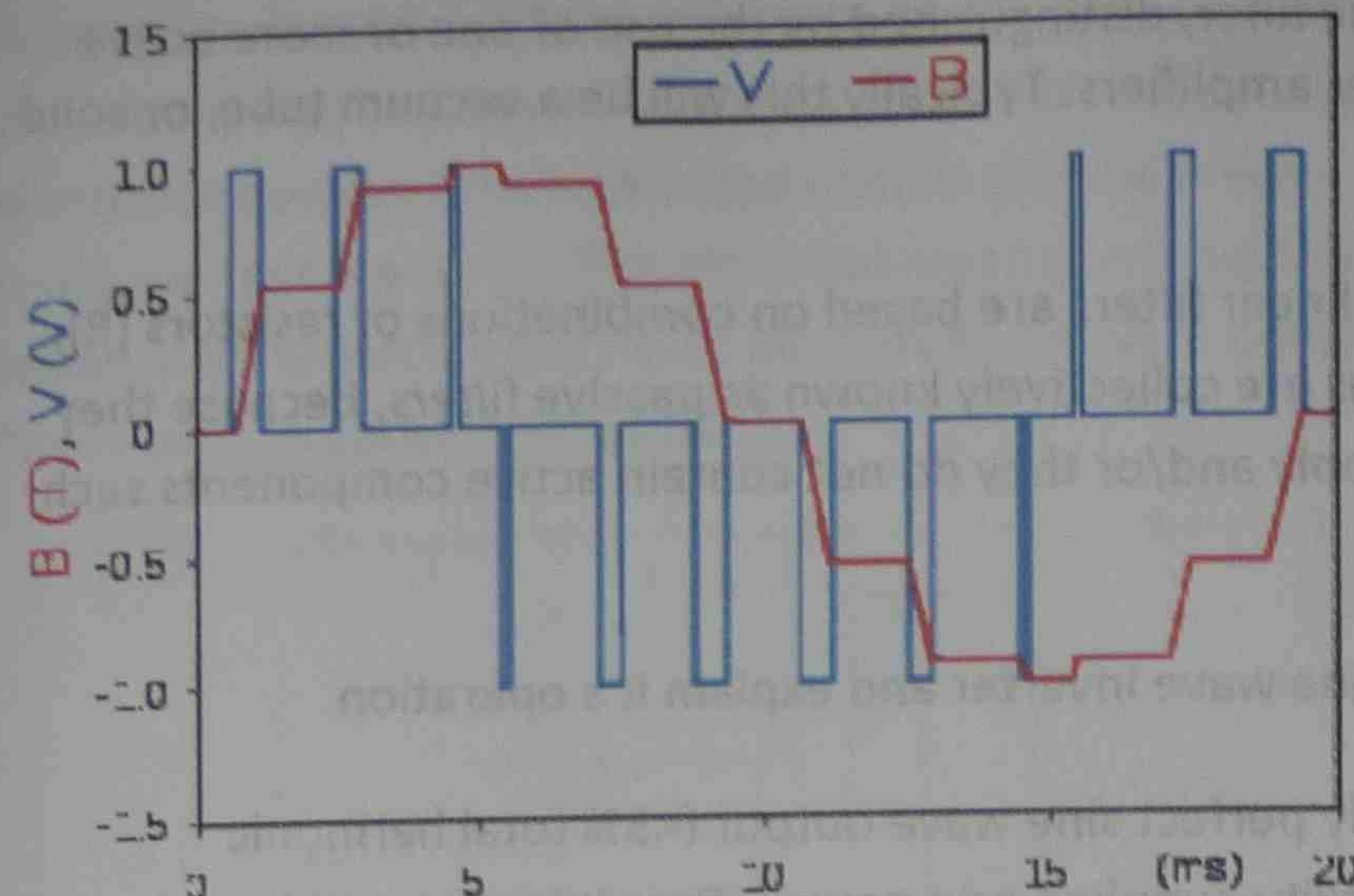
Q19.Explain inverter circuit protection and snubber.

The only way an Inverter could overload a circuit would be on the supply side. The fusing/protection for the inverter is incorrect.

Power electronic circuits and their switching devices and components can be protected from overcurrent by placing fuses at suitable locations. Heat sinks, fins and fans are used to take the excess heat away from switching devices and other components

Protection of switching devices and circuits: Switching devices and circuit components may fail due to the following reasons.
1. Overheating – thermal failure
2. Overcurrent
3. Overvoltage – usually happens during turn-off
4. Excessive
dt
di
5. Excessive
dt
dv
6. Switching loss –excessive switching loss is a major contributing factor of overheating.

Q20.Explain PWM with sketch.



An example of PWM in an AC motor drive: the phase-to-phase voltage (blue) is modulated as a series of pulses that results in a sine-like flux density waveform (red) in the magnetic circuit of the motor. The smoothness of the resultant waveform can be controlled by the width and number of modulated impulses (per given cycle)

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PWM has also been used in certain communication systems where its duty cycle has been used to convey information over a communications.

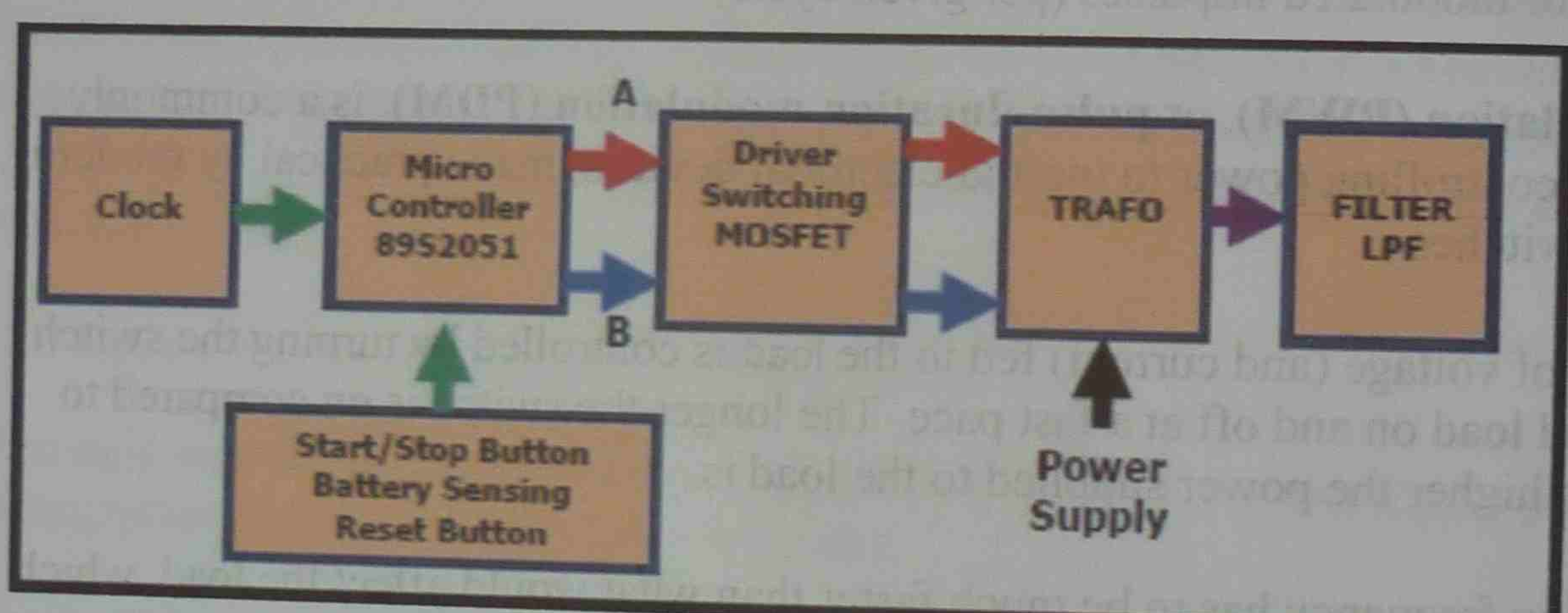
Q21.Explain active filter and passive filter.

An **active filter** is a type of analog electronic filter, distinguished by the use of one or more active components i.e. voltage amplifiers or buffer amplifiers. Typically this will be a vacuum tube, or solid-state (transistor or operational amplifier).

Passive filters: Passive implementations of linear filters are based on combinations of resistors (R), inductors (L) and capacitors (C). These types are collectively known as passive *filters*, because they do not depend upon an external power supply and/or they do not contain active components such as transistors.

Q22.Sketch the example diagram of pure sine wave inverter and explain it's operation.

A **pure sine wave** inverter produces a nearly perfect sine wave output (<3% total harmonic distortion) that is essentially the same as utility-supplied grid power. Thus it is compatible with all AC electronic devices. This is the type used in grid-tie inverters. Its design is more complex, and costs more per unit power.[3] The electrical inverter is a high-power electronic oscillator. It is so named because early mechanical AC to DC converters were made to work in reverse, and thus were "inverted", to convert DC to AC.



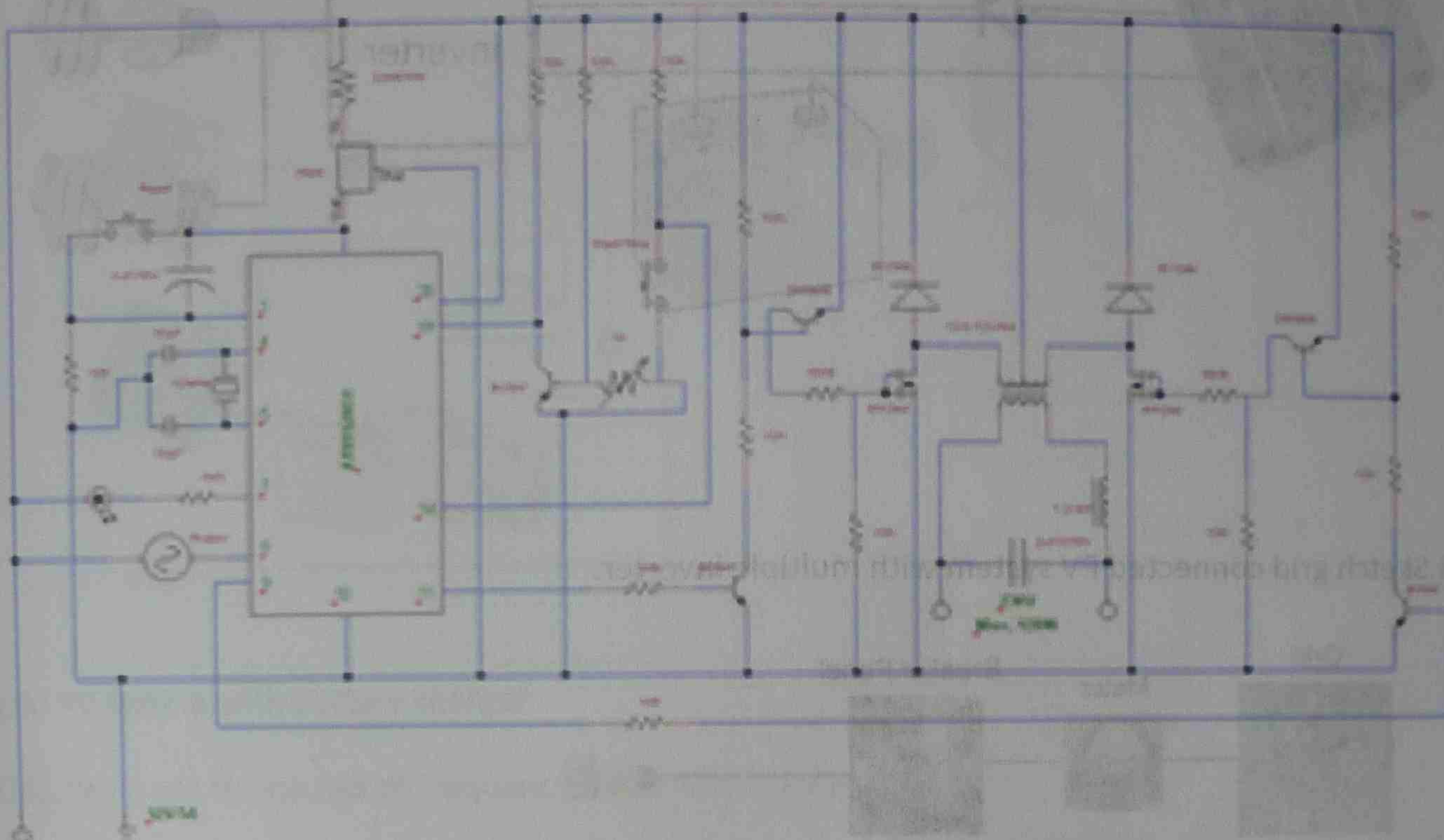
Q25.Explain filter design.

Filter design is the process of designing a filter (in the sense in which the term is used in signal processing, statistics, and applied mathematics), often a linear shift-invariant filter, that satisfies a set of requirements, some of which are contradictory. The purpose is to find a realization of the filter that meets each of the requirements to a sufficient degree to make it useful.

The filter design process can be described as an optimization problem where each requirement contributes with a term to an error function which should be minimized. Certain parts of the design process can be automated, but normally an experienced electrical engineer is needed to get a good result.

Q26.Sketch pure sine wave inverter circuit and explain the operation.

A **pure sine wave** inverter produces a nearly perfect sine wave output (<3% total harmonic distortion) that is essentially the same as utility-supplied grid power. Thus it is compatible with all AC electronic devices. This is the type used in grid-tie inverters. Its design is more complex, and costs more per unit power.[3] The electrical inverter is a high-power electronic oscillator. It is so named because early mechanical AC to DC converters were made to work in reverse, and thus were "inverted", to convert DC to AC.

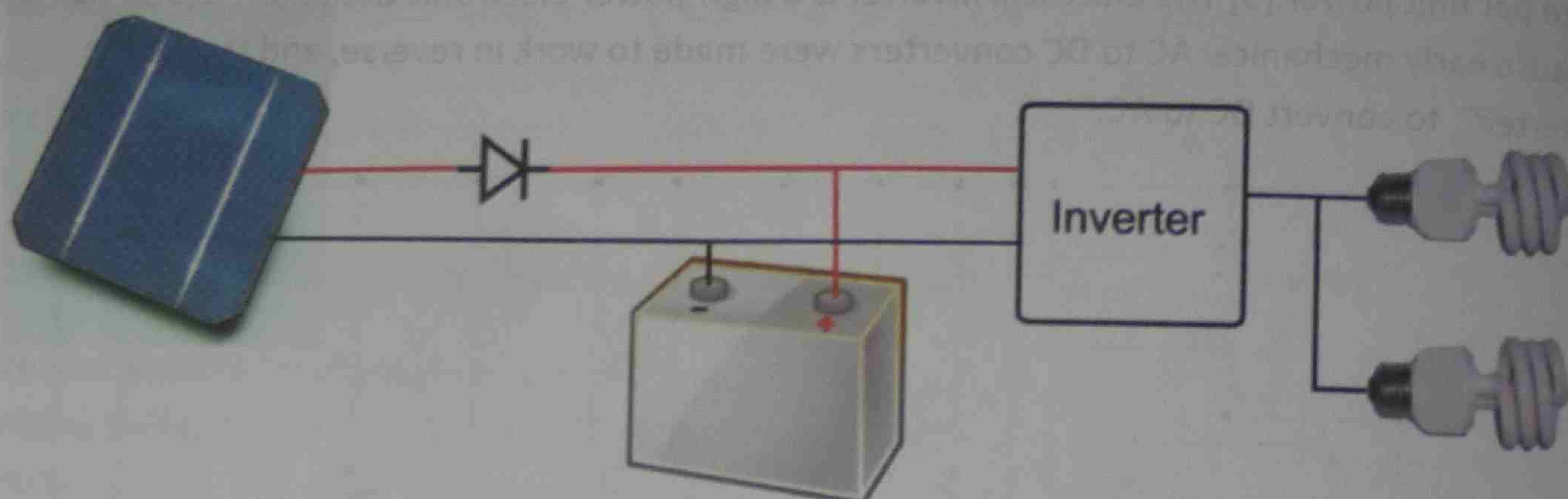


Q27.Sketch overview of grid connected inverter system and explain it's operation.

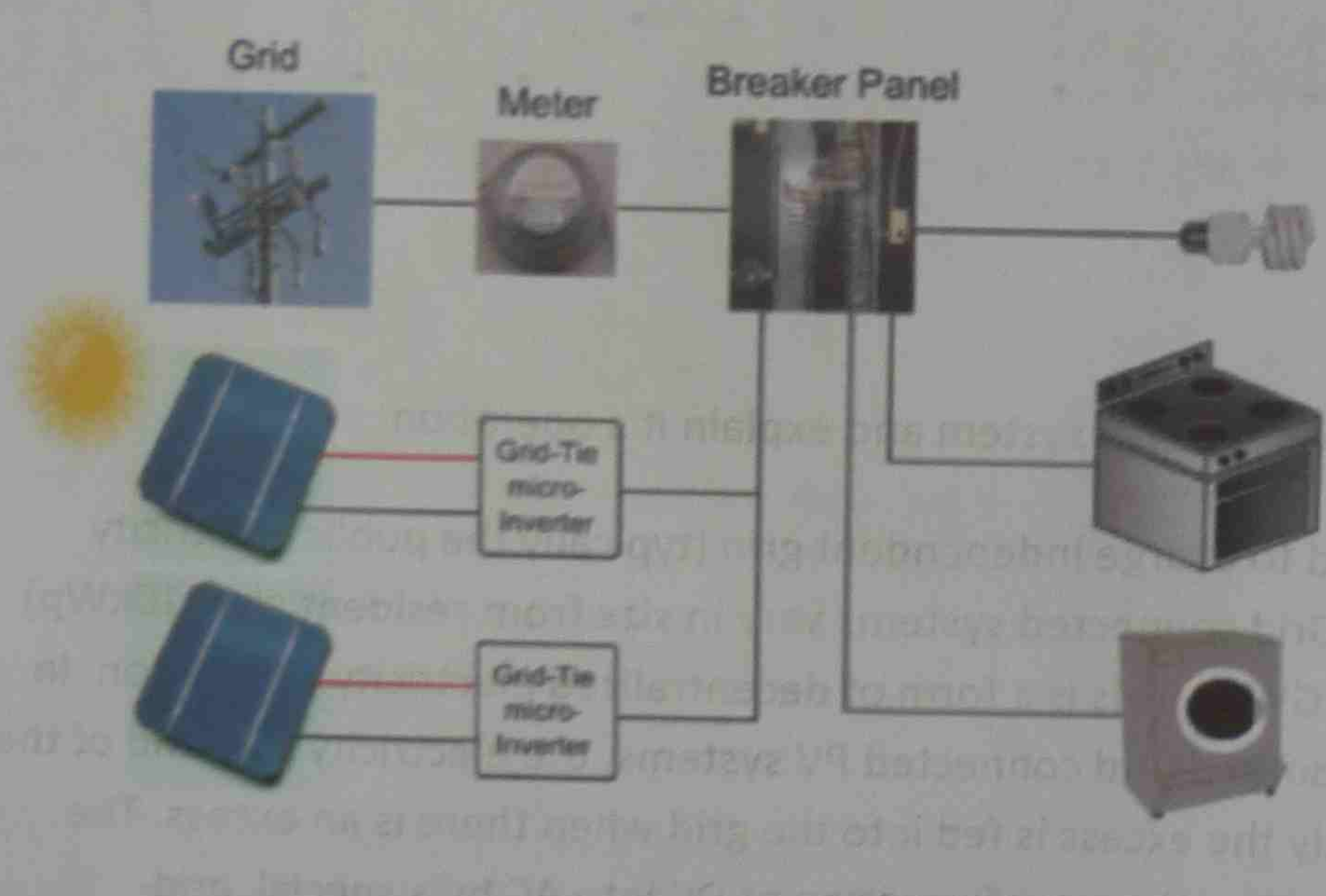
A grid connected system is connected to a large independent grid (typically the public electricity grid) and feeds power into the grid. Grid connected systems vary in size from residential (2-10kWp) to solar power stations (up to 10s of GWp). This is a form of decentralized electricity generation. In the case of residential or building mounted grid connected PV systems, the electricity demand of the building is met by the PV system. Only the excess is fed into the grid when there is an excess. The feeding of electricity into the grid requires the transformation of DC into AC by a special, grid-controlled solar inverter.

A grid-tie inverter (GTI) is a special type of inverter that converts direct current(DC) electricity into alternating current(AC) electricity and feeds it into an existing electrical grid. GTIs are often used to convert direct current produced by many renewable energy sources, such as solar panels or small wind turbines, into the alternating current used to power homes and businesses. The technical name for a grid-tie inverter is "grid-interactive inverter". They may also be called synchronous inverters. Grid-interactive inverters typically cannot be used in standalone applications where utility power is not available.

Grid-connected photovoltaic power systems are power systems energised by photovoltaic panels which are connected to the utility grid. Grid-connected photovoltaic power systems comprise of Photovoltaic panels, MPPT, solar inverters, power conditioning units and grid connection equipments. Unlike Stand-alone photovoltaic power systems these systems do not have batteries. When conditions are right, the grid-connected PV system supplies the excess power, beyond consumption by the connected load, to the utility grid.



Q28.Sketch grid connected PV system with multiple inverter.



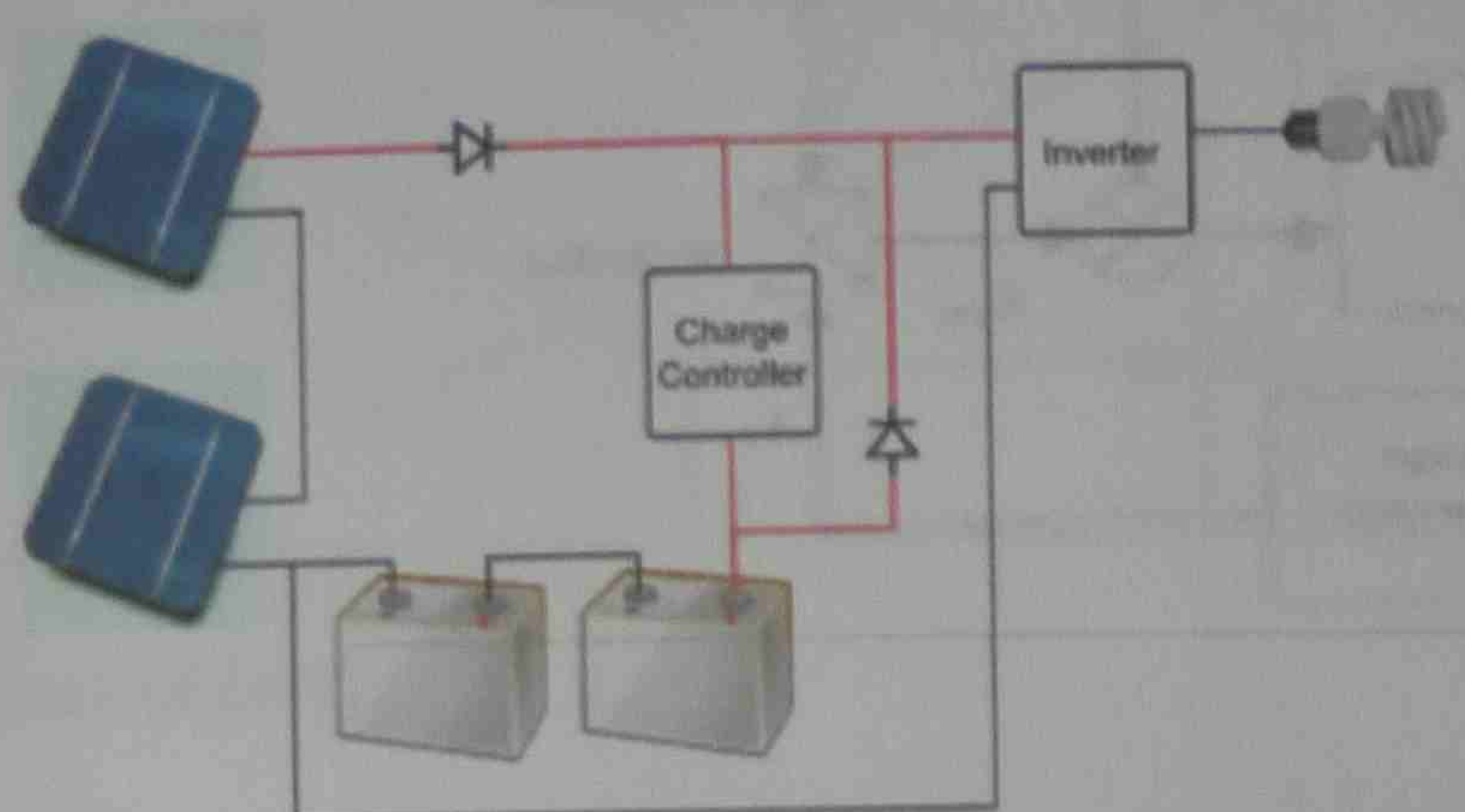
Q29.Explain the energy saving aspects of solar electrical system.

The average household today pays nearly $170 each month in home energy costs. Some estimates have energy costs pegged at almost $200 per month, a cost of $2,400 for the entire year.

It's important to look at the long term picture when evaluating the amount of savings the addition of a solar panel system to one's home will bring. With energy expenses rising each year of due to rising utility rates it's easy to see how fast the money saved builds up.

Q30.Explain PV inverter system with sketch.

A **solar inverter** or **PV inverter** is a critical component in a solar energy system. It performs the conversion of the variable DC output of the Photovoltaic (PV) modules into a utility frequency AC current that can be fed into the commercial electrical grid or used by a local, off-grid electrical network. An inverter allows use of ordinary mains-operated appliances on a direct current system. Solar inverters have special functions adapted for use with PV arrays, including maximum power point tracking and anti-islanding protection.



grid PV system with battery charger.

Q31.What are the causes of frequency distortion to PV inverter?

An inverter selected for in grid-connected PV applications has to meet the requirements of a relevant standard that specifies distortion limits. In Australia this would be AS4777.2. The question is whether the levels of low frequency harmonics in the output of unipolar inverters fall within the limits specified by the standard. This question is best answered on a case by case basis. For the inverter considered in section 3 above, the third harmonic is the worst one and its levels are shown in figure 10.
Total harmonic distortion is shown in figure 11. It has been assumed that non-zero switching delay is the only reason for the generation of low frequency harmonics. The inverter is designed for a rated output of 4 A, therefore it would satisfy the requirements of AS4777.2 even if switching delay is as high as 8 μs. Individual levels for the second to the ninth harmonic should be limited to 4% whereas total harmonic distortion should be limited to 5%

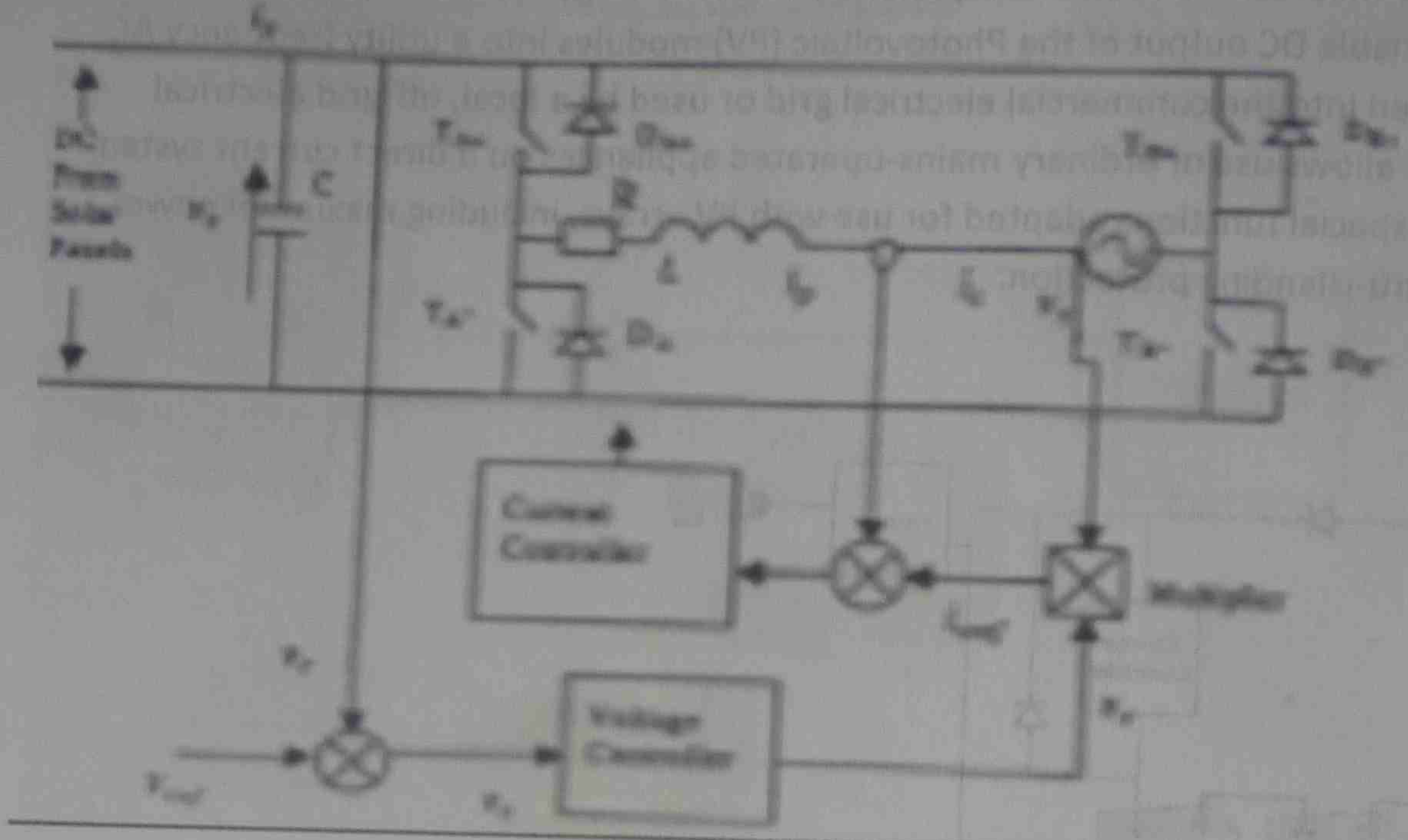
Q32.Write the equation for switching delay.

It is given by the following formula:

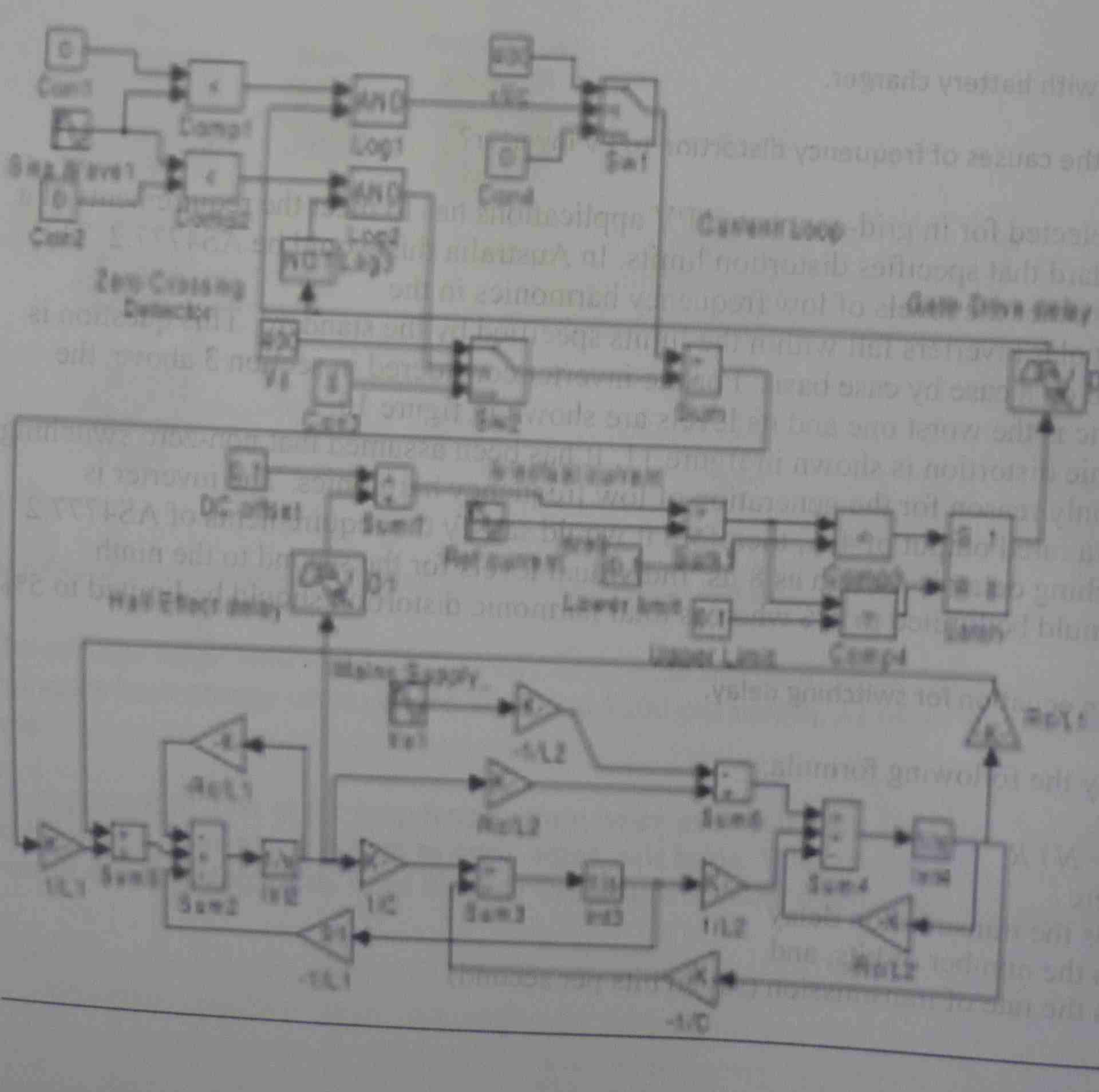
$$D_T = N / R$$

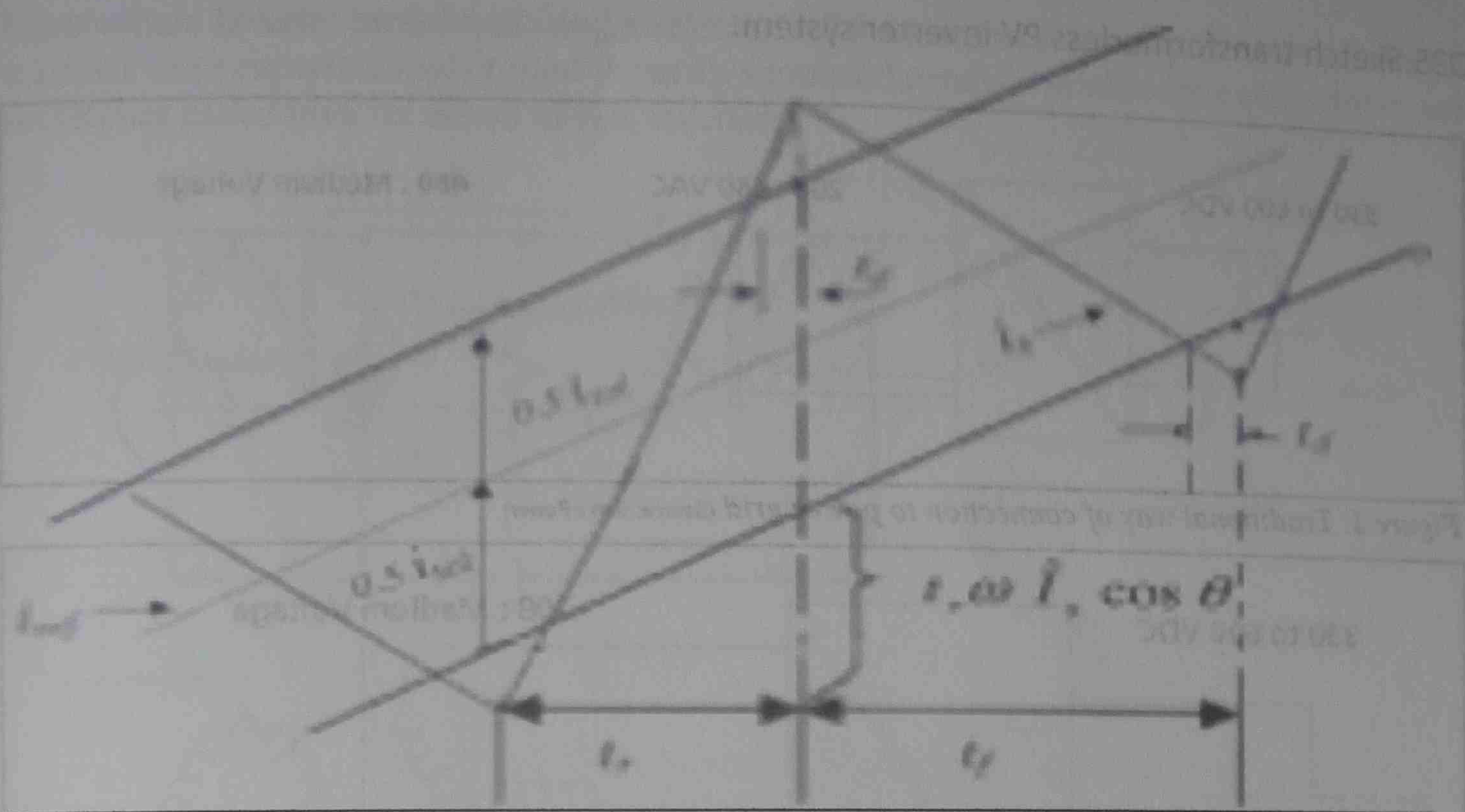
where
D_T is the transmission delay
N is the number of bits, and
R is the rate of transmission (say in bits per second)

Q33.Sketch inverter output current diagrams & total harmonic distortion for unipolar switching & bipolar switching.



Single-phase grid connected PV inverter system.





(Is = peak of $isref$)

Bipolar Mode

Q34.What are the topologies of grid connected inverter?

Grid-tie inverters that are available on the market today use a number of different technologies. The inverters may use the newer high-frequency transformers, conventional low-frequency transformers, or without transformer. Instead of converting direct current directly to 120 or 240 volts AC, high-frequency transformers employ a computerized multi-step process that involves converting the power to high-frequency AC and then back to DC and then to the final AC output voltage.[1] Transformerless inverters, which boast lighter weight and higher efficiencies than their counterparts with transformers, are popular in Europe. However, transformerless inverters have been slow to enter the US market. Until 2005, NEC code required all solar electric systems to be negative grounded, an electrical configuration that interferes with the operation of transformerless inverters. The issue at stake currently is that there are concerns about having transformerless electrical systems feed into the public utility grid since the lack of galvanic isolation between the DC and AC circuits could allow the passage of dangerous DC faults to be transmitted to the AC side.

Most grid-tie inverters on the market include a maximum power point tracker on the input side that enables the inverter to extract a maximum amount of power from its intended power source. Since MPPT algorithms differ for solar panels and wind turbines, specially made inverters for each of these power sources are available.

Q35.Sketch transformerless PV inverter system.

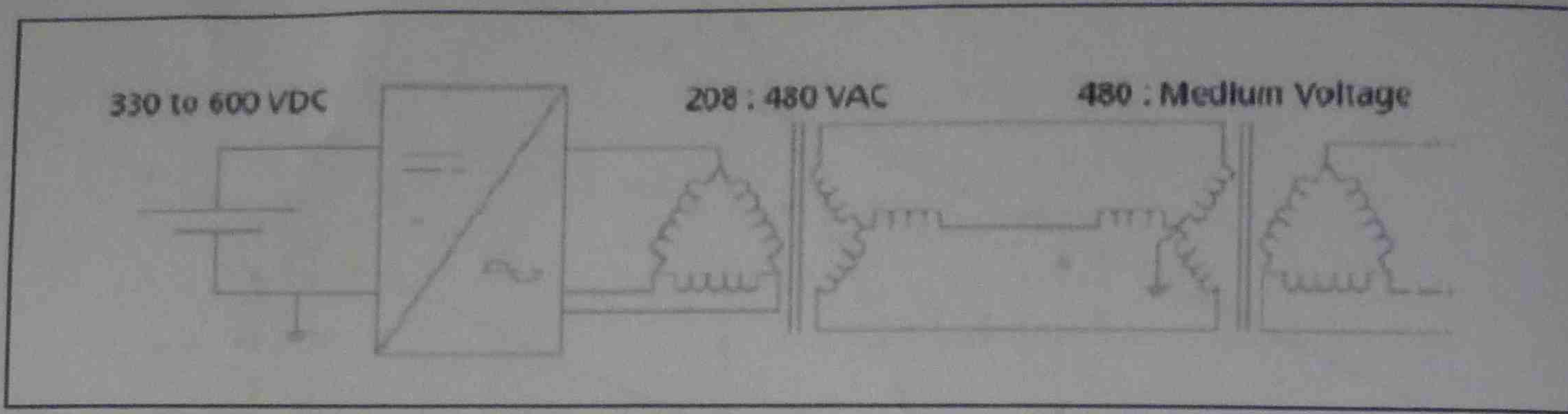


Figure 1. Traditional way of connection to power grid (Source: Samil Power)

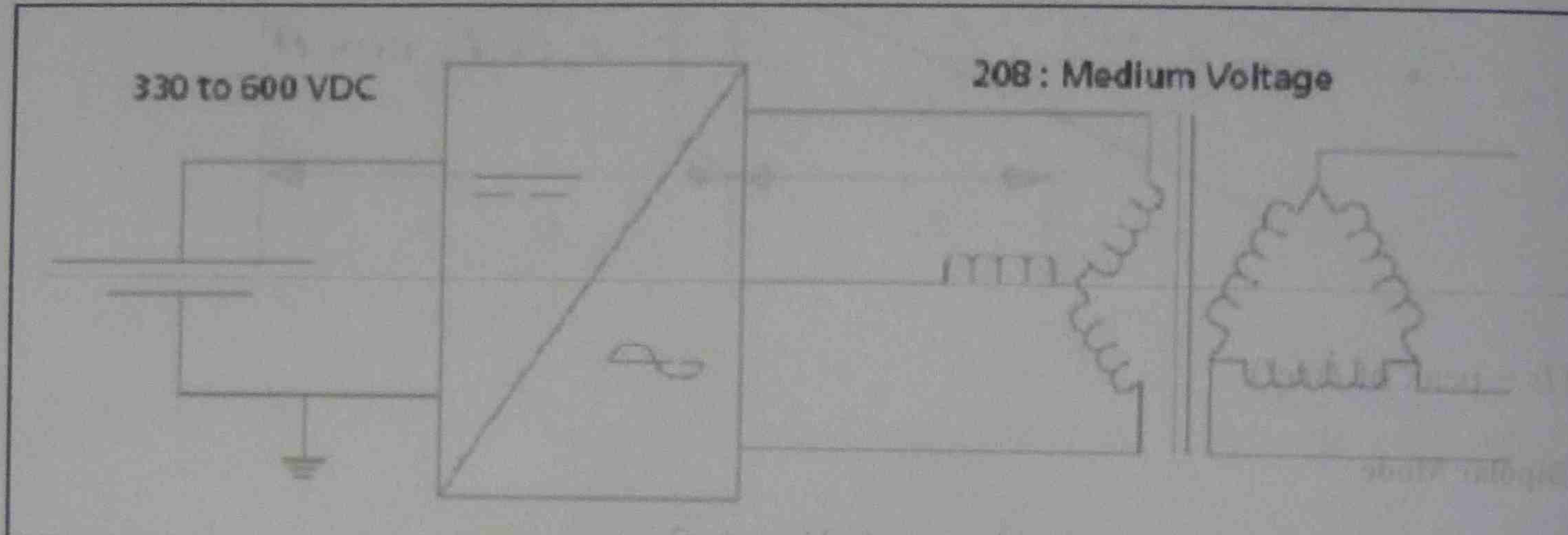
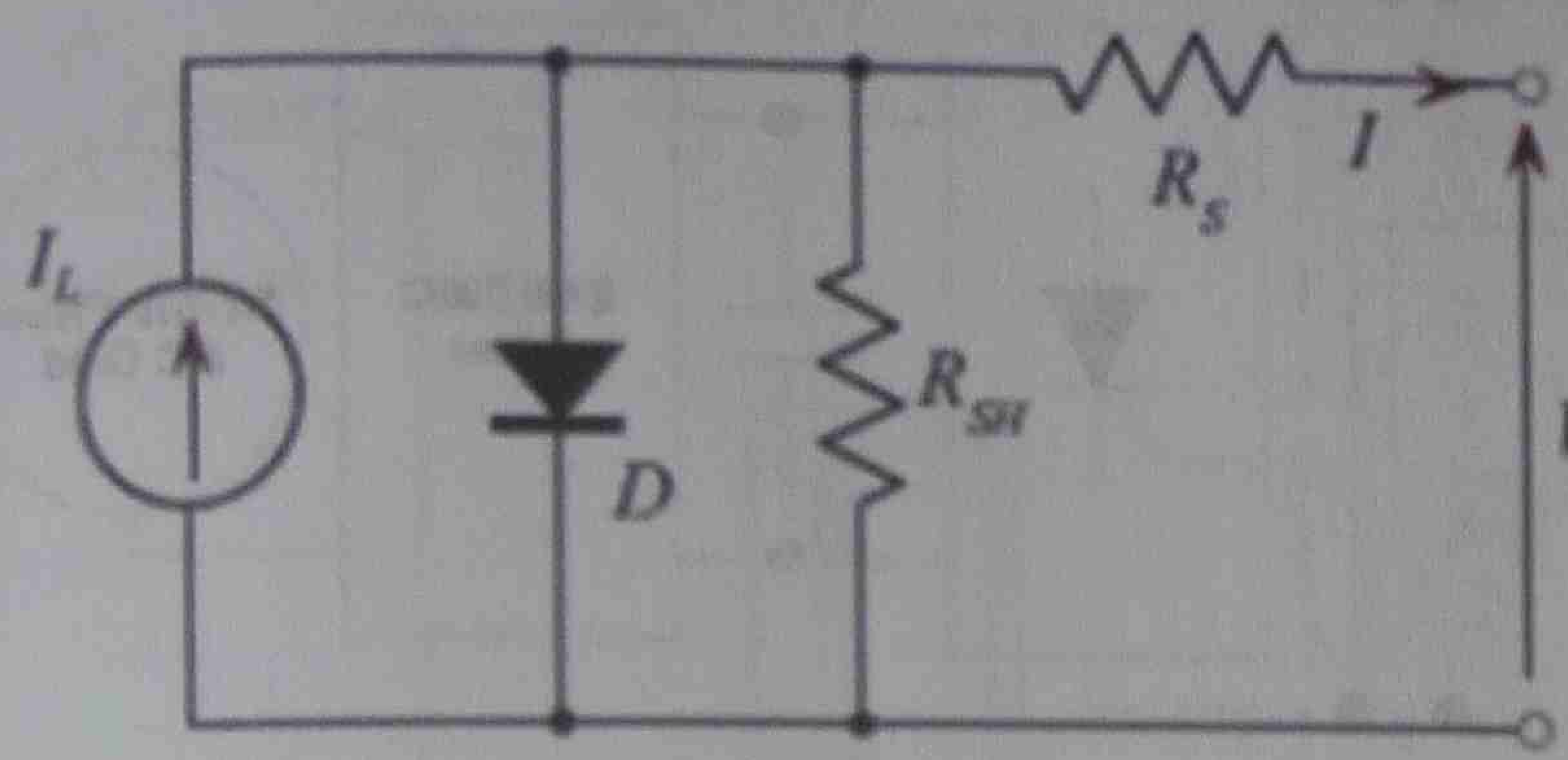


Figure 2. New way of connection to power grid (Source: Samil Power)

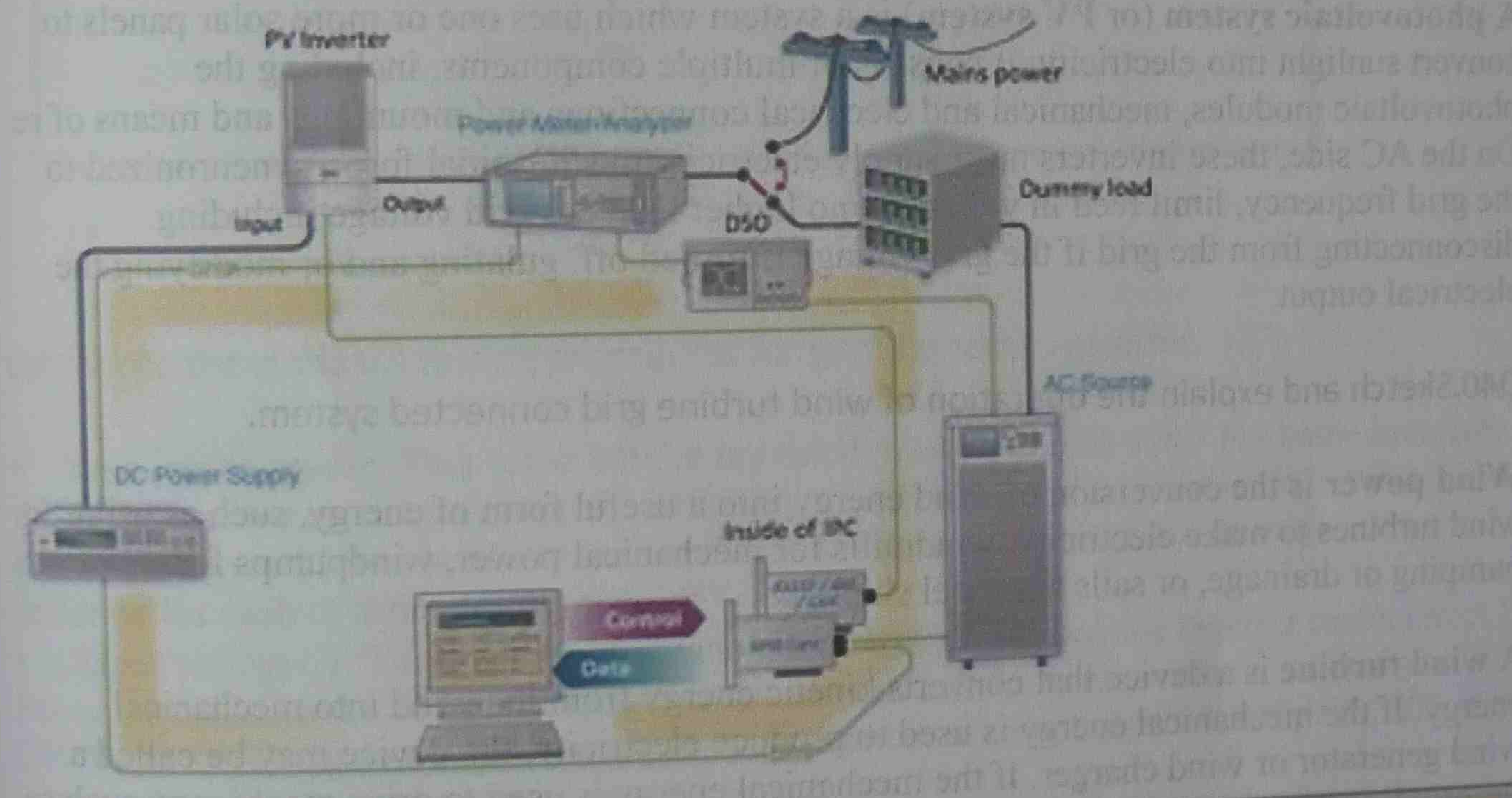
Q36.Sketch PV inverter with frequency transformer .

A variable-frequency drive controls the operating speed of an AC motor by controlling the frequency and voltage of the power supplied to the motor. An inverter provides the controlled power. In most cases, the variable-frequency drive includes a rectifier so that DC power for the inverter can be provided from main AC power. Since an inverter is the key component, A number of political, environmental and technical factors have resulted in the increase of implementation of renewable technology including grid connected photovoltaic inverters. As a result, new topologies for grid connected inverters providing higher efficiencies and lower manufacturing costs have been developed. In particular, designs utilising transformerless topologies have steadily increased. While there are clear associated advantages of implementing these new transformerless topologies, new potential issues such as DC current injection and capacitive leakage currents are introduced. Part A of this report presents a clearly defined test circuit setup and procedure for testing DC current injection for grid-connected single-phase photovoltaic inverters implementing both transformerless and high frequency transformer topologies. The results demonstrated that the test circuit setup and testing procedure is suitable for inclusion in a future amendment to AS4777.2. It is however proposed that before these amendments are recommended, further investigation is required to determine what power levels all inverters are required to be tested at and how many tests per inverter are required. Part B of this report defines and models a variety of transformerless inverter topologies, switching schemes and output filter configurations and clearly defines their operation. All of these various models have been simulated to determine which designs are suitable for applications in regards to reducing capacitive leakage currents in an effort to eliminate potential risks to users and to ensure electromagnetic compatability. Two commercially available and one anonymous Grid-connected Transformerless Single-phase

Photovoltaic Inverter models utilising a selection of the simulated topologies and switching schemes were experimentally tested to verify simulated results. variable-frequency drives are sometimes called inverter drives or just inverters.



Q37.Sketch PV inverter with several conversion stage & high frequency transformer.



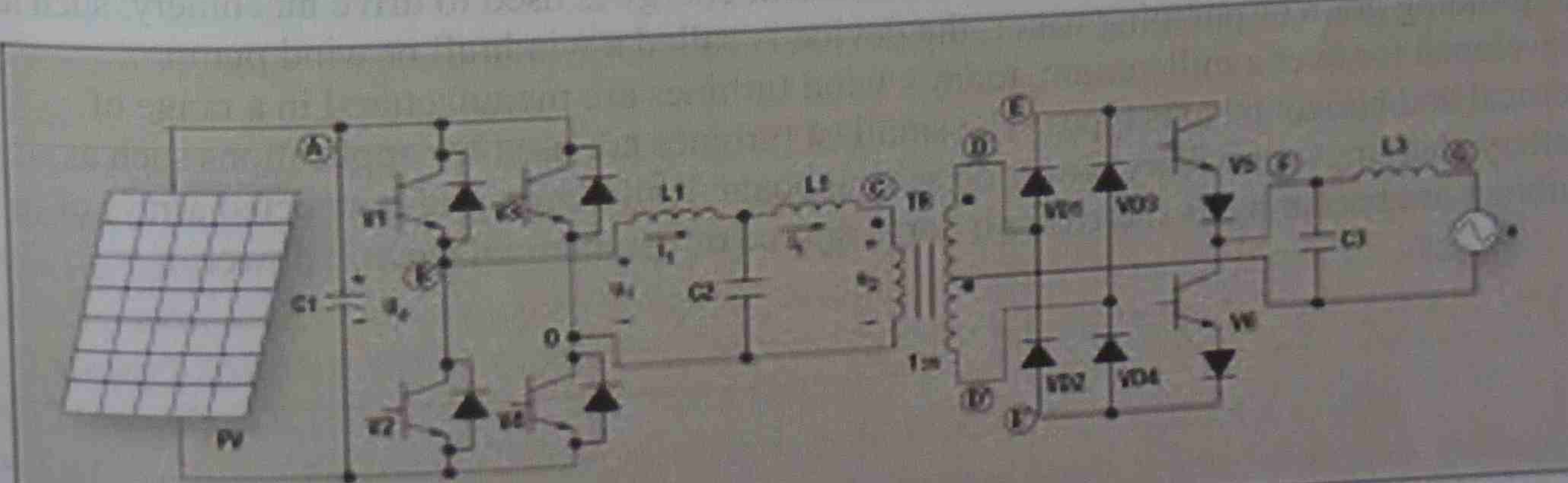
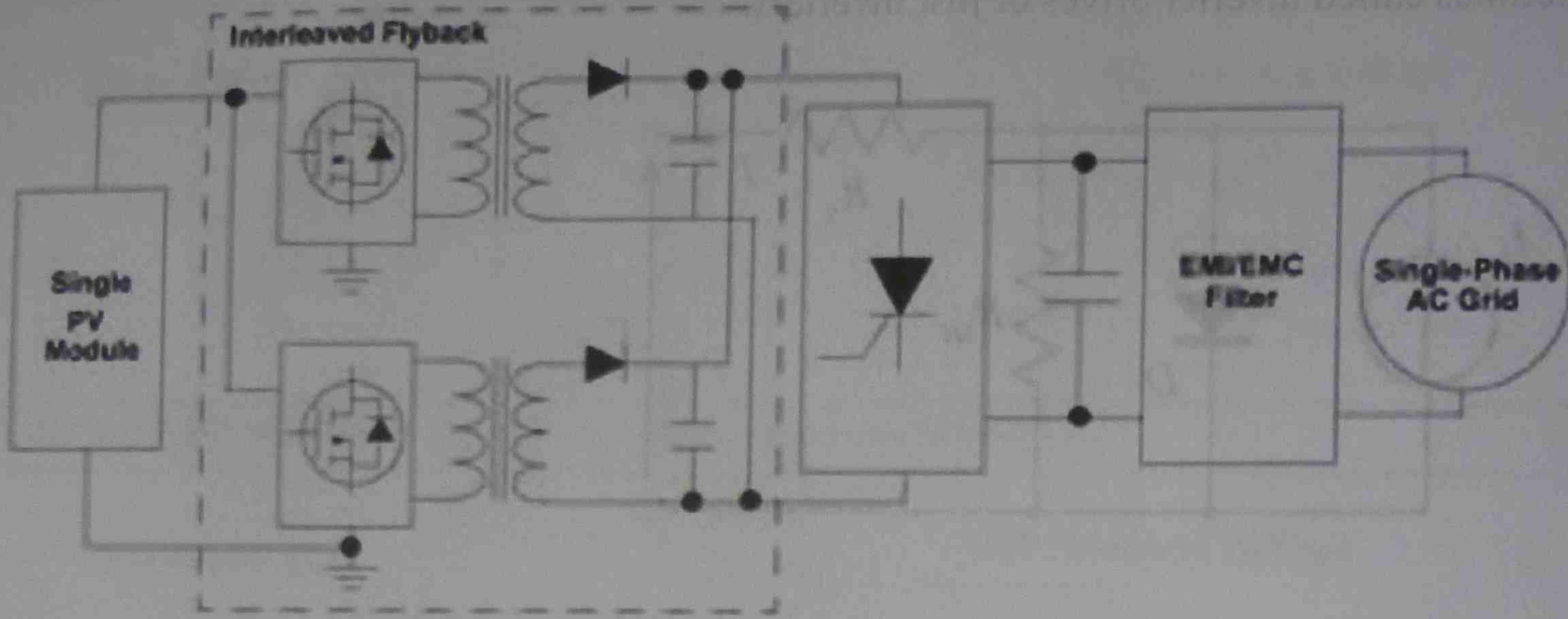


Fig. 1. System topology of the proposed single-phase current-source grid-connected inverter that consists of a high-frequency full-bridge inverter, immittance converter, center-tapped transformer, high-frequency bridge rectifier, power-frequency inverter and low-pass filter.

Q38.Sketch PV inverter with several conversion stages including boost stage



A single-**stage microinverter** performs DC **boost** and AC waveform

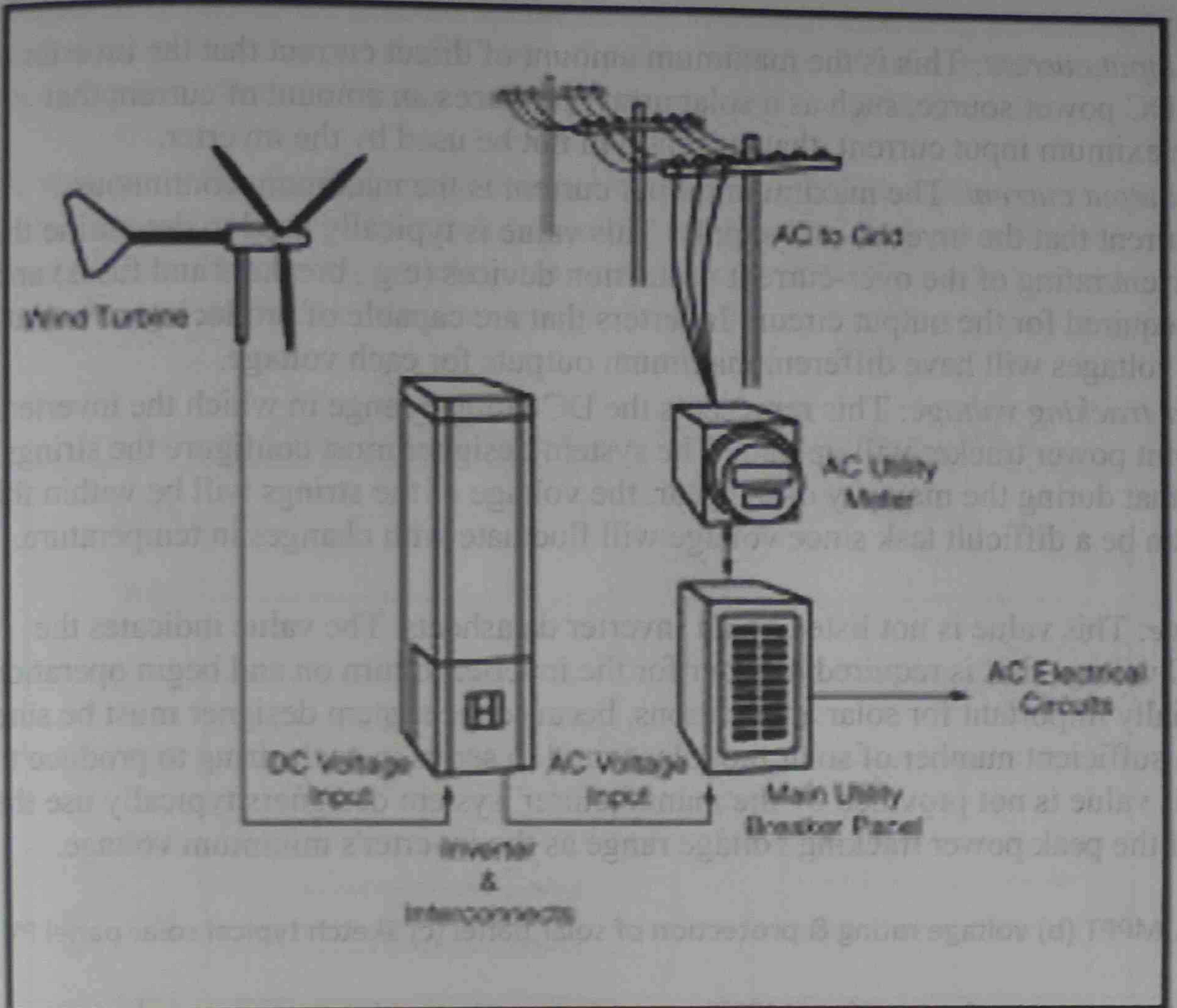
Q39.Explain the configuration and standards for grid connected PV system with diagram.

A **photovoltaic system** (or **PV system**) is a system which uses one or more solar panels to convert sunlight into electricity. It consists of multiple components, including the photovoltaic modules, mechanical and electrical connections and mountings and means of re On the AC side, these inverters must supply electricity in sinusoidal form, synchronized to the grid frequency, limit feed in voltage to no higher than the grid voltage including disconnecting from the grid if the grid voltage is turned off. gulating and/or modifying the electrical output.

Q40.Sketch and explain the operation of wind turbine grid connected system.

Wind power is the conversion of wind energy into a useful form of energy, such as using wind turbines to make electricity, windmills for mechanical power, windpumps for water pumping or drainage, or sails to propel ships.

A **wind turbine** is a device that converts kinetic energy from the wind into mechanical energy. If the mechanical energy is used to produce electricity, the device may be called a wind generator or wind charger. If the mechanical energy is used to drive machinery, such as for grinding grain or pumping water, the device is called a windmill or wind pump. Developed for over a millennium, today's wind turbines are manufactured in a range of vertical and horizontal axis types. The smallest turbines are used for applications such as battery charging or auxiliary power on sailing boats; while large grid-connected arrays of turbines are becoming an increasingly large source of commercial electric power.



Q41.Write the standard testing procedures for grid connected inverter.

- *Rated output power*: This value will be provided in watts or kilowatts. For some inverters, they may provide an output rating for different output voltages. For instance, if the inverter can be configured for either 240 VAC or 208 VAC output, the rated power output may be different for each of those configurations.
- *Output voltage(s)*: This value indicates to which utility voltages the inverter can connect. For smaller inverters that are designed for residential use, the output voltage is usually 240 VAC. Inverters that target commercial applications are rated for 208, 240, 277, 400, or 480 VAC and may also produce three phase power.
- *Peak efficiency*: The peak efficiency represents the highest efficiency that the inverter can achieve. Most grid-tie inverters on the market as of July 2009 have peak efficiencies of over 94%, some as high as 96%. The energy lost during inversion is for the most part converted into heat. This means that in order for an inverter to put out the rated amount of power it will need to have a power input that exceeds the output. For example, a 5000 W inverter operating at full power at 95% efficiency will require an input of 5,263 W (rated power divided by efficiency). Inverters that are capable of producing power at different AC voltages may have different efficiencies associated with each voltage.
- *CEC weighted efficiency*: This efficiency is published by the California Energy Commission on its GoSolar website. In contrast to peak efficiency, this value is an average efficiency and is a better representation of the inverter's operating profile. Inverters that are capable of producing power at different AC voltages may have different efficiencies associated with each voltage.

- *Maximum input current*: This is the maximum amount of direct current that the inverter will use. If a DC power source, such as a solar array, produces an amount of current that exceeds the maximum input current, that current will not be used by the inverter.
- *Maximum output current*: The maximum output current is the maximum continuous alternating current that the inverter will supply. This value is typically used to determine the minimum current rating of the over-current protection devices (e.g., breakers and fuses) and disconnects required for the output circuit. Inverters that are capable of producing power at different AC voltages will have different maximum outputs for each voltage.
- *Peak power tracking voltage*: This represents the DC voltage range in which the inverter's maximum point power tracker will operate. The system designer must configure the strings optimally so that during the majority of the year, the voltage of the strings will be within this range. This can be a difficult task since voltage will fluctuate with changes in temperature.

- *Start voltage*: This value is not listed on all inverter datasheets. The value indicates the minimum DC voltage that is required in order for the inverter to turn on and begin operation. This is especially important for solar applications, because the system designer must be sure that there is a sufficient number of solar modules wired in series in each string to produce this voltage. If this value is not provided by the manufacturer, system designers typically use the lower band of the peak power tracking voltage range as the inverter's minimum voltage.

Q42.Explain (a)MPPT (b) voltage rating & protection of solar panel (c) Sketch typical solar panel PV curve.

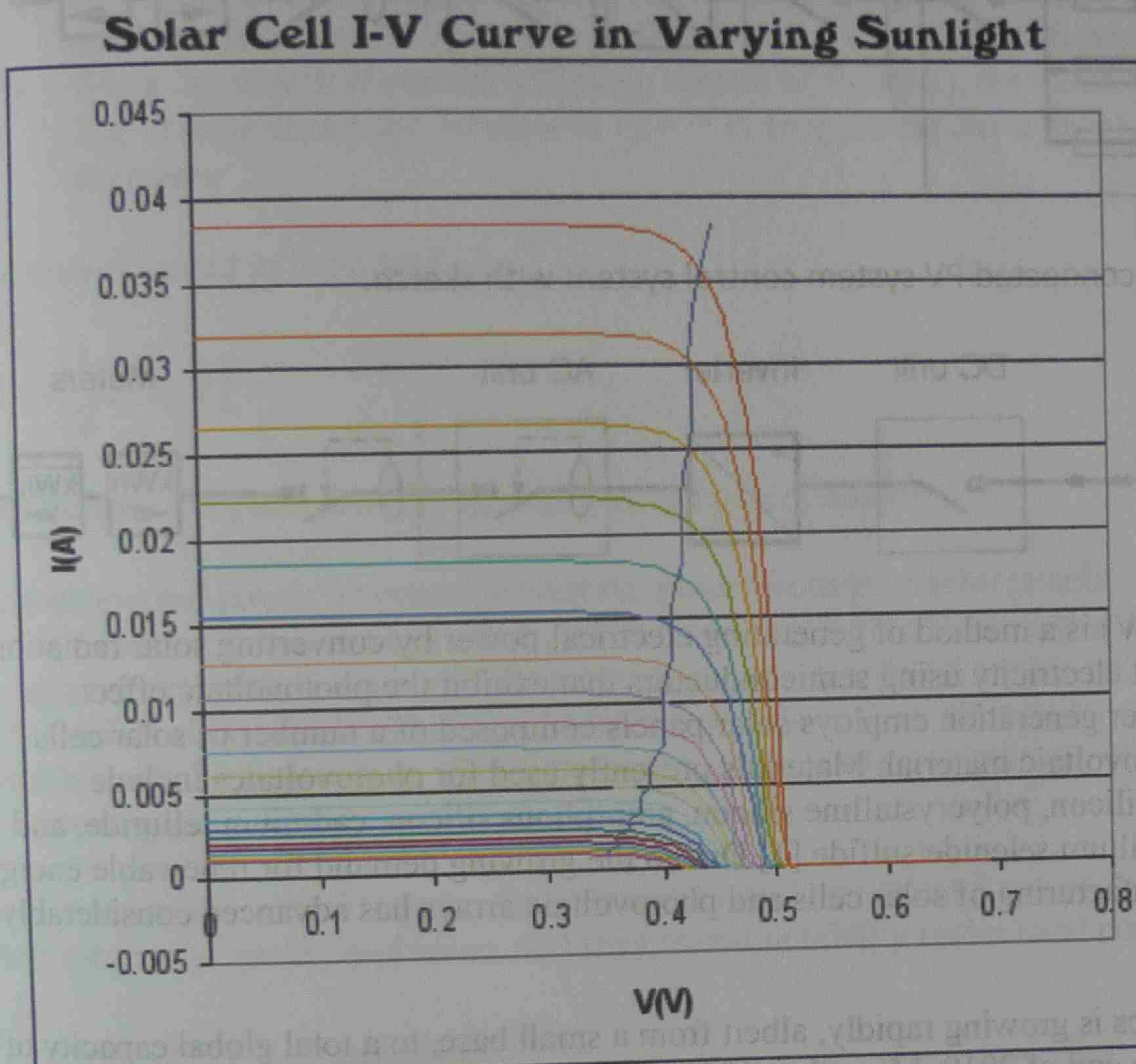
a) **Maximum power point tracking** (MPPT) is a technique that grid tie inverters, solar battery chargers and similar devices use to get the maximum possible power from the PV array. Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency known as the *I-V curve*. It is the purpose of the MPPT system to sample the output of the cells and apply a resistance (load) to obtain maximum power for any given environmental conditions. Essentially, this defines the current that the inverter should draw from the PV in order to get the maximum possible power (since power equals voltage times current).

This method makes use of the fact that the ratio of maximum power point voltage to the open circuit voltage is often close to a constant value, with 0.76 being a common estimate. One problem with this method arises from the fact that it requires momentarily setting the PV array current to 0 to measure the array's open circuit voltage. The array's operating voltage is then set to (for example) 76% of this measured value. But during the time the array is disconnected, the available energy is wasted. It has also been found that while 76% of the open circuit voltage is often a very good approximation, it does not always coincide with the maximum power point.[5] Thus this method may not give as much efficiency as others, especially if conditions are highly variable or the physical behavior of the cell deviates from expectations. Its main advantage is that it is relatively simple to implement and thus usually less expensive.

Normally, grid-tied inverters will shut off if they do not detect the presence of the utility grid. If, however, there are load circuits in the electrical system that happen to resonate at the frequency of the utility grid, the inverter may be fooled into thinking that the grid is still active even after it had been shut down. This is called islanding.

An inverter designed for grid-tie operation will have anti-islanding protection built in; it will inject small pulses that are slightly out of phase with the AC electrical system in order to cancel any stray resonances that may be present when the grid shuts down.

The voltage and/or the frequency change during the grid failure is measured and a positive feedback loop is employed to push the voltage and /or the frequency further away from its nominal value. Frequency or voltage may not change if the load matches very well with the inverter output or the load has a very high quality factor (reactive to real power ratio).

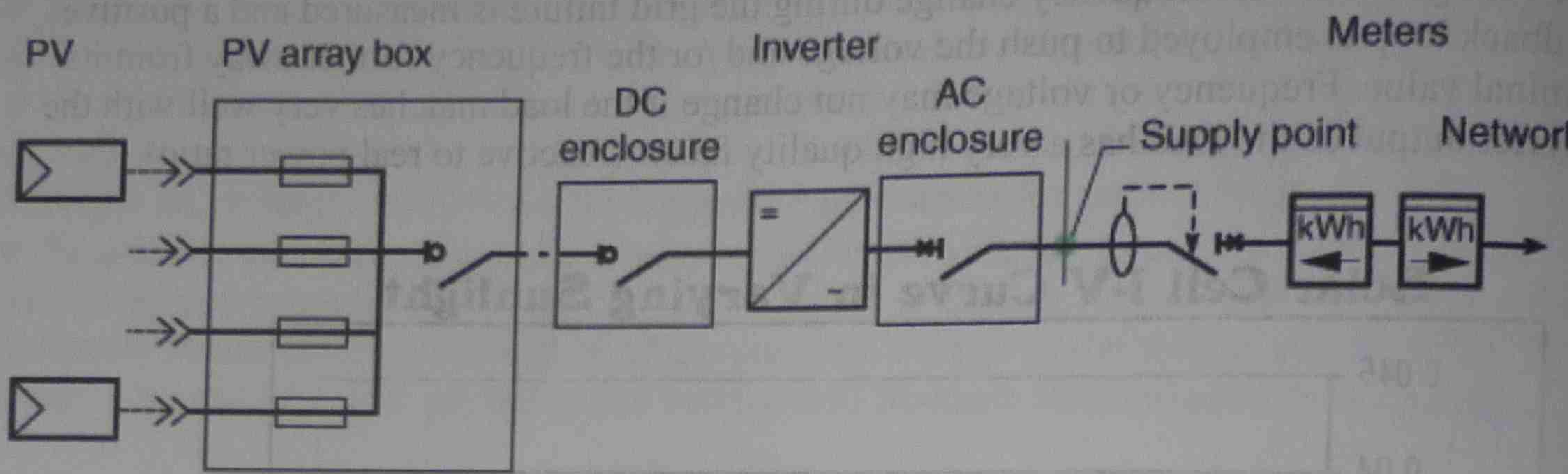


Q43.Sketch multi string PV inverter system.

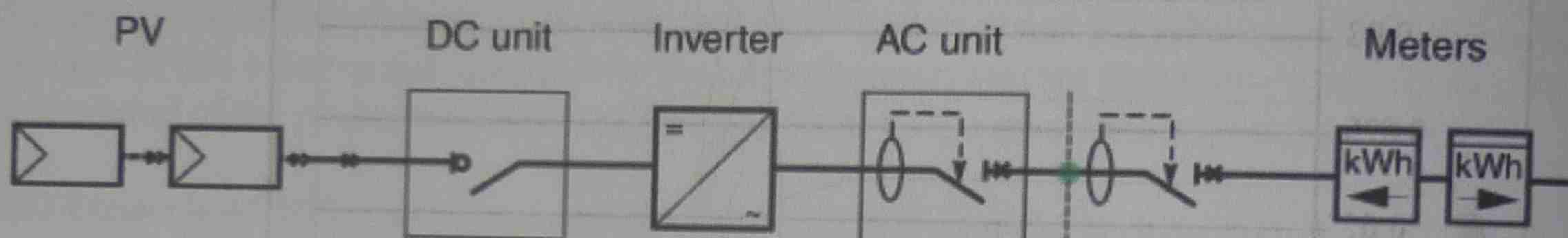
A **solar micro-inverter**, also referred as microinverter or micro inverter, converts direct current (DC) from a single solar panel to alternating current (AC). The electric power from several micro-inverters is combined and fed into an existing electrical grid. Micro-inverters contrast with conventional central inverter devices, which are connected to multiple solar panels.

Micro-inverters have several advantages over conventional central inverters. The main advantage is that, even small amounts of shading, debris or snow lines in any one solar panel, or a panel failure, does not disproportionately reduce the output of an entire array. Each micro-inverter obtains optimum power by performing maximum power point tracking for its connected panel.

Their primary disadvantages are that they have a higher equipment initial cost per peak watt than the equivalent power in a central inverter, and are normally located near the panel, where they may be harder to maintain. These issues are however surpassed by micro-inverters having much higher durability and simplicity of initial installation.



Q44.Explain grid connected PV system control system with sketch.



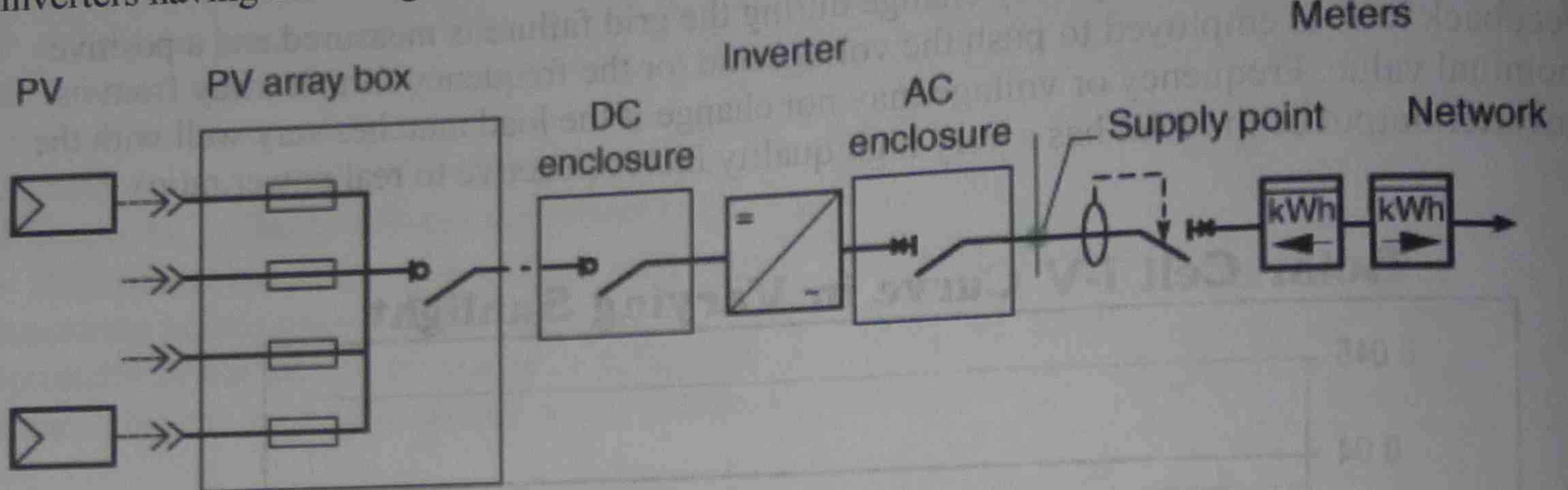
Photovoltaics (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material. Materials presently used for photovoltaics include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium selenide/sulfide.[1] Due to the growing demand for renewable energy sources, the manufacturing of solar cells and photovoltaic arrays has advanced considerably in recent years.

Solar photovoltaics is growing rapidly, albeit from a small base, to a total global capacity of 40,000 MW at the end of 2010. More than 100 countries use solar PV. Installations may be ground-mounted (and sometimes integrated with farming and grazing) or built into the roof or walls of a building (building-integrated photovoltaics).

Q45.Write the mathematical modelling for switched mode inverter.

A **switched-mode power supply (switching-mode power supply, SMPS,** or simply **switcher)** is an electronic power supply that incorporates a switching regulator in order to be highly efficient in the conversion of electrical power. Like other types of power supplies, an SMPS transfers power from a source like the electrical power grid to a load (e.g., a personal computer) while converting voltage and current characteristics. An SMPS is usually employed to efficiently provide a regulated output voltage, typically at a level different from the input voltage. Unlike a linear power supply, the pass transistor of a switching mode supply switches very quickly (typically between 50 kHz and 1 MHz) between full-on and full-off states, which minimizes wasted energy. Voltage regulation is provided by varying the ratio of on to off time. In contrast, a linear power supply must dissipate the excess voltage to

Their primary disadvantages are that they have a higher equipment initial cost per peak watt than the equivalent power in a central inverter, and are normally located near the panel, where they may be harder to maintain. These issues are however surpassed by micro-inverters having much higher durability and simplicity of initial installation.



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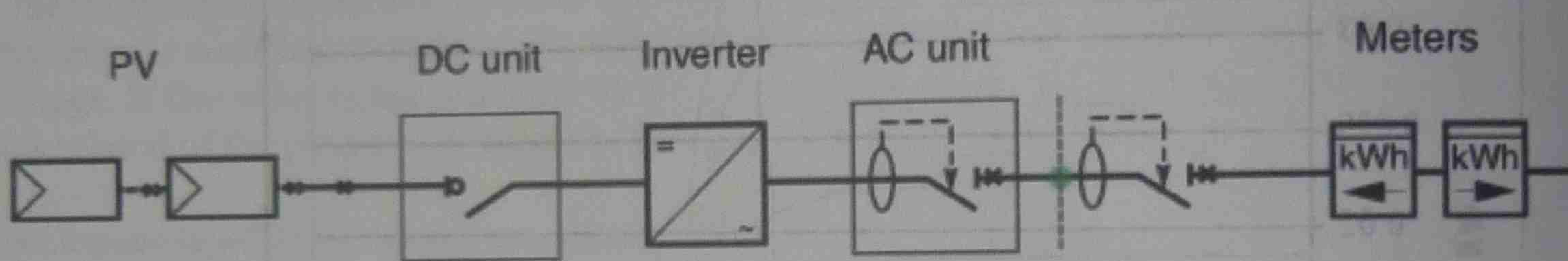

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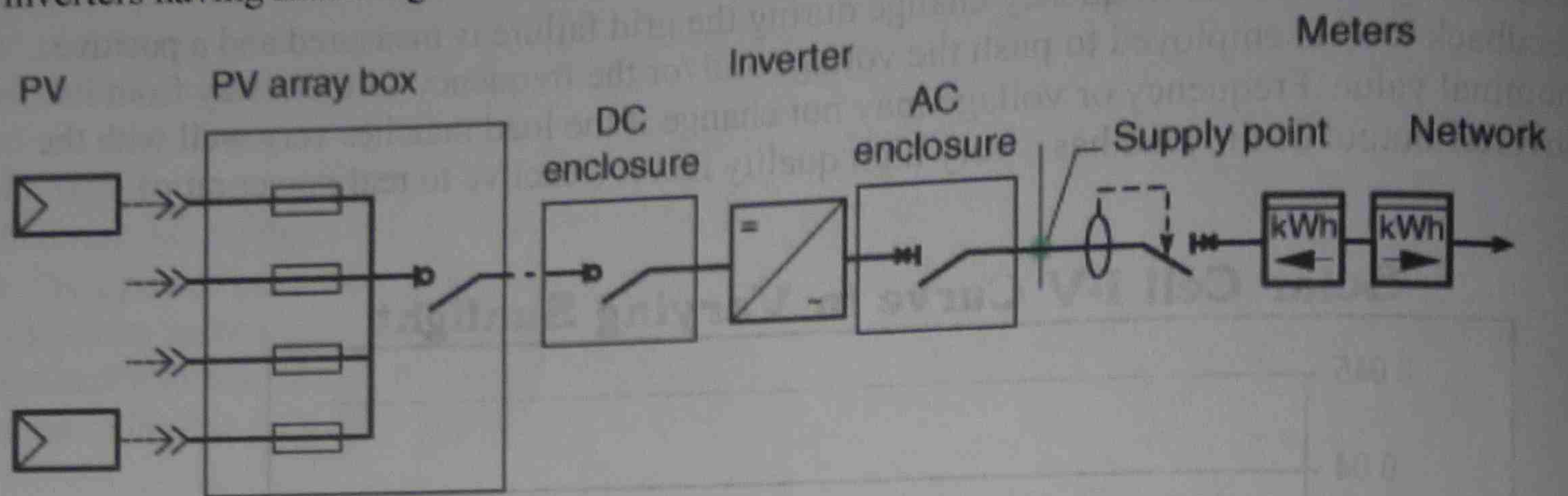

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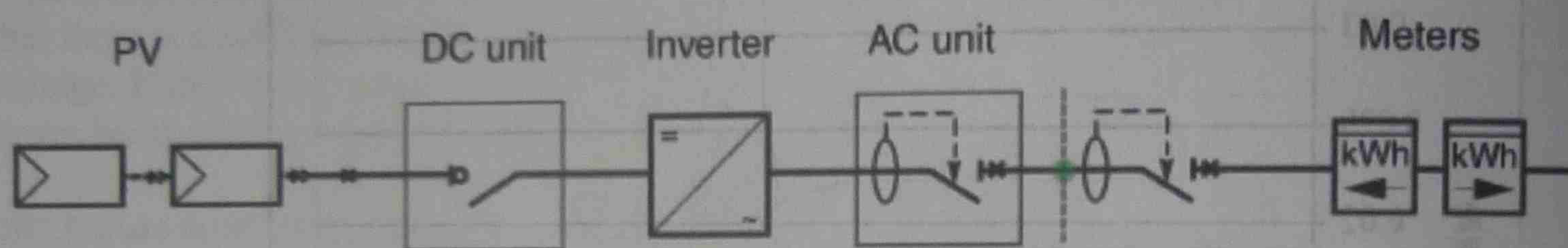

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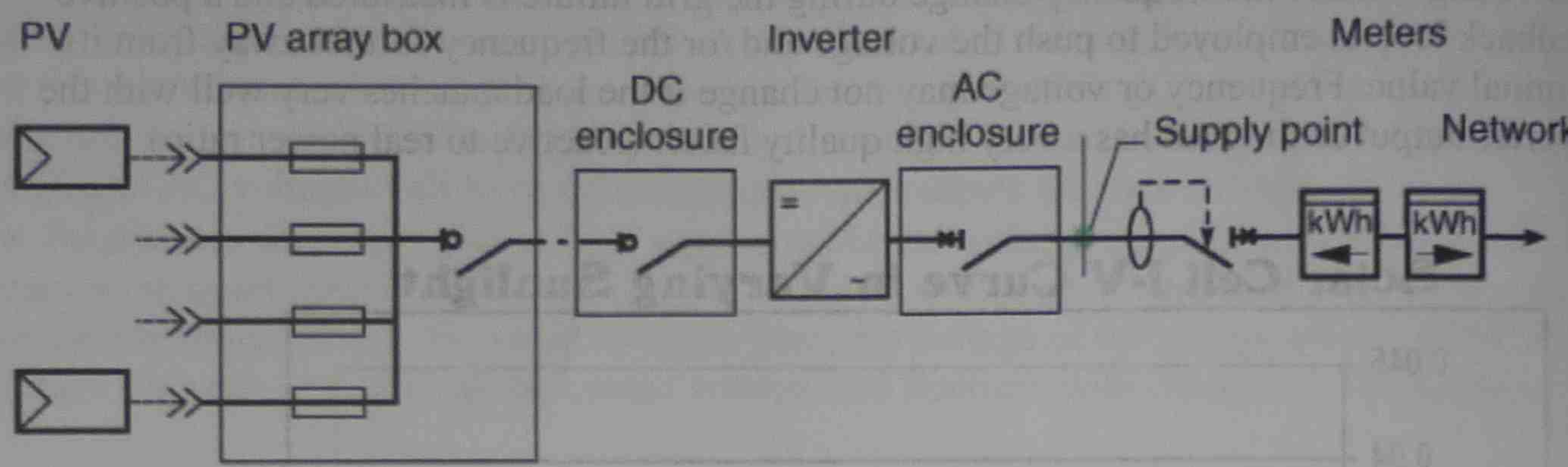

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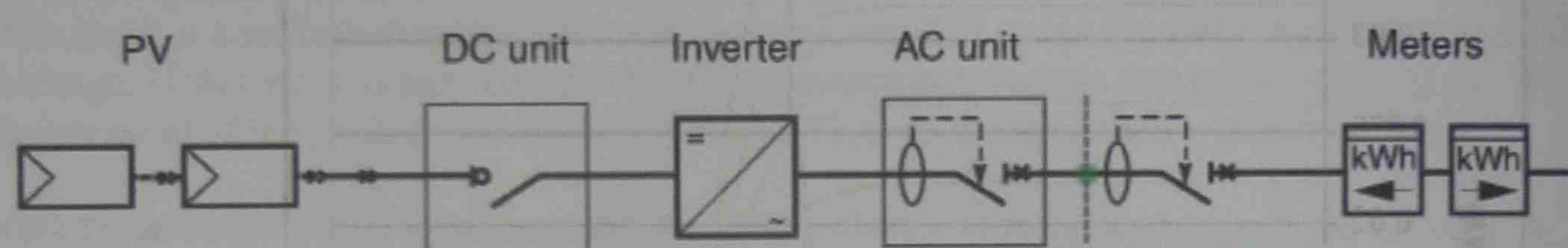

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Switching regulators are used as replacements for the linear regulators when higher efficiency, smaller size or lighter weight are required. They are, however, more complicated, their switching currents can cause electrical noise problems if not carefully suppressed, and simple designs may have a poor power factor.

- When the switch pictured above is closed (On-state, top of figure 2), the voltage across the inductor is $V_L = V_i - V_o$. The current through the inductor rises linearly. As the diode is reverse-biased by the voltage source V, no current flows through it;
- When the switch is opened (off state, bottom of figure 2), the diode is forward biased. The voltage across the inductor is $V_L = - V_o$ (neglecting diode drop). Current I_L decreases.

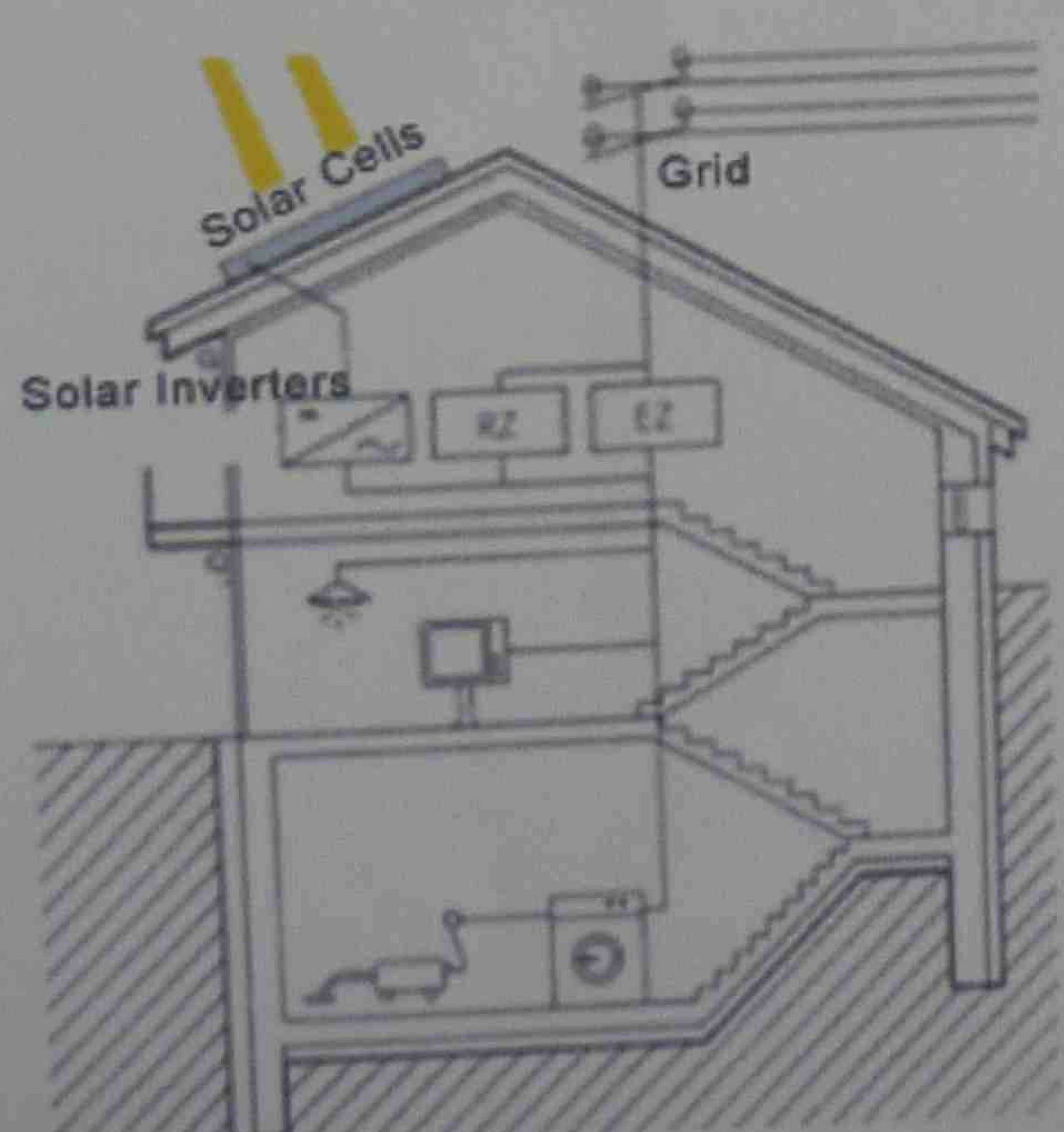
The energy stored in inductor L is

$$E = \frac{1}{2}L \times I_L^2$$

Q46. Express the parameters of grid connected power inverter.

Grid-connected power inverters convert the power from your solar panels into electricity suitable for use in the home or office, when it is connected to the power grid.
Here, a battery bank is not needed to store any excess generated power, as that can be delivered directly into the power grid for someone else to use, giving you a credit. At times of insufficient solar power (e.g. night time), extra power that's needed may be drawn back from the power grid.

Solazone supply several brands of grid inverters, and recommend any of these models for their reliability, quality and value, and their tested reliability under local conditions.



ULTIMO COLLEGE OF TAFE

Course name : Advance Diploma in Electrical engineering

Course no. : 17794

Student name : THI TRUONG

Student number : 210182527

SUBJECT : ASSIGNMENT KO25

SOLVE BASIC PROBLEMS IN PHOTOVOTAIC ENERGY APPARATUS

TEACHER'S NAME : KYAW NAING

Q16.Explain (a) Characteristics of sunlight (b) black body (c)emergency density of black body radiation distribution of sunlight.

The Earth's most important energy source is the Sun. Thanks to the sunrays the surface of the Earth and the air right above the surface warms up, therefore the Earth's average temperature reaches +17°C even though it is in the outer space which is -270°C. This way life can develop and be maintained on the Earth.

Inside the Sun there is thermonuclear fusion, thanks to which heat is produced, while Hydrogen is transformed to Helium.

Due to the nuclear fusion the temperature of the Sun's surface approaches the 6000°K.

As a consequence of this high temperature the Sun emits short waves of electromagnetic rays of light.

From the sun-radiance power of ($4x10^{23}$ kW) the surface of the Earth reaches 173×10^{12} kW.

From the sunrays approaching the edge of the atmosphere only some proportion reaches the surface of the Earth. According to the calculations out of the total sunrays 23% is absorbed by the gases in the air, transforming it to heat, 26% is reflected or radiated back to the space in the form of stray rays.

This way only 51% reaches the surface of the Earth, 33% as direct shortwave radiation and 18% as diffuse radiation. Out of this proportion the Earth's surface reflects 10%, 5% is absorbed in the atmosphere, and 5% exits to the space.

The sunray household of the Earth – **which exceeds the energy needs of the humanity more than thousand times** – is constantly balanced in average, but the value is variable with the weather changes. The main cause of this phenomenon is the Earth's geometrical relationship to the Sun.

The proportion of the sunrays at the edge of the atmosphere can be divided in the following matter:

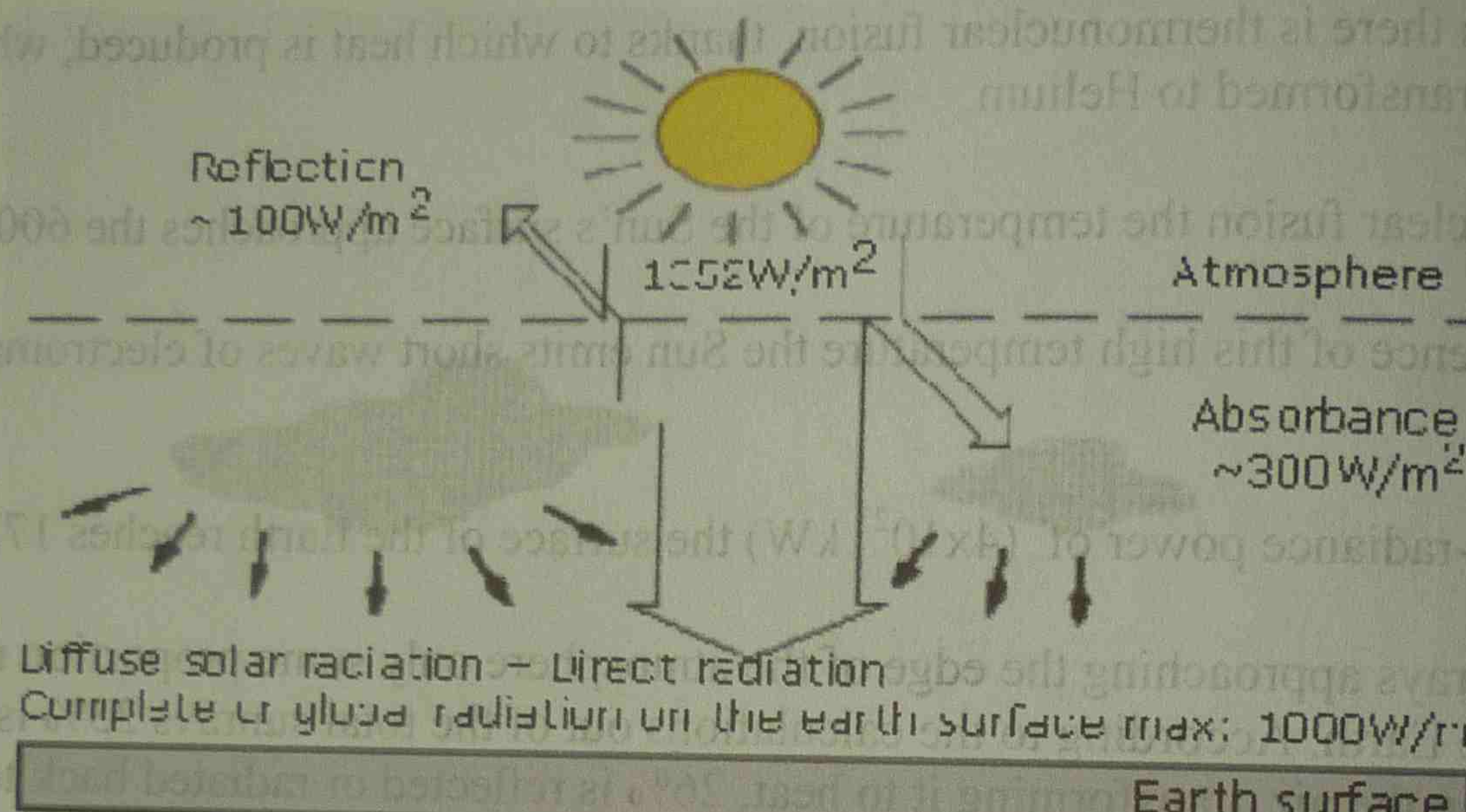
- Ultraviolet radiation 9%.
- Visible light 49%.
- Infrared (heat-) radiation 42%.

According to the data described above the atmosphere weakens the sunrays arriving to the Earth surface, which is highly effected by the clouds and fog present, due to the weather changes.

These clouds reflect or absorb most of the sunrays. Between the axis of the Earth and its circle around the Sun there is 23,5° difference, therefore the visible orbit of the Sun on the

sky is different every day. This orbit is
naturally influences the usable energy.

Since Hungary can be found in the north tempered zone, on the north latitude between 45,8° and 48,6°, the number of sunny hours is approximately **2100 hours/year**, the heat quantity of the arriving sunrays is ~**1300 kWh/m² year**, the highest peak summertime, at noon, in case of clean sky can reach, or exceed the **1000 W/m²**



A **black body** is an idealized physical body that absorbs all incident electromagnetic radiation. Because of this perfect absorptivity at all wavelengths, a black body is also the best possible emitter of thermal radiation, which it radiates incandescently in a characteristic, continuous spectrum that depends on the body's temperature. At Earth-ambient temperatures this emission is in the infrared region of the electromagnetic spectrum and is not visible. The object appears black, since it does not reflect or emit any visible light.

The thermal radiation from a black body is energy converted electrodynamically from the body's pool of internal thermal energy at any temperature greater than absolute zero. It is called blackbody radiation and has a frequency distribution with a characteristic frequency of maximum radiative power that shifts to higher frequencies with increasing temperature. As the temperature increases past a few hundred degrees Celsius, black bodies start to emit visible wavelengths, appearing red, orange, yellow, white, and blue with increasing temperature. When an object is visually white, it is emitting a substantial fraction as ultraviolet radiation.

Blackbody emission provides insight into the thermodynamic equilibrium state of cavity radiation. If each Fourier mode of the absolutely stable equilibrium radiation in a cavity with perfectly reflective walls were considered as a degree of freedom, and if all those degrees of freedom could freely exchange energy, then, according to the equipartition theorem in classical physics, each degree of freedom would have one and the same quantity of energy. This approach led to the paradox known as the ultraviolet catastrophe, that there would be an infinite amount of energy in any continuous field. The study of the laws of black bodies helped to establish the foundations of quantum mechanics.

Q17.Describe solar insolation measurement.

Insolation is a measure of solar radiation energy received on a given surface area in a given time. It is commonly expressed as average irradiance in watts per square meter (W/m2) or kilowatt-hours per square meter per day (kW·h/(m2·day)) (or hours/day). In the case of photovoltaics it is commonly measured as kWh/(kW_p·y) (kilowatt hours per year per kilowatt peak rating).

The object or surface that solar radiation strikes may be a planet, a terrestrial object inside the atmosphere of a planet, or any object exposed to solar rays outside of an atmosphere, including spacecraft. Some of the solar radiation will be absorbed, while the remainder will be reflected. Usually the absorbed solar radiation is converted to thermal energy, causing an increasing in the object's temperature. Some systems, however, may store or convert a portion of the solar energy into another form of energy, as in the case of photovoltaics or plants. The proportion of radiation reflected or absorbed depends on the object's reflectivity or albedo.

Q19.Explain solar geometry.

The solar geometry model takes input of date, time and location of an observer on the earth and returns information about the location of the sun. The model can work in two modes: as a single shot calculation which is carried out each time an input variable is changed or it can be set so to automatically increment time and will run continuously.
User Input
The model takes the following inputs:

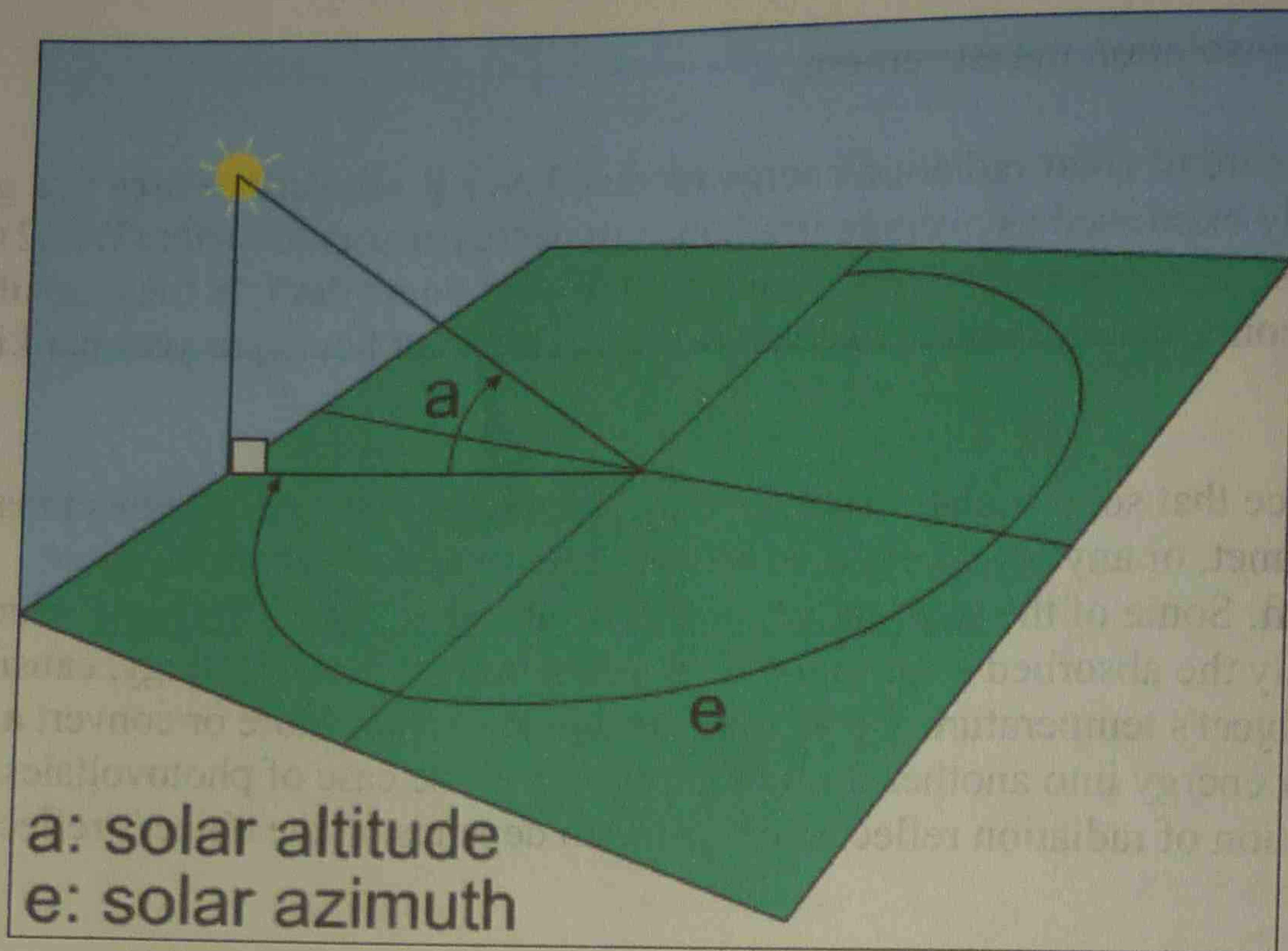
- **The date**
  - a year in the range 1800 - 2100,
  - a month
  - the day of the month
- **The time of day:**
  - hour (24 hour clock),
  - minute
- **Location on the earth**
  - latitude (degrees),
  - longitude(degrees)
- **The orientation and tilt of the surface of any building**

Q20.Explain altitudes and azimath angles

Model Output
The model provides the following outputs.

- the **altitude and azimuth** (see figure below) of the sun at that time and location,
- **the geometry of the sun with respect to any specified building.**
- the **length of a shadow** cast by a 1 metre pole

- tables and graphs of the monthly and diurnal ... and **azimuth**



Q21.Write the formula to calculate standard solar time.

The Local Standard Time Meridian (LSTM) is a reference meridian used for a particular time zone and is similar to the Prime Meridian, which is used for Greenwich Mean Time. The LSTM is illustrated below.

The (LSTM) is calculated according to the equation: $LSTM = 15° \times \Delta T_{GMT}$

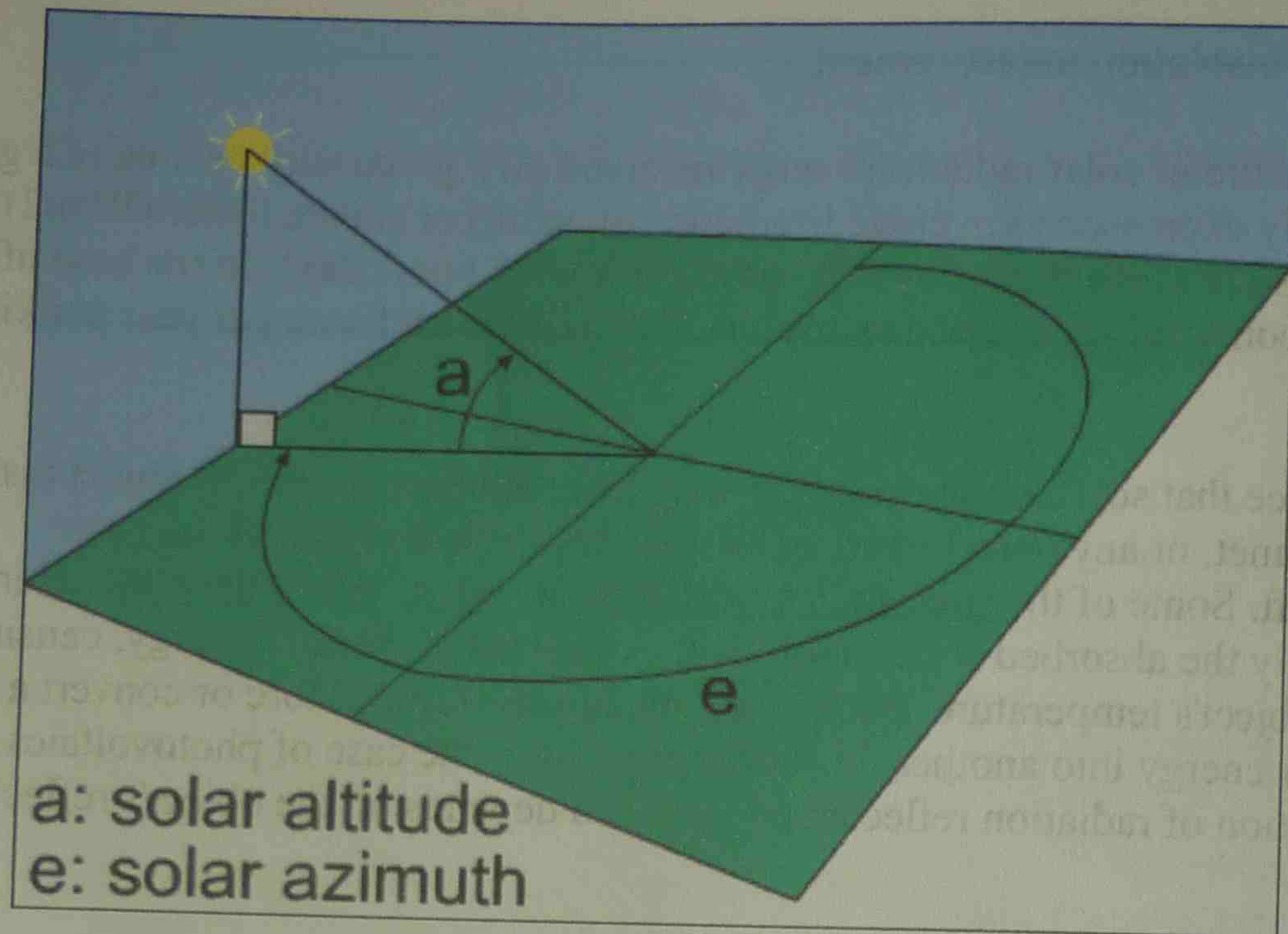
where ΔT_{GMT} is the difference of the Local Time (LT) from Greenwich Mean Time (GMT) in hours. 15°= 360°/24 hours.

Q22.What are the properties of semiconductor.

A **semiconductor** is a material with electrical conductivity due to electron flow (as opposed to ionic conductivity) intermediate in magnitude between that of a conductor and an insulator. This means a conductivity roughly in the range of 103 to 10−8 siemens per centimeter. Semiconductor materials are the foundation of modern electronics, including radio, computers, telephones, and many other devices. Such devices include transistors, solar cells, many kinds of diodes including the light-emitting diode, the silicon controlled rectifier, and digital and analog integrated circuits. Similarly, semiconductor solar photovoltaic panels directly convert light energy into electrical energy. In a metallic conductor, current is carried by the flow of electrons. In semiconductors, current is often schematized as being carried either by the flow of electrons or by the flow of positively charged "holes" in the electron structure of the material.

Common semiconducting materials are crystalline solids, but amorphous and liquid semiconductors are known. These include hydrogenated amorphous silicon and mixtures of arsenic, selenium and tellurium in a variety of proportions. Such compounds share with better known semiconductors intermediate conductivity and a rapid variation of conductivity with

- tables and graphs of the **monthly and diurnal variation of the solar altitude and azimuth**



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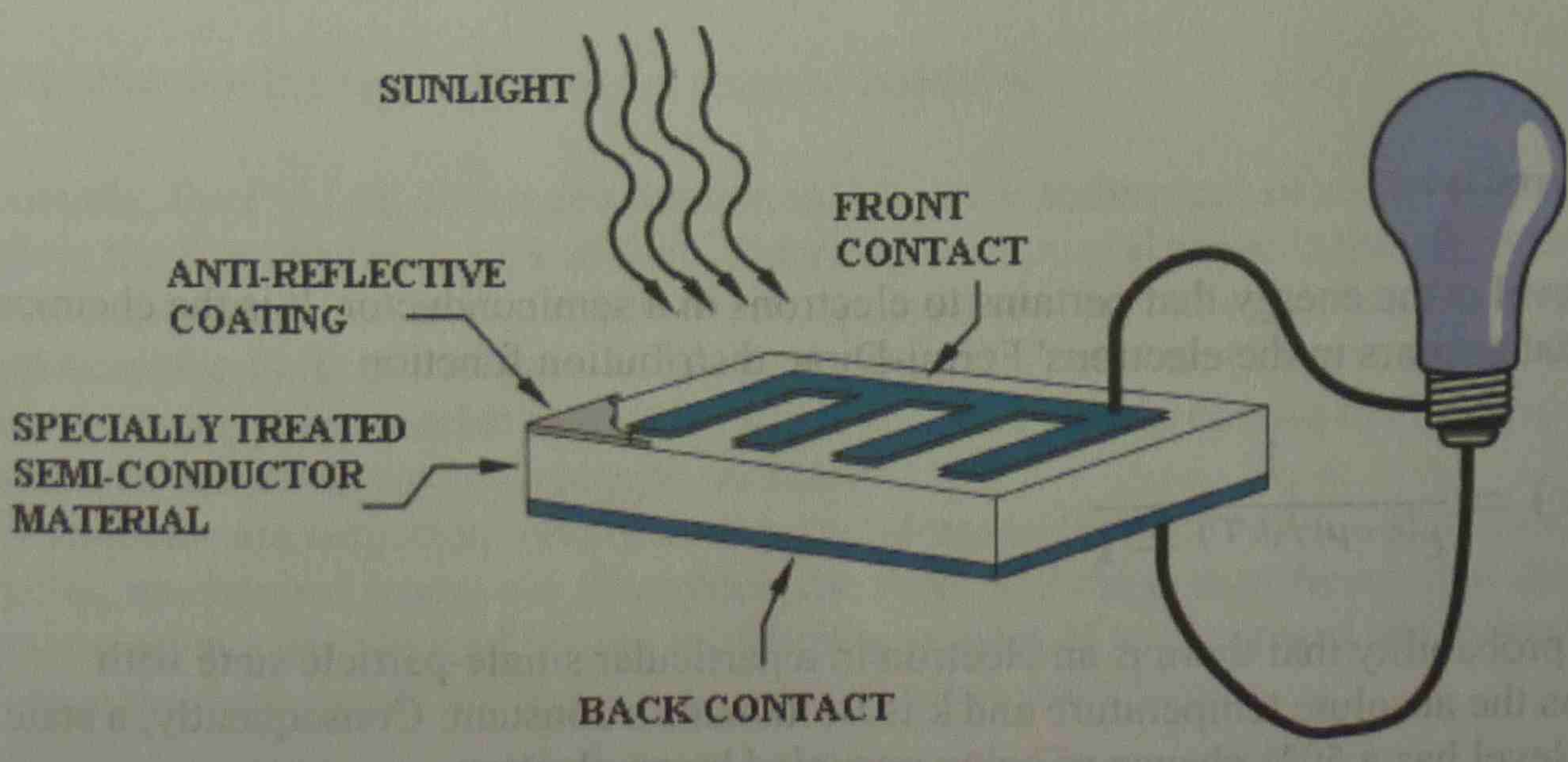
Silicon is used to create most semiconductors commercially. Dozens of other materials are used, including germanium, gallium arsenide, and silicon carbide. A pure semiconductor is often called an "intrinsic" semiconductor. The electronic properties and the conductivity of a semiconductor can be changed in a controlled manner by adding very small quantities of other elements, called "dopants", to the intrinsic material. In crystalline silicon typically this is achieved by adding impurities of boron or phosphorus to the melt and then allowing the melt to solidify into the crystal. This process is called "doping".

Q23.Sketch the atomic structure of photovoltaic material & explain the construction & operation.

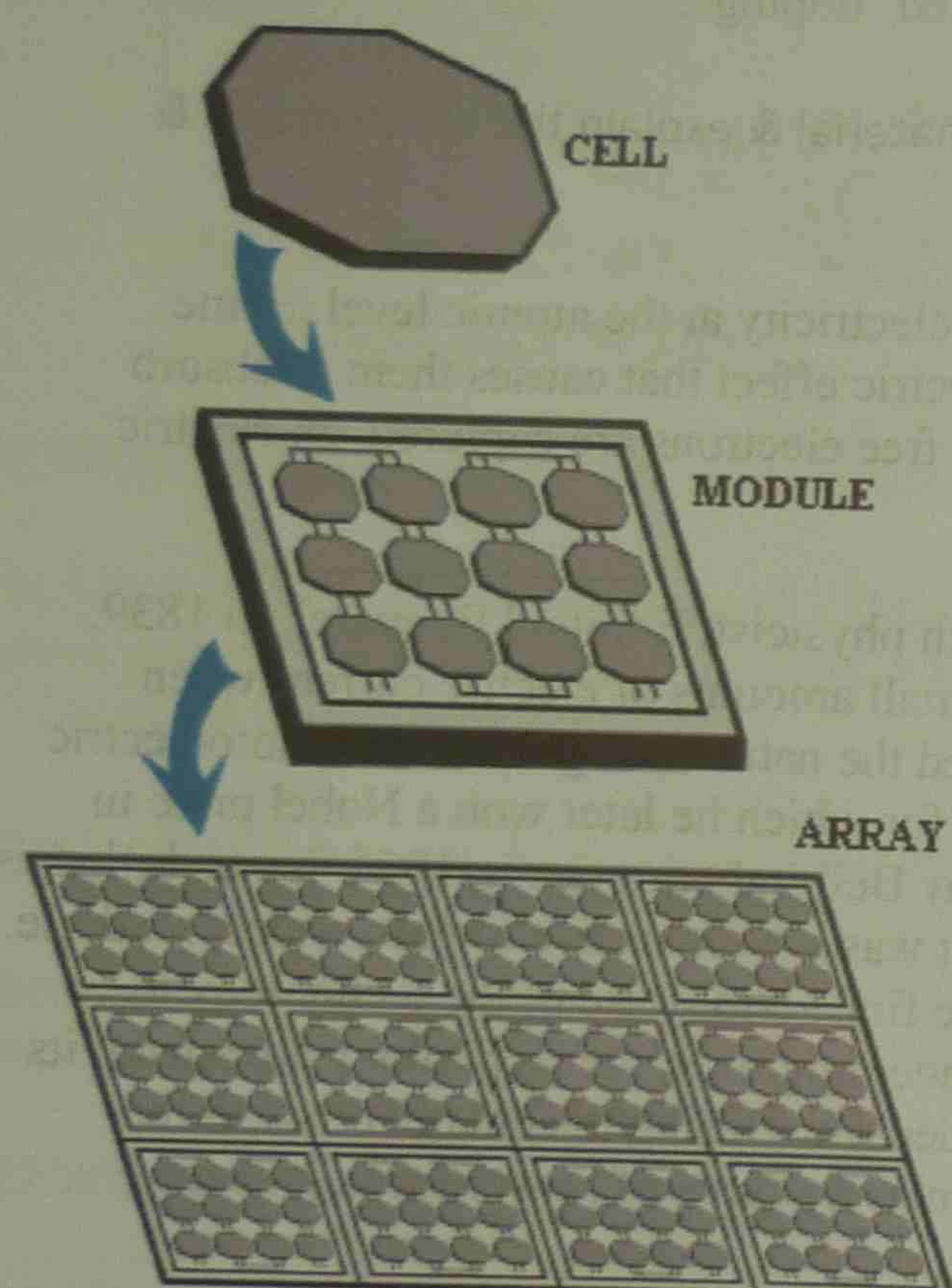
Photovoltaics is the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, an electric current results that can be used as electricity.

The photoelectric effect was first noted by a French physicist, Edmund Bequerel, in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. In 1905, Albert Einstein described the nature of light and the photoelectric effect on which photovoltaic technology is based, for which he later won a Nobel prize in physics. The first photovoltaic module was built by Bell Laboratories in 1954. It was billed as a solar battery and was mostly just a curiosity as it was too expensive to gain widespread use. In the 1960s, the space industry began to make the first serious use of the technology to provide power aboard spacecraft. Through the space programs, the technology advanced, its reliability was established, and the cost began to decline. During the energy crisis in the 1970s, photovoltaic technology gained recognition as a source of power for non-space applications.



The diagram above illustrates the operation of a basic photovoltaic cell, also called a solar cell. Solar cells are made of the same kinds of semiconductor materials, such as silicon, used in the microelectronics industry. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current -- that is, electricity. This electricity can then be used to power a load, such as a light or a tool.

A number of solar cells electrically connected to each other and mounted in a support structure or frame is called a photovoltaic module. Modules are designed to supply electricity at a certain voltage, such as a common 12 volts system. The current produced is directly dependent on how much light strikes the module.



Q24.What is fermi level?

The **Fermi level** is the energy that pertains to electrons in a semiconductor. It is the chemical potential μ that appears in the electrons' Fermi-Dirac distribution function

$$F_o(\epsilon) = \frac{1}{e^{(\epsilon-\mu)/(kT)} + 1}$$

which is the probability that there is an electron in a particular single-particle state with energy ϵ. T is the absolute temperature and k is Boltzmann's constant. Consequently, a state at the Fermi level has a 50% chance of being occupied by an electron.

Q25.Explain fermi conductor.

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Q26.Explain poly crystalline silicon.

Polycrystalline silicon, also called **polysilicon**, is a material consisting of small silicon crystals. It differs from single-crystal silicon, used for electronics and solar cells, and from amorphous silicon, used for thin film devices and solar cells.

Q27.Write the process to manufacture solar module.

Solar cells are often electrically connected and encapsulated as a **module**. Photovoltaic modules often have a sheet of glass on the front (sun up) side, allowing light to pass while protecting the semiconductor wafers from abrasion and impact due to wind-driven debris, rain, hail, etc. Solar cells are also usually connected in series in modules, creating an additive voltage. Connecting cells in parallel will yield a higher current. Modules are then interconnected, in series or parallel, or both, to create an **array** with the desired peak DC voltage and current.

To make practical use of the solar-generated energy, the electricity is most often fed into the electricity grid using inverters (grid-connected photovoltaic systems); in stand-alone systems, batteries are used to store the energy that is not needed immediately. Solar panels can be used to power or recharge portable devices.

Q28.What are the types of stresses on solar modules?

Recently, the PV-Lab developed competencies in the techniques of solar cells encapsulation. While the front end activities of the Laboratory are directed towards the performances, the back end is more in relation to the industrial world. We aim to understand the requirements and needed criteria of each part of a photovoltaic (PV) module (front and back sheet, encapsulants, paint, mechanical constraint, etc.) to be able to choose the most adequate materials according to the European standards.
PV modules are subjected to various types of stresses, like humidity, UV radiation, thermal cycles, mechanical stress, etc. Therefore, the study and the comprehension of the phenomena governing this last stage of the manufacturing process of a solar panel are indeed essential to ensure the final quality of the modules and lifetime over 25 years.

The encapsulation (polymers) materials of a PV module aim at:

- ensuring a high optical transmission,
- ensuring a good electrical insulation,
- being highly stable under UV radiation,
- acting as a barrier against water vapour and oxygen transmission,
- presenting an adequate interfacial adhesion to prevent delamination process,
- providing a structural support.

Q29.Explain solar cell semi conductor dark and illuminated current

In a traditional solid-state semiconductor, a solar cell is made from two doped crystals, one doped with n-type impurities (n-type semiconductor), which add additional free conduction band electrons, and the other doped with p-type impurities (p-type semiconductor), which add additional electron holes. When placed in contact, some of the electrons in the n-type portion flow into the p-type to "fill in" the missing electrons, also known as electron holes. Eventually enough electrons will flow across the boundary to equalize the Fermi levels of the two materials. The result is a region at the interface, the p-n junction, where charge carriers are depleted and/or accumulated on each side of the interface. In silicon, this transfer of electrons produces a potential barrier of about 0.6 to 0.7 V.

When placed in the sun, photons of the sunlight can excite electrons on the p-type side of the semiconductor, a process known as photoexcitation. In silicon, sunlight can provide enough energy to push an electron out of the lower-energy valence band into the higher-energy conduction band. As the name implies, electrons in the conduction band are free to move about the silicon. When a load is placed across the cell as a whole, these electrons will flow out of the p-type side into the n-type side, lose energy while moving through the external circuit, and then back into the p-type material where they can once again re-combine with the valence-band hole they left behind. In this way, sunlight creates an electrical current.

In any semiconductor, the band gap means that only photons with that amount of energy, or more, will contribute to producing a current. In the case of silicon, the majority of visible light from red to violet has sufficient energy to make this happen. Unfortunately higher energy photons, those at the blue and violet end of the spectrum, have more than enough energy to cross the band gap; although some of this extra energy is transferred into the electrons, the majority of it is wasted as heat. Another issue is that in order to have a reasonable chance of capturing a photon, the n-type layer has to be fairly thick. This also increases the chance that a freshly ejected electron will meet up with a previously created hole in the material before reaching the p-n junction. These effects produce an upper limit on the efficiency of silicon solar cells, currently around 12 to 15% for common modules and up to 25% for the best laboratory cells (about 30% is the theoretical maximum efficiency for single band gap solar cells, see Shockley-Queisser limit.).

By far the biggest problem with the conventional approach is cost; solar cells require a relatively thick layer of doped silicon in order to have reasonable photon capture rates, and silicon processing is expensive. There have been a number of different approaches to reduce this cost over the last decade, notably the thin-film approaches, but to date they have seen limited application due to a variety of practical problems. Another line of research has been to dramatically improve efficiency through the multi-junction approach, although these cells are very high cost and suitable only for large commercial deployments. In general terms the

The encapsulation (polymers) materials of a PV module aim at:
- ensuring a high optical transmission,
- ensuring a good electrical insulation,
- being highly stable under UV radiation,
- acting as a barrier against water vapour and oxygen transmission,
- presenting an adequate interfacial adhesion to prevent delamination process,
- providing a structural support.

Q29.Explain solar cell semi conductor dark and illuminated current

In a traditional solid-state semiconductor, a solar cell is made from two doped crystals, one doped with n-type impurities (n-type semiconductor), which add additional free conduction band electrons, and the other doped with p-type impurities (p-type semiconductor), which add additional electron holes. When placed in contact, some of the electrons in the n-type portion flow into the p-type to "fill in" the missing electrons, also known as electron holes. Eventually enough electrons will flow across the boundary to equalize the Fermi levels of the two materials. The result is a region at the interface, the p-n junction, where charge carriers are depleted and/or accumulated on each side of the interface. In silicon, this transfer of electrons produces a potential barrier of about 0.6 to 0.7 V.

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Q30.What are the output parameters of solar cell?

I_V measurements are performed to characterize solar cells. Figure 4 shows a typical I_V curve with some of the following solar cell output parameters indicated

_ Short-circuit current, I_{sc}, is the maximum current at zero voltage. The short-circuit current density, J_{sc}, is often used (see Section 2.3.2).

_ Open-circuit voltage, V_{oc}, is the maximum voltage at zero current.

_ Maximum power point, P_{mp}, is the maximum power output at optimal

operating condition, i.e. $P_{mp} = V_{mp} I_{mp}$.

A realistic distributed equivalent circuit for the buried emitter silicon solar cell is presentedtaking into consideration the carriers paths through the planar and vertical junctions. In addition, a new theoretical model for the cell characteristics including the cell's mismatching, series resistance, different junctions (planar and vertical) and junctions geometry is considered in this work. The results are compared with the published data.

Q31.What are the production steps of solar cells?

A typical representative of a silicon solar cell consists of a photoactive p/n junction formed on the surface, a front ohmic contact stripe and fingers, a back ohmic contact that covers the entire back surface, and an antireflection coating on the front surface.

For silicon solar cell production either poly-crystalline or mono-crystalline material is used. Poly-crystalline silicon for photo-voltaic applications is normally produced by casting methods while mono-crystalline silicon is prepared in a Czochralski growing process.

The poly-crystalline or mono-crystalline ingots are cut to wafers. Poly-crystalline material is mostly cut to square wafers with a side length of 125mm or 150mm while mono-crystalline material is used to produce round wafers of 100 - 150mm of diameter. Sometimes square material with rounded edges is prepared from round wafers (125mm side length) in order to get a denser packing of the solar c The main process steps in solar cell production are the preparation of the p/n junction by doping and the metallization or contacting of the photovoltaic cell. Beside that, further deposition processes are used to establish an antireflection coating or to improve the solar cell setup. ells in the solar module.

Q32.Write the equation for the cost of electricity by using solar cell.

Assume that we have a time series of system wholesale prices, w_t, and system demand quantities, Q_t, and that those system demand quantities were generated by a flat retail price that covered wholesale energy costs. That flat retail rate for energy (excluding capital costs of transmission and distribution, taxes and other fees) would be

$$\bar{P} = \frac{1}{1-\phi} \cdot \frac{\sum_{t=1}^{T} Q_t \cdot w_t}{\sum_{t=1}^{T} Q_t}$$

Q33.What is optical loss?

In metallic conductor systems, reflections of a signal traveling down a conductor can occur at a discontinuity or impedance mismatch. The ratio of the amplitude of the reflected wave Vr to the amplitude of the incident wave Vi is known as the reflection coefficient Γ.

$$\Gamma - \frac{V_r}{V_i}$$

Q34.Write the equation to calculate dark cell current.

Unstimulated (in the dark), cyclic-nucleotide gated channels in the outer segment are open because cyclic GMP (cGMP) is bound to them. Hence, positively charged ions (namely sodium ions) enter the photoreceptor, depolarizing it to about −40 mV (resting potential in other nerve cells is usually −65 mV). This depolarizing current is often known as dark current.

Two important quantities to characterize a solar cell are

- Open circuit voltage (V_{oc}): The voltage between the terminals when no current is drawn (infinte load resistance)
- Short circuit current (I_{sc}): The current when the terminals are connected to eachother (zero load resistance)

The short circuit current increases with light intensity, as higher intensity means more photons, which in turn means more electrons. Since the short circuit current I_{sc} is roughly proportional to the area of the solar cell, the short circuit current density, $J_{sc} = I_{sc}/A$, is often used to compare solar cells.

When a load is connected to the solar cell, the current decreases and a voltage develops as charge builds up at the terminals. The resulting current can be viewed as a superposition of the short circuit current, caused by the absorbtion of photons, and a *dark current*, which is caused by the potential built up over the load and flows in the opposite direction. As a solar cell contains a PN-junction (LINK), just as a diode, it may be treated as a diode. For an ideal diode, the dark current density is given by

$$J_{dark}(V) = J_c(e^{qV/k_BT} - 1)$$

Here J_0 is a constant, q is the electron charge and V is the voltage between the terminals. The resulting current can be approximated as a superposition of the short circuit current and the dark current:

$$J = J_{sc} - J_0(e^{qV/k_BT} - 1)$$

Q35.Write the equation to calculate solar cell current.

$$J = J_{sc} \quad J_0(e^{q(V+JAR_s)/kT} \quad 1) \quad \frac{V + JAR_s}{R_P}$$

Q36.Write the equation for maximum power output related to series resistance.

$$\eta = \frac{R_{\mathrm{load}}}{R_{\mathrm{load}} + R_{\mathrm{source}}} = \frac{1}{1 + \frac{R_{\mathrm{source}}}{R_{\mathrm{load}}}}$$

The theorem was originally misunderstood (notably by Joule) to imply that a system consisting of an electric motor driven by a battery could not be more than 50% efficient since, when the impedances were matched, the power lost as heat in the battery would always be equal to the power delivered to the motor. In 1880 this assumption was shown to be false by either Edison or his colleague Francis Robbins Upton, who realized that maximum efficiency was not the same as maximum power transfer. To achieve maximum efficiency, the resistance of the source (whether a battery or a dynamo) could be made close to zero. Using this new understanding, they obtained an efficiency of about 90%, and proved that the electric motor was a practical alternative to the heat engine.

Q37.Explain solar radiation and shading assessment procedures.

Sunlight, in the broad sense, is the total frequency spectrum of electromagnetic radiation given off by the Sun. On Earth, sunlight is filtered through the Earth's atmosphere, and solar radiation is obvious as daylight when the Sun is above the horizon.

When the direct solar radiation is not blocked by clouds, it is experienced as **sunshine**, a combination of bright light and radiant heat. When it is blocked by the clouds or reflects off of other objects, it is experienced as diffused light.

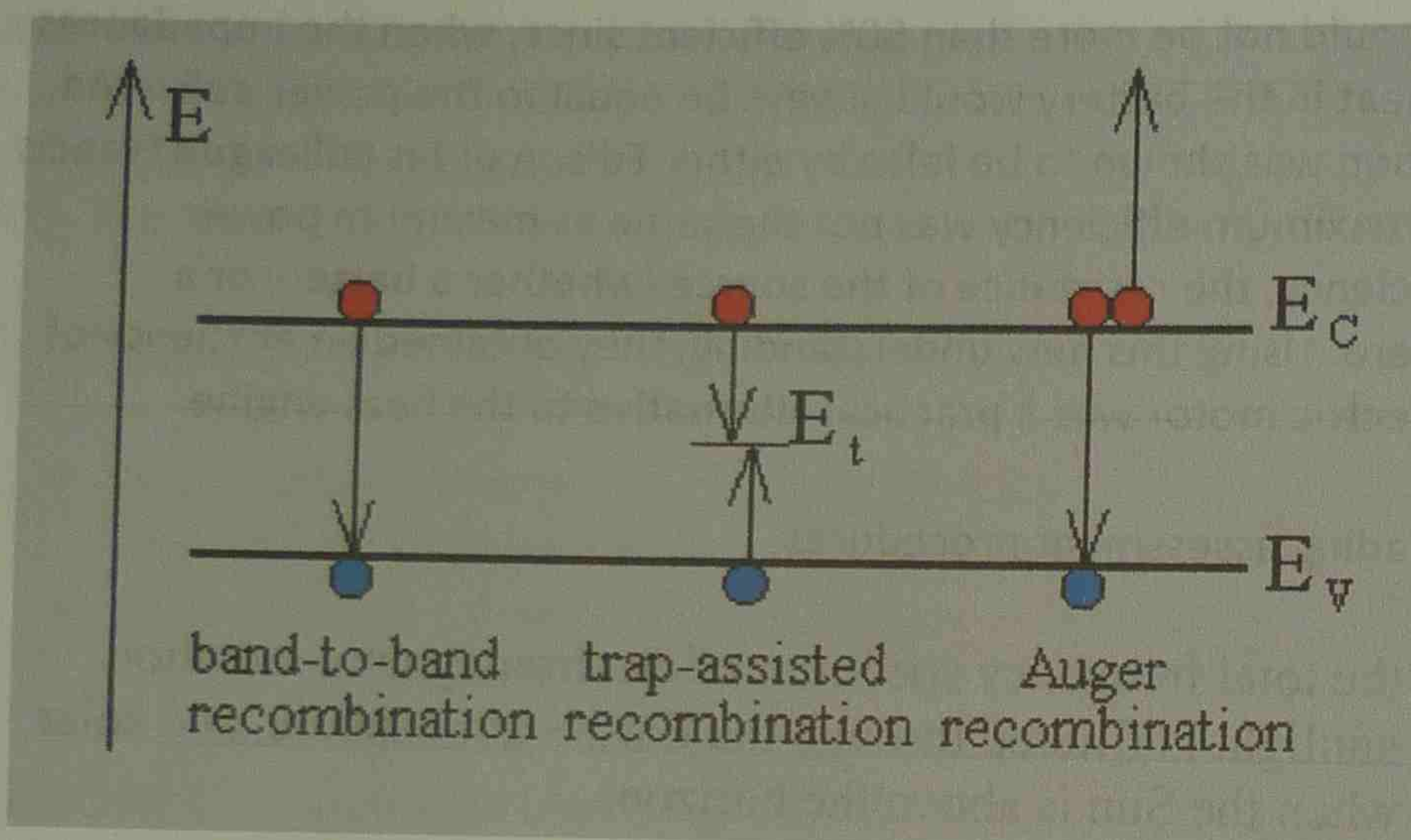
shading assessment procedures

If the location for your planned PV array has trees, chimneys, dormer windows, tall buildings next door, or other features that may shade the system either now or in the future this can have a major impact on the performance of the system.

In these situations the standard SAP2005 method of assessing the performance of the system isn't particularly accurate, and we'd strongly recommend that you ask us to produce a proper Shading Impact Assessment for you so that you can accurately assess the implications of this shading for the long term financial returns from the system.

Q39.Explain (a) Recombining process (b) Radiative recombination (c)Auger recombination (d)Recombination through traps (e)Recombination at surface (f)electronic matching.

Recombination of electrons and holes is a process by which both carriers annihilate each other: the electrons fall in one or multiple steps into the empty state which is associated with the hole. Both carriers eventually disappear in the process. The energy difference between the initial and final state of the electron is given off. This leads to one possible classification of the recombination processes: In the case of radiative recombination this energy is emitted in the form of a photon, in the case of non-radiative recombination it is passed on to one or more phonons and in Auger recombination it is given off in the form of kinetic energy to another electron. Another classification scheme considers the individual energy levels and particles involved. These different processes are further illustrated with the figure below.

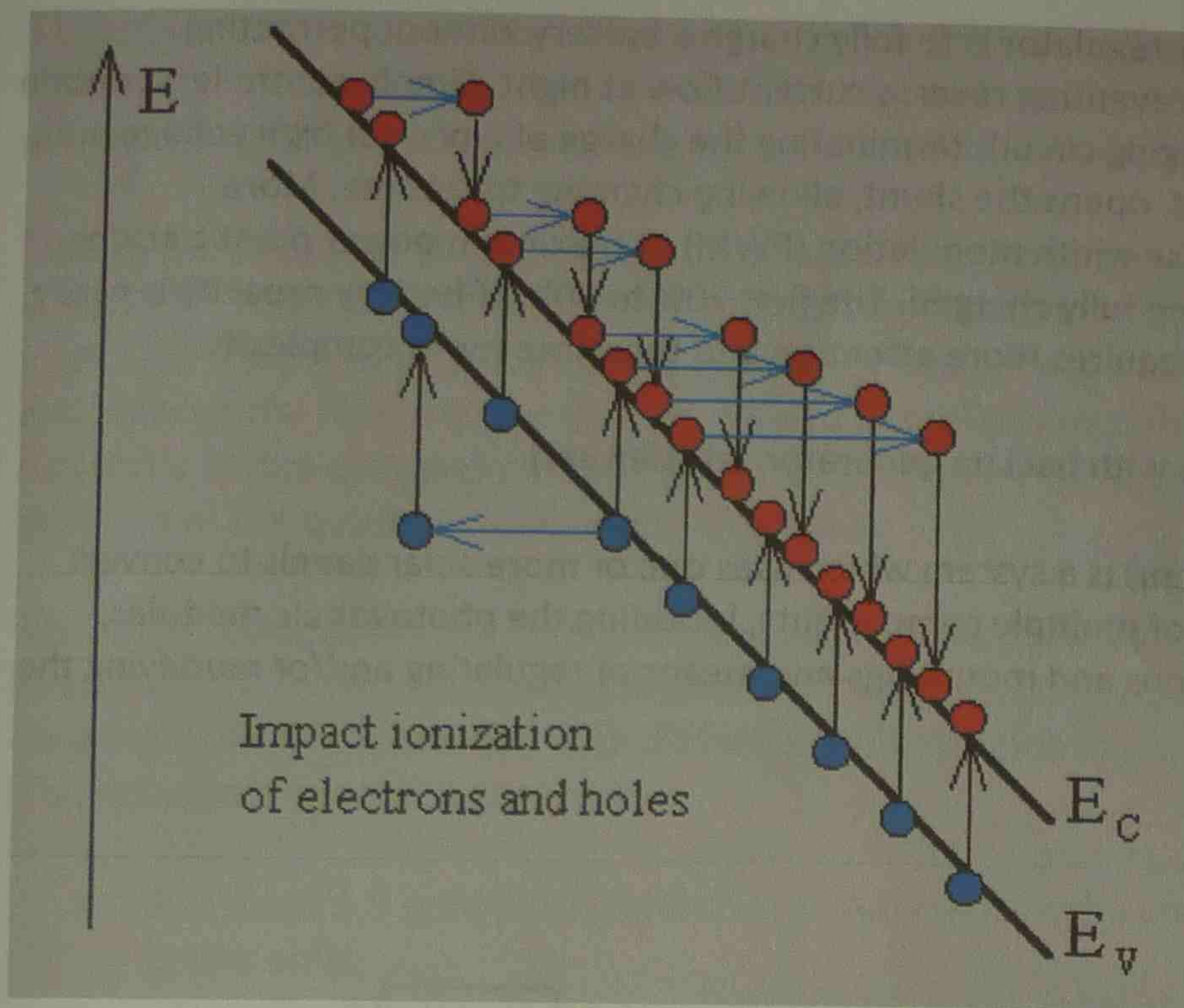


Trap-assisted recombination occurs when an electron falls into a "trap", an energy level within the bandgap caused by the presence of a foreign atom or a structural defect. Once the trap is filled it can not accept another electron. The electron occupying the trap energy can in a second step fall into an empty state in the valence band, thereby completing the recombination process. One can envision this process either as a two-step transition of an electron from the conduction band to the valence band or also as the annihilation of the electron and hole which meet each other in the trap.

Carrier generation due to light absorption occurs if the photon energy is large enough to lift an electron from the valence band into an empty state in the conduction band, generating one electron-hole pair. The photon energy needs to be at least equal to the bandgap energy to satisfy this condition. The photon is absorbed in this process and the excess energy, E_{ph}-E_g is added to the electron and the hole in the form of kinetic energy.

Carrier generation or **ionization due to a high energy beam** consisting of *charged* particles is similar except that the available energy can be much larger than the bandgap energy so that multiple electron-hole pairs can be formed. The high-energy particle gradually loses its energy and eventually stops. This generation mechanism is used in semiconductor-based nuclear particle counters. As the number of ionized electron-hole pairs varies with the energy of the particle, one can also use such detector to measure the particle energy.

Finally there is a generation process called **impact ionization**, the generation mechanism which is the counterpart of Auger recombination. Impact ionization is caused by an electron (hole) with an energy which is much larger (smaller) than the conduction (valence) band edge. The detailed mechanism is illustrated with the figure below:

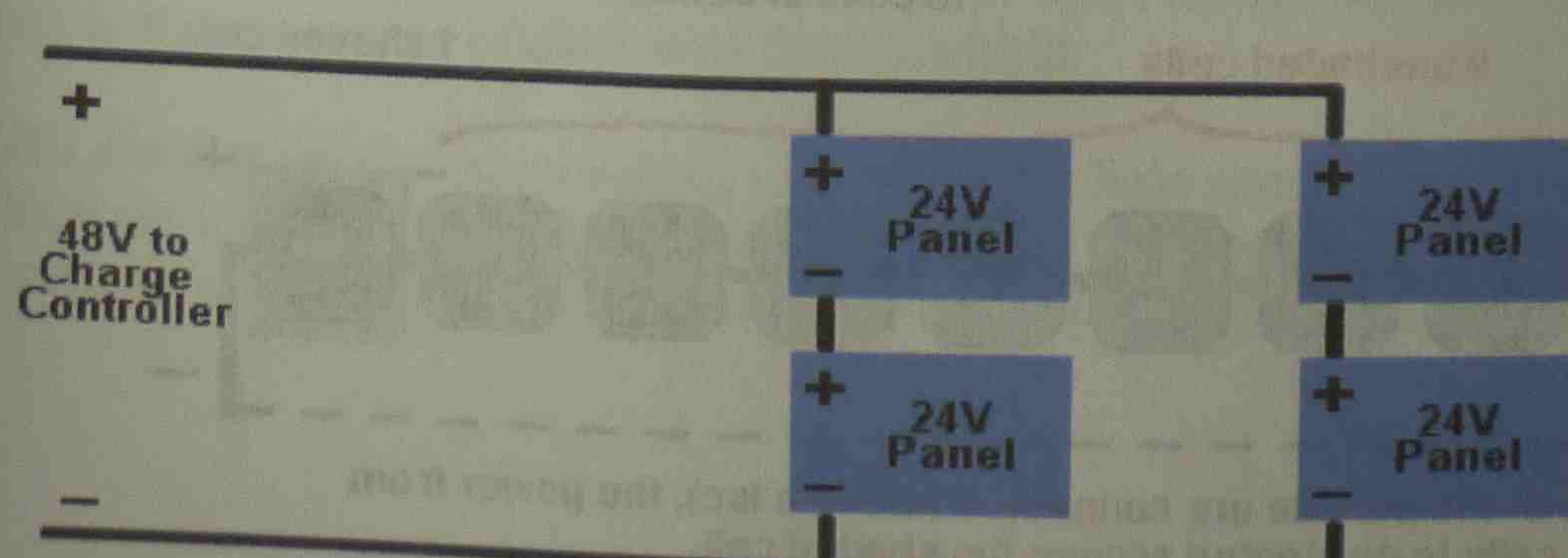


Band-to-band recombination depends on the density of available electrons and holes. Since both carrier types need to be available in the recombination process, the rate is expected to be proportional to the product of *n* and *p*.

Recombination at semiconductor surfaces and interfaces can have a significant impact on the behavior of devices. This is due to the fact that surfaces and interfaces typically contain a large number of recombination centers because of the abrupt termination of the semiconductor crystal which leaves a large number of electrically active dangling bonds. In addition the surfaces and interfaces are more likely to contain impurities since they are exposed during the device fabrication process.

Q40.Sketch PV system configuration circuits.

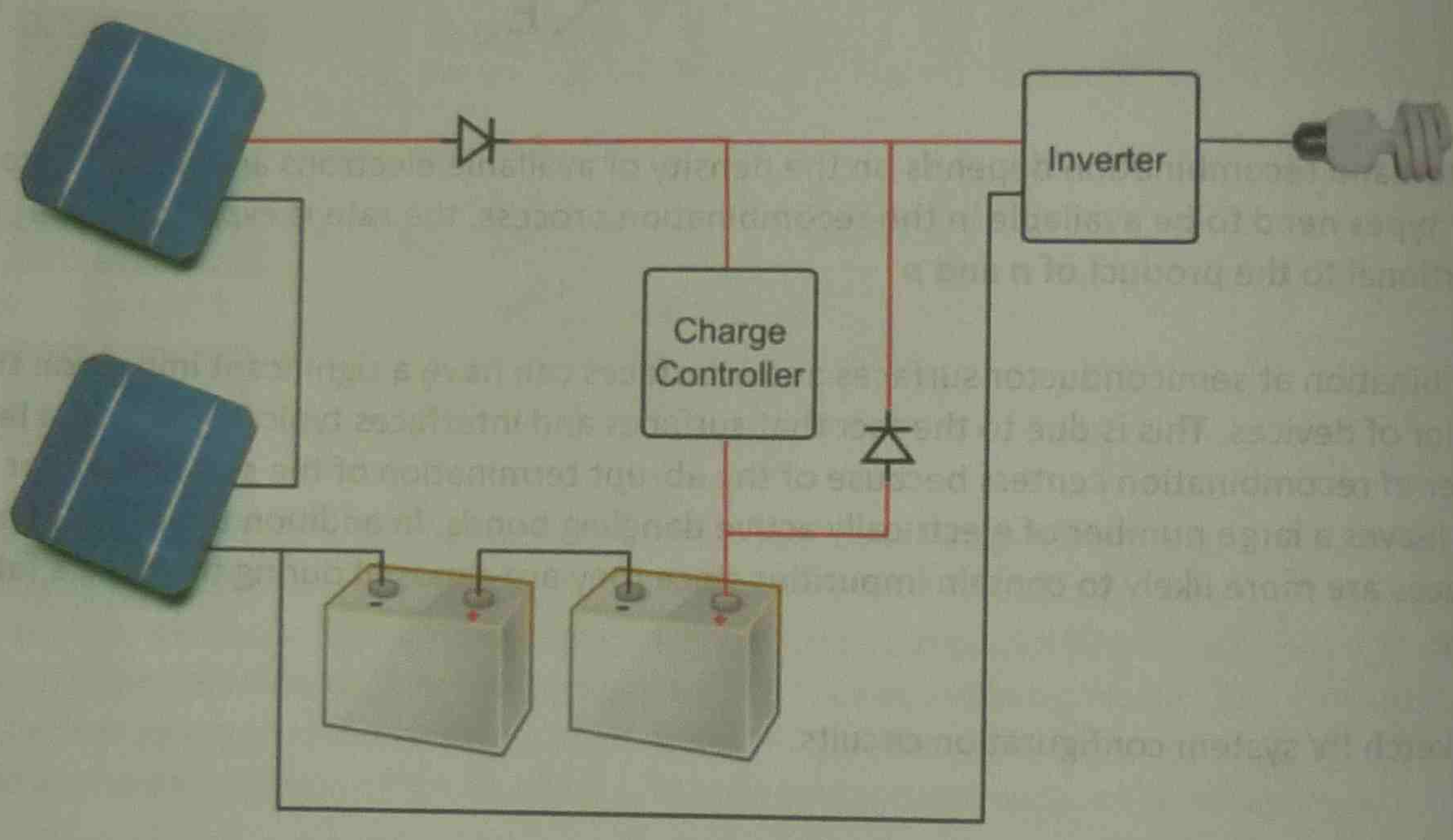
Q41.PV only system using integrated charge regulator, load controller.



The main function of a controller or regulator is to fully charge a battery without permitting overcharge and at the same time preventing reverse current flow at night. Simple controllers contain a transistor that shunts the PV charging circuit, terminating the charge at a pre-set high voltage and, once a pre-set reconnect is reached, opens the shunt, allowing charging to resume. More sophisticated controllers utilize pulse width modulation (PWM) or maximum power point tracking (MPPT) to assure the battery is being fully charged. The first 70% to 80% of battery capacity is easily replaced, but the last 20% to 30% requires more attention and therefore more complexity.

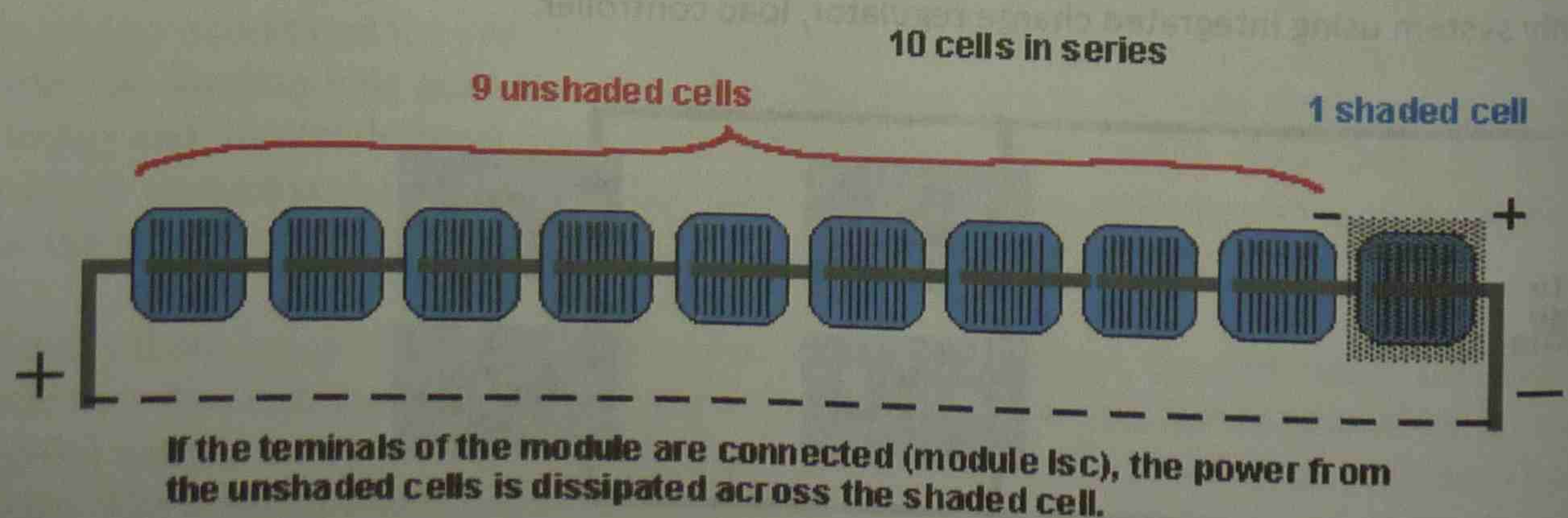
Q42.Sketch & explain dc PV system with backup generator set (Gen set)

A **photovoltaic system** (or **PV system**) is a system which uses one or more solar panels to convert sunlight into electricity. It consists of multiple components, including the photovoltaic modules, mechanical and electrical connections and mountings and means of regulating and/or modifying the electrical output.



Q44.Explain (a) Hot spot heating (b) Efficiency limit losses & measurement

Hot-spot heating occurs when there is one low current solar cell in a string of at least several high short-circuit current solar cells.



If the teminals of the module are connected (module Isc), the power from the unshaded cells is dissipated across the shaded cell.

The efficiency of a solar cell may be broken down into reflectance efficiency, thermodynamic efficiency, charge carrier separation efficiency and conductive efficiency. The overall efficiency is the product of each of these individual efficiencies.

Due to the difficulty in measuring these parameters directly, other parameters are measured instead: thermodynamic efficiency, quantum efficiency, V_{OC} ratio, and fill factor. Reflectance losses are a portion of the quantum efficiency under "external quantum efficiency". Recombination losses make up a portion of the quantum efficiency, V_{OC} ratio, and fill factor. Resistive losses are predominantly categorized under fill factor, but also make up minor portions of the quantum efficiency, V_{OC} ratio.

The most fundamental of solar cell characterisation techniques is the measurement of cell efficiency. Standardised testing allows the comparison of devices manufactured at different companies and laboratories with different technologies to be compared.
The standards for cell testing are:

- Air mass 1.5 spectrum (AM1.5) for terrestrial cells and Air Mass 0 (AM0) for for space cells.
- Intensity of 100 mW/cm^2 (1 kW/m^2, one-sun of illumination)
- Cell temperature of 25 °C (not 300 K)
- Four point probe to remove the effect of probe/cell contact resistance

Q45.Explain PV cell interconnection & module fabrication.

In one aspect, the invention provides photovoltaic modules. In one embodiment, a photovoltaic module includes a plurality of photovoltaic cells, at least two of which include a photosensitized nanomatrix layer and a charge carrier media. Preferably, the cells further include a catalytic media layer. The photovoltaic cells are disposed between a first electrical connection layer and a second electrical connection layer. In one embodiment, the cells are interconnected in series and the electrical connections layers each include conductive and insulative regions.

A **solar cell** (also called **photovoltaic cell** or **photoelectric cell**) is a solid state electrical device that converts the energy of light directly into electricity by the photovoltaic effect.

Assemblies of cells used to make solar modules which are used to capture energy from sunlight, are known as solar panels. The energy generated from these solar modules, referred to as solar power, is an example of solar energy.

Photovoltaics is the field of technology and research related to the practical application of photovoltaic cells in producing electricity from light, though it is often used specifically to refer to the generation of electricity from sunlight.

Cells are described as *photovoltaic cells* when the light source is not necessarily sunlight. These are used for detecting light or other electromagnetic radiation near the visible range, for example infrared detectors, or measurement of light intensity.

Q46.What is efficiency limit for black body cell?

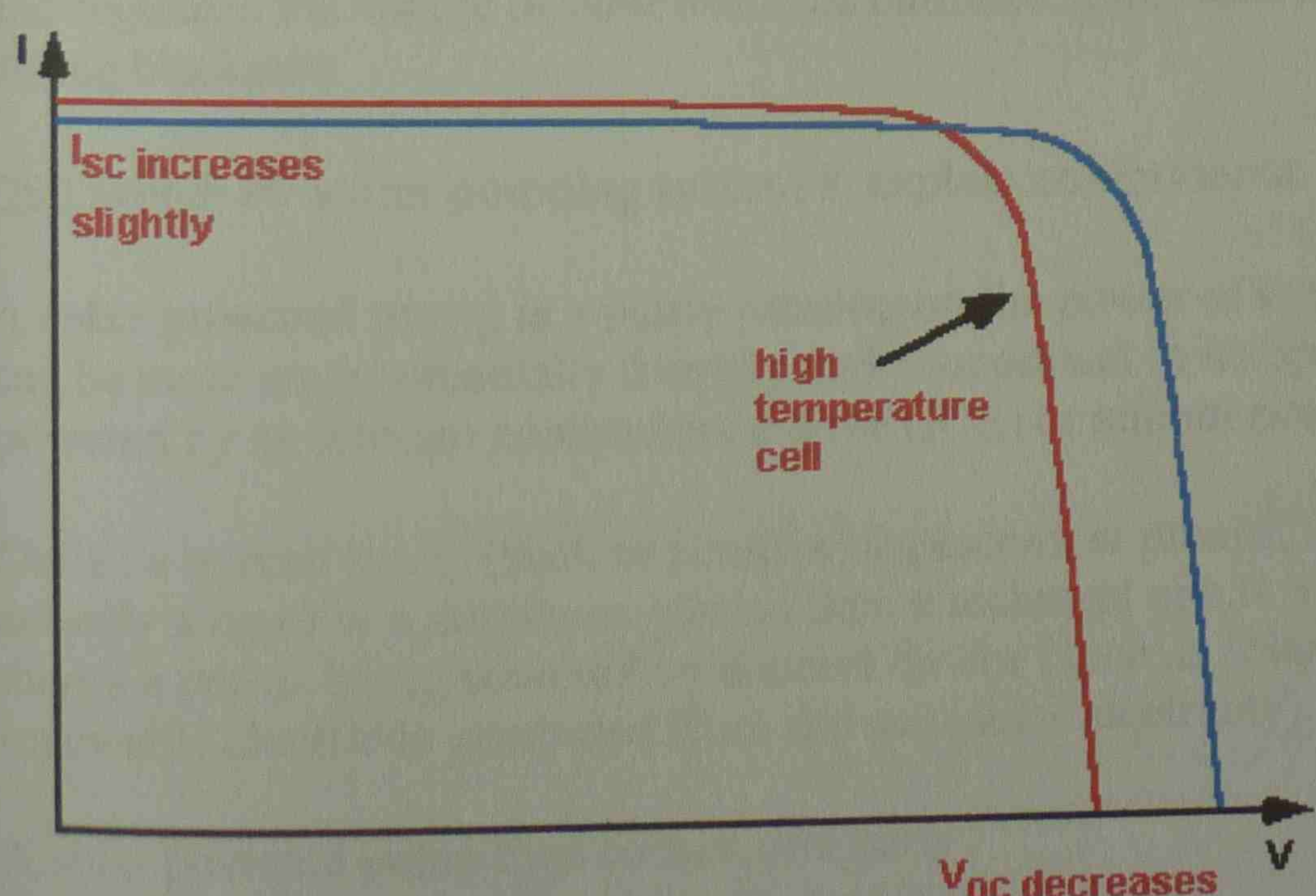
Any material above absolute zero temperature will emit radiation through blackbody radiation. In the case of a solar cell at ambient room temperature, at 300 Kelvin, a baseline energy is always being emitted. This energy cannot be captured by the cell, and represents about 7% of the available incoming energy.

This radiation effect is dependent on cell temperature. Any energy lost in a cell is generally turned into heat, so any inefficiency in the cell increases the cell temperature when it is placed in sunlight. As the temperature of the cells increases, the blackbody radiation also increases, until an equilibrium is reached. In practice this equilibrium is normally reached at temperatures as high as 360 Kelvin, and cells normally operate at lower efficiencies than their room temperature rating. Module datasheets normally list this temperature dependancy as T_{NOTC}.

Q47.What is the effect of temperature?

Like all other semiconductor devices, solar cells are sensitive to temperature. Increases in temperature reduce the band gap of a semiconductor, thereby effecting most of the semiconductor material parameters. The decrease in the band gap of a semiconductor with increasing temperature can be viewed as increasing the energy of the electrons in the material. Lower energy is therefore needed to break the bond. In the bond model of a semiconductor band gap, reduction in the bond energy also reduces the band gap. Therefore increasing the temperature reduces the band gap.

In a solar cell, the parameter most affected by an increase in temperature is the open-circuit voltage. The impact of increasing temperature is shown in the figure below.



The effect of temperature on the IV characteristics of a solar cell.

Q48.Explain the interaction of light with semi conductor.

In a traditional solid-state semiconductor, a solar cell is made from two doped crystals, one with a slight negative bias (n-type semiconductor), which has extra free electrons, and the other with a slight positive bias (p-type semiconductor), which is lacking free electrons. When placed in contact, some of the electrons in the n-type portion will flow into the p-type to "fill in" the missing electrons, also known as an electron hole. Eventually enough will flow across the boundary to equalize the Fermi levels of the two materials. The result is a region at the interface, the p-n junction, where charge carriers are depleted and/or accumulated on each side of the interface. In silicon, this transfer of electrons produces a potential barrier of about 0.6V to 0.7V.

When placed in the sun, photons in the sunlight can strike the bound electrons in the p-type side of the semiconductor, giving them more energy, a process known technically as photoexcitation. In silicon, sunlight can provide enough energy to push an electron out of the lower-energy valence band into the higher-energy conduction band. As the name implies, electrons in the conduction band are free to move about the silicon. When a load is placed across the cell as a whole, these electrons will flow out of the p-type side into the n-type side, lose energy while moving through the external circuit, and then back into the p-type material where they can once again re-combine with the valence-band hole they left behind, producing a lower-energy photon. In this way, sunlight creates an electrical current.

Q49.What are the components of PV electrical system?

Solar Electric (or Solar PV) systems convert sunlight to electricity. The systems consist of modules - or solar panels - inverter, charger and batteries. The PV modules generate DC electricity and send it to the inverter, the inverter transforms DC power into AC electricity and regulates the charge of batteries. The batteries store electricity that can be used at night or during blackouts.

Q50.Sketch PV water pumping system & explain components.

A **solar powered pump** is a pump running on the power of the sun. A solar powered pump can be more environmentally friendly and economical in its operation compared to pumps powered by an internal combustion engine (ICE) or animal power.

Unlike a normal pump (such as positive displacement pumps, ...), the solar powered pump is actually a more of a dictionary phrase than a technical one.It is only used to describe that there's a pump, being powered by another device (such as solar panels), being powered by the renewable electricity generated from the sun (solar electricity).

A solar powered pump thus consist of 4 parts :

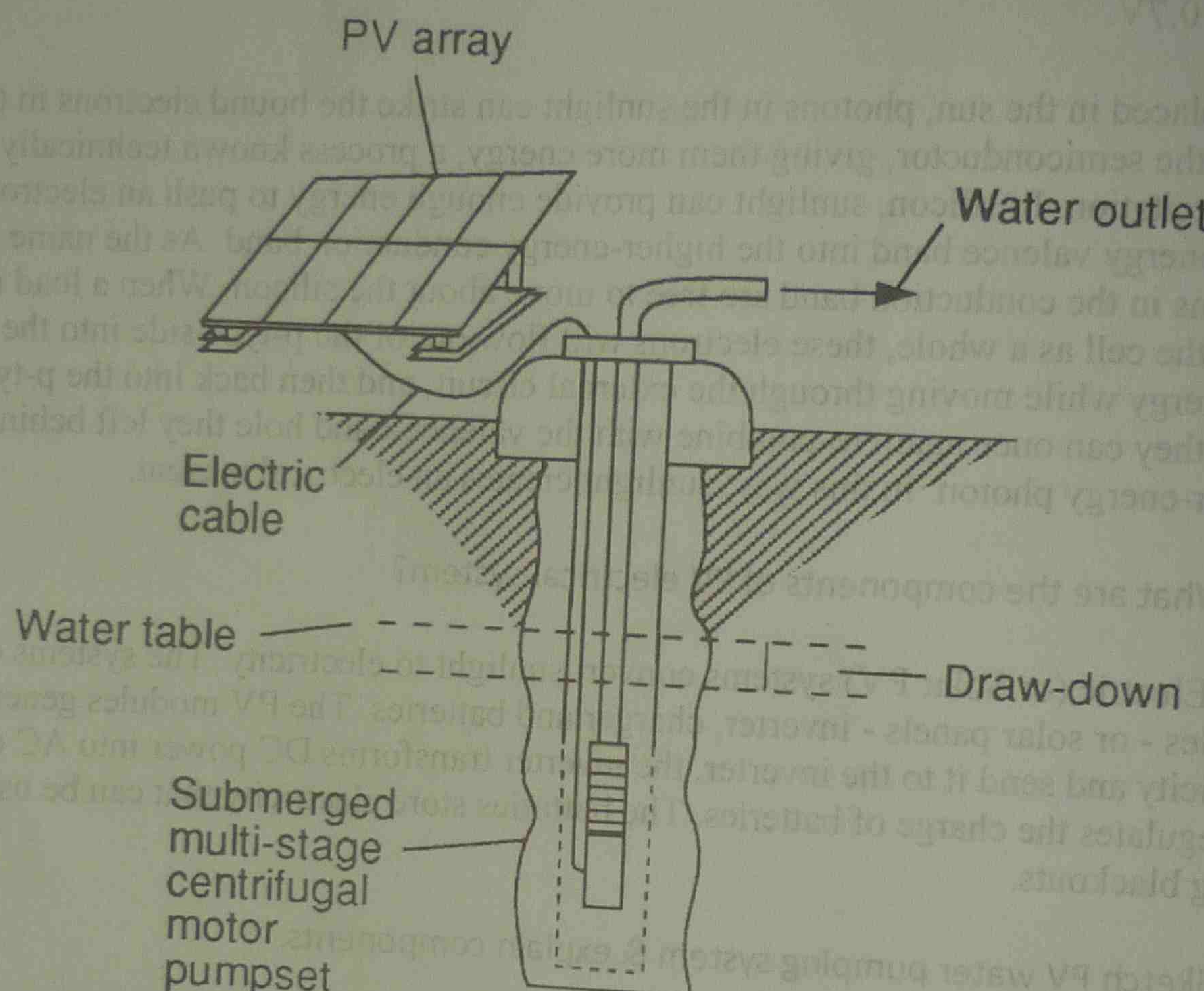
- the actual fluid pump (that actually moves (pumps) gases or liquids under pressure)
- the controller (adjusting speed and output power according to input from solar panels)
- the engine (usually an electric motor)
- the energy source being powered by the sun (usually photovolatic cells (solar panels))

Solar array (photovolatic cells, solar panels) takes up 50% - 80% of the whole setup cost, which is the most expensive part.

There are two major types of solar pumps, DC (direct current) and AC (alternating current).

DC solar pump:

- power output up to 2kW
- suitable for small applications (garden fountain, landscaping)
- relatively low-priced (require slightly less solar panel)
- low compatibility (only selected controller work selected motor)



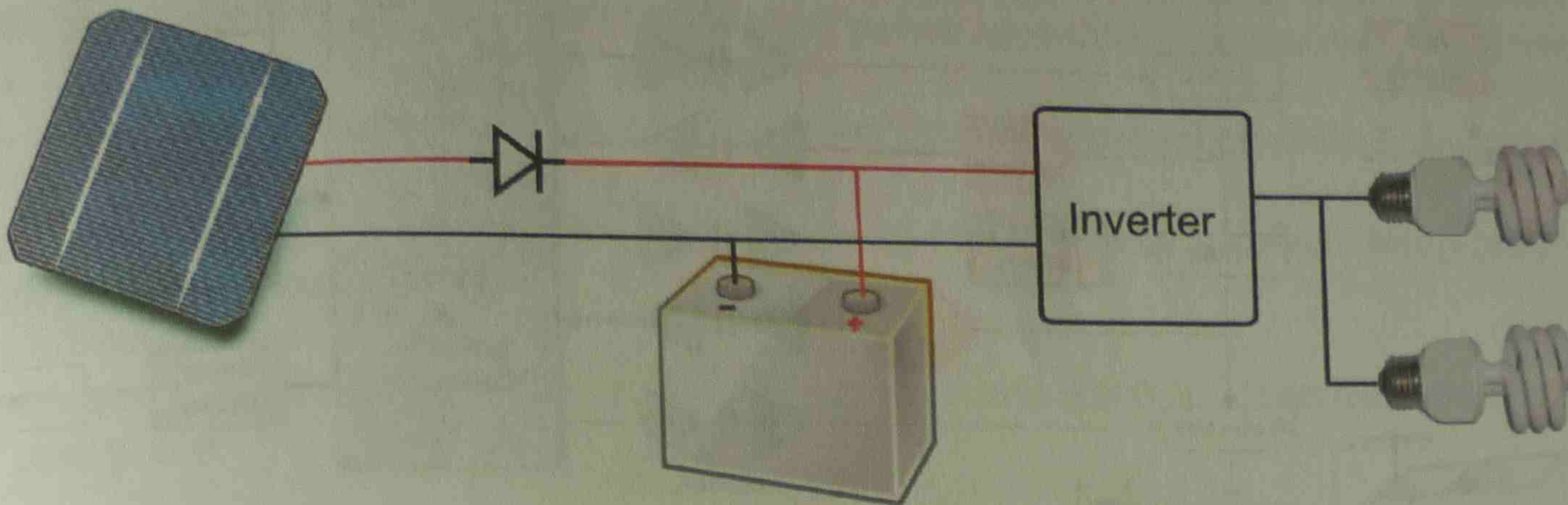
Q51.Exelectrical system plain power conditioning circuitry of solar water pump.

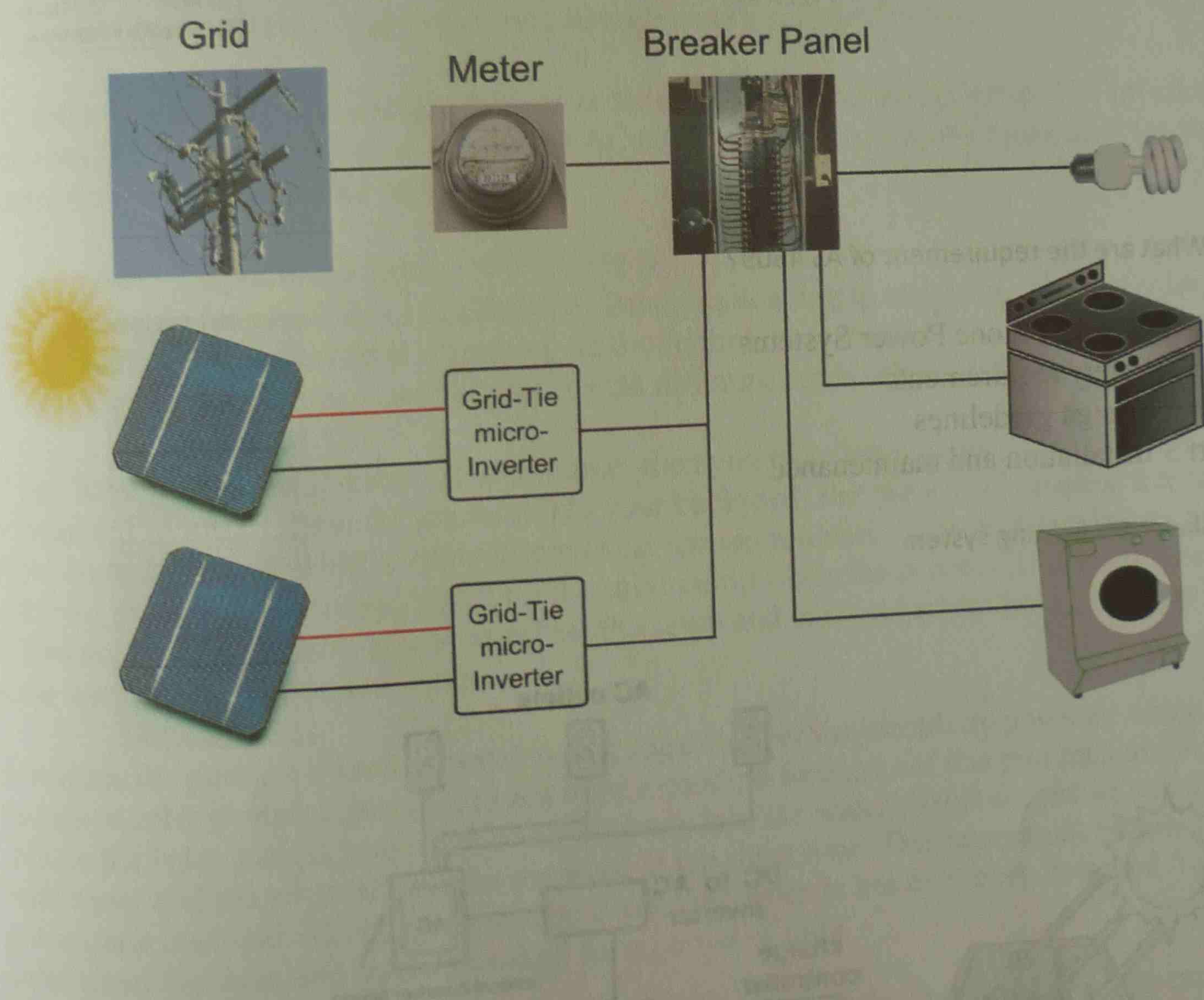
Photovoltaic pumps are made up of a number of components. There is a photovoltaic array which converts solar energy directly into electricity as DC. The pump will have an electric motor to drive it.. The characteristics of these components need to be matched to get the best performance. The pump motor unit will have its own optimum speed and load depending on the type and size of the pump.

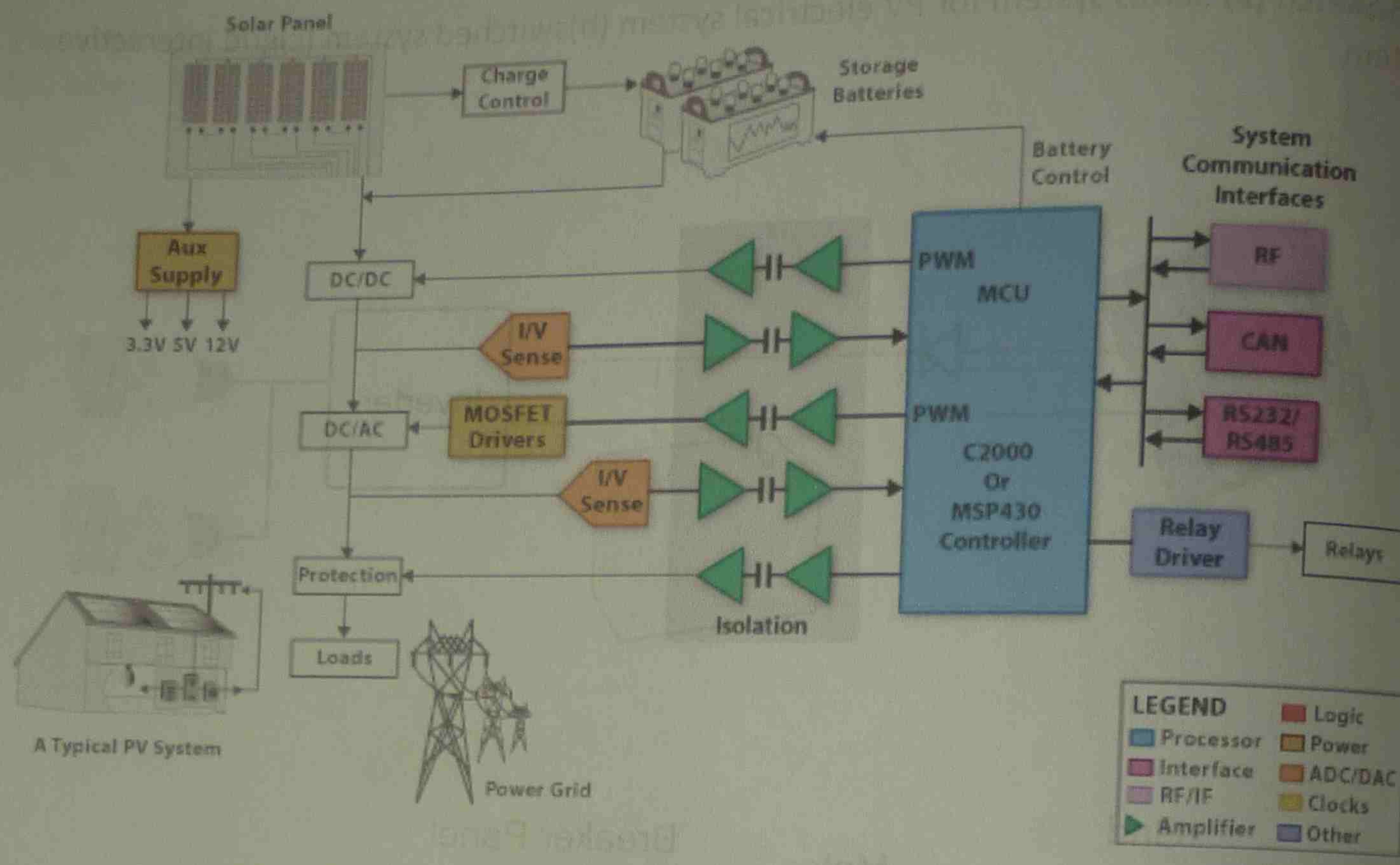
Q52.Write the equations for PV water pumping.

$H(S,p) = U + pV$

Q53.Sketch (a) Series system for PV electrical system (b)switched system (c)grid interactive system.



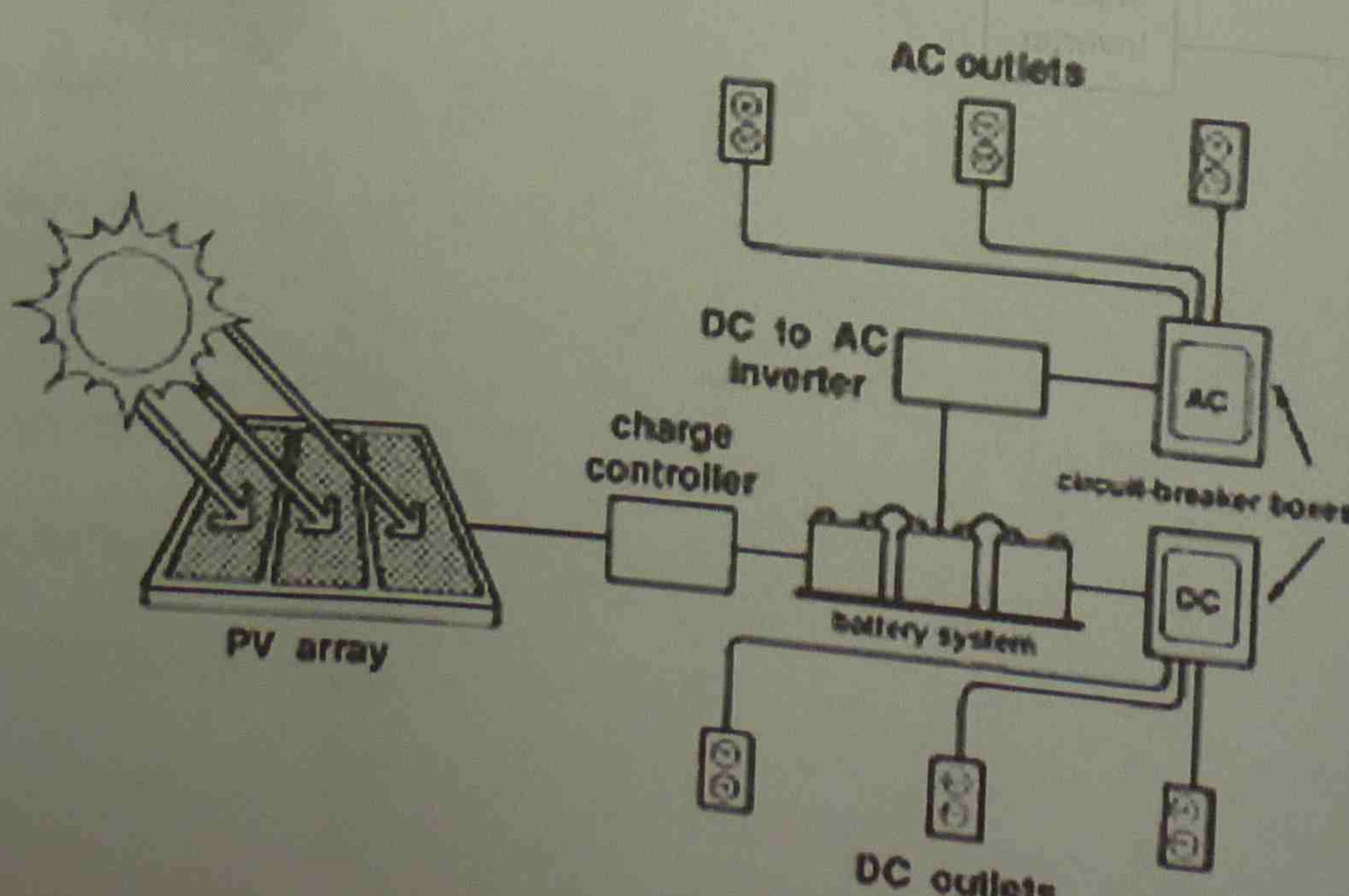




Q54.What are the requirement of AS 4509?

- AS 4509 Stand-alone Power Systems
- Part 1 Safety requirements
- Part 2 Design guidelines
- Part 3 Installation and maintenance

Q55.Sketch PV lighting system



Q57.Explain PV water system for water pumping.

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DC solar pump:

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- suitable for small applications (garden fountain, landscaping)
- relatively low-priced (require slightly less solar panel)
- low compatibility (only selected controller work selected motor)

AC solar pump: A solar pumping inverter is needed in AC solar pump setup. The inverter converts DC generated from solar array to AC to drive the pumps in the mean time (as the controller) to control output and speed.

- power output range from 150W to 55kW
- suitable for all kinds of applications from landscaping to irrigation, especially large scale such as farmland irrigation, desert control, etc.
- high compatibility (inverter works with different kinds of AC motor and pump)

If you have got a solar fountain at your home, then you must have learned that it is very convenient to install the solar fountain into your backyard. But the actual situation may be that you do not know what to do with your soar garden fountain or the tabletop fountain. After all, why should you pay to set up the solar pump while the process is so easy? The following 3steps will help you accomplish the setup and then just enjoy the beauty your new solar water fountain brings to you.

1. Initiate the pump All kind of water pump, regardless of the electricity powered water pumps or solar powered pumps can not have a good performance if it is pumping air. To initiate the solar pumps, you need to put the body into the water so that the intake can fill with water and the air inside can be removed at the same time. This process takes little time but is quite essential. This step should be every time when is has ever been detached from the solar water fountain and has not worked for a period of time.

2. Expose the solar panel to sunlight With the solar power as the energy source, you can place the solar powered fountain anywhere as you like, however be sure the solar panel must be located where the panel can receive maximum sunbeam. The longer the solar panel is exposed, the more power it will get for the fountain to work.

3. Get the debris out of the water Though most solar powered pumps are equipped with a filter to prevent dust and waste from block the solar fountain intake, the choice of water type