Solar PV Standardised Training Manual

SNV

Developed by SNV for the Rural Solar Market Development

Preamble

This Solar PV Standardised Training Manual has been developed by SNV Zimbabwe to provide basic technical training in the sizing, installation and maintenance of photovoltaic systems. In addition, it is a post training referral resource in troubleshooting and maintenance of systems. The manual covers the following:

a) Introduction to renewable energy in Zimbabwe
b) Electricity basics
c) Solar energy principles and applications
d) Photovoltaic technology and application
e) System sizing
f) Safety precautions, basic maintenance and trouble shooting

The manual is designed for use by anyone who wishes to develop his/her technical knowledge in PV. However, it is particularly targeted at those who wish to engage in the business of supplying and installing PV products. This manual does not guarantee the quality of installations carried out by trainees. It is recommended that all installations are carried out in a responsible and professional way. All electrical work should be performed by a qualified electrician to guarantee the installation and/or repairs.

About SNV

SNV is a not-for-profit international development organisation. Founded in the Netherlands nearly 50 years ago, we have built a long-term, local presence in 38 of the poorest countries in Asia, Africa and Latin America. Our global team of local and international advisors work with local partners to equip communities, businesses and organisations with the tools, knowledge and connections they need to increase their incomes and gain access to basic services – empowering them to break the cycle of poverty and guide their own development.

Through its Renewable Energy arm, SNV Zimbabwe has implemented the Rural Solar Market Development Project contributing to the success of most of its private sector partners' rural distribution capacities. The project has also helped partners to offer innovative next-generation solutions for efficient use of solar energy today and in the future.

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Tips For Using This Manual

The following tools are included to aid in detailed training:

1. Worked examples to test trainees' grasp of concepts.
2. Practical exercises to aid trainees in putting theory into practice.
3. Graphics to illustrate concepts and applications.

For quick reference the following are provided:

1. Highlighted Do's and Don'ts for care and maintenance of system components.
2. A list of FAQs

This manual is meant to be used hand-in-hand with the Solar PV Referral Manual and its accompanying PullOut Booklet.

ABBREVIATIONS

°C	Degrees Celcius
A	Amperes
AC	Alternating Current
Ah	Ampere hours
DC	Direct Current
E	Energy
FAQ	Frequently Asked Question
GWh	Gigawatt hour
I	Current
kW	Kilowatt
kWh	Kilowatt hour
m/s	Metres per second
MJ	Megajoule
MW	Megawatt
NGO	Non-Governmental Organisation
P	Power
PJ	Petajoule
PV	Photvoltaic
R	Resistance
REA	Rural Electrification Agency
SHS	Solar home system
STC	Standard Test Conditions
TV	Television
V	Volts
W/m2	Watts per square metre
Wh	Watt hour

LIST OF VISUAL AIDS

UNIT 1:

An Introduction to Renewable Energy in Zimbabwe

Learning Outcomes

By completing this unit, trainees will have basic understanding of:

i. The various sources of energy and the differences between the renewable and non-renewable energy technologies
ii. The energy situation in Zimbabwe including electrification rates, and the contribution of the different energy resources to the energy supply of the country.
iii. The basics of solar energy technologies and their application
iv. The advantages and disadvantages of solar technology

In this Unit

- Energy Challenges in Zimbabwe
- Status of Renewable Energy in Zimbabwe
- Solar Energy in Zimbabwe
- Pros and Cons of Solar Energy

Introduction

The existence of life on earth requires energy in its various forms. Ultimately, directly or indirectly, the sun provides all the power we need to exist and supports all life forms.

From solar ovens to solar panels, solar energy has been harnessed by humans since the beginning of human history. As far back as the 5th century, humans were constructing homes and buildings to maximize use of energy from the sun. Today, we know the sun as our closest star in the universe. This ball of gas has a large build-up of heat and pressure in its core that causes it to emit heat and radiant energy. More energy from the sun falls on the earth in one hour than humans consume in one year.

Unlike various forms of conventional (non-renewable) sources of energy such as coal, oil or natural gas, solar energy is a renewable form of energy, along with biomass, hydro, waste and wind. Though a variety of technologies have been developed to take advantage of solar energy in recent years, solar power accounts for less than one percent of electricity use in the Zimbabwe. However, given the abundance of solar energy and its popular appeal, this resource is likely to play a prominent role in our energy future.

Energy Challenges in Zimbabwe

Only 37% of Zimbabwe's population has access to electricity. Of the rural population, just 13% has access to electricity, mainly accounted for by growth points, business centres and mission stations. The statistics show that the poor are not connected to the grid and as such end up spending more on energy than the rich. The most recent national energy balance study (2009) shows that biomass contributes about 61% of the national energy consumption while electricity contributes just above 13%. Forests are disappearing very fast, causing desertification thus threatening the country and region's food security. Moreover, forests are carbon sinks and their disappearance contributes to global warming. Decentralised renewable energy schemes have the potential to meet the social and economic energy demands for the rural population in a sustainable manner.

Levels of investment in Zimbabwe's electricity generation sector are low due to political and economic reasons. Some of the existing power plants are operating at very low capacities for various reasons, some of which are:

(i) Some power stations are operating beyond their life spans
(ii) Frequent breakdowns due to ineffective / lack of maintenance and ageing of equipment and infrastructure
(iii) Inadequate coal supplies
(iv) Shortage of qualified and experienced manpower

The main cause of low investment in power generation is scarcity of capital for building new power plants, refurbishing of existing power plants and importing energy equipment and electricity. The economies of the countries which used to supply Zimbabwe with electricity have grown so much that they no longer have much to spare. Furthermore, Zimbabwe does not have the capacity to produce energy system components locally apart from batteries and other accessories resulting in an unsustainable over reliance on imports.

Status of Renewable Energy in Zimbabwe

Research has shown that the country has enormous energy resources which far exceed energy requirements. Most of these resources are grossly underutilized, particularly natural gas, hydro resources and the abundant solar energy available throughout the year. Thus the problem is not lack of energy resources but its development and utilization. The country has the potential to become a major net exporter of energy for several decades to come. Despite having significant renewable energy resources, the large power stations (with the exception of hydro power plants including Kariba) tend to be coal powered. As such, there is significant opportunity for electricity in Zimbabwe to be generated mainly from renewable energy sources.

Biomass Fuels

Unprocessed plant material combusted for the generation of heat

The traditional use of biomass is the burning of firewood for cooking and space heating. However, there are more sustainable means of using biomass for energy generation. Agricultural production can lead to large quantities of biomass, as at Triangle and Hippo Valley Estates where sugarcane bagasse is used to contribute significantly to their electricity needs, with the excess exported to the national power grid. The plants have capacity to produce 150MW with technological improvements and shift of business focus from disposing the bagasse to efficient electricity generation. Olivine Industries is known to be firing two of its boilers using waste from cotton seed de-hulling.

Sawmills in the eastern part on the country produce a lot of sawmill dust (about 50PJ/year) which can be burnt to generate electricity. Forest residue from commercial forests is estimated at 70,000 tonnes and has potential for the generation of 150MW power and the creation of a more formalised wood fuel and charcoal market. Three companies – Allied Timbers, Border Timbers and The Wattle Company – generate over 40,000m^3 of pine waste per year.

Biofuels

Fuel produced by processing plant material such as Jatropha

The Government has made a policy decision to embark on a programme to produce and use bio-diesel. Bio-diesel production in Zimbabwe offers improved energy security, import substitution, employment opportunities, empowerment and poverty alleviation in rural areas, reclamation and rehabilitation of degraded lands. The national bio-diesel production programme is based on Jatropha Curcas L as the feedstock material. The bio-diesel plant installed at Mount Hampden, near Harare is believed to be the largest such plant in Africa. Efforts should be directed at ensuring the efficient operation of the plant and ensure a consistent supply of raw material at a reasonable cost.

Ethanol

Fuel produced by processing of sugar cane

Triangle Ltd's enthanol plant resumed production in 2008 following refurbishment. In 2009, the plant produced 1 million litres of fuel grade ethanol. The refurbishment cost over $3 million. The Zimbabwean Government, in partnership with two investors has embarked another ethanol project valued at $600 million at the Agricultural and Rural Development Authority (ARDA) estates in Chisumbanje. The project will use 20,000 hectares of sugarcane plantations to provide 80% of Zimbabwe's ethanol needs and supply electricity (30 MW) to Mutare and several parts of Manicaland province.

Ethanol Gel Fuel, a compound of ethyl alcohol (ethanol) and organic pulp (cellulose) is another important source of household and institutional fuel that has been introduced on the Zimbabwean market. The calorific value of gel fuel compares favourably with that of paraffin. Access of households to paraffin has been hit by supply shortages. Given that the major raw material of gel fuel (ethanol) is locally produced, it becomes a more economic option as a substitute for the imported paraffin. Ethanol gel is considered to be a 'green fuel' because not only is it renewable, but is also manufactured entirely from organic compounds hence its combustion results in no net carbon dioxide emissions.

Wind

Use of wind's mechanical energy (captured using turbines) to pump water or generate electricity

In Zimbabwe wind speeds are generally low (about 3m/s) but can be used for water pumping and driving grinding mills. Electricity can be produced at small power levels (1 to 100kW) and from hybrid systems with micro photovoltaic generators for isolated sites in rural areas.

Wind energy technology development has a more attractive investment potential as it offers less capital investment than hydro and thermal power generators, because wind driven turbines generate electricity as soon as they are installed, unlike hydro and thermal power generators which require more infrastructural development. A small wind farm was established at Temaruru Business Centre near Rusape and six wind turbines of 1kwh were installed to power shops.

Small Hydropower

Use of mechanical energy in flowing water (captured using turbines) to pump water or generate electricity

In some areas of Zimbabwe, particularly in the Eastern Highlands, feasibility studies that have been carried out show that there are a number of perennial rivers with sufficient capacity that can be tapped for mini-hydro power development. Potential also exists at many irrigation dams throughout Zimbabwe to develop small-scale hydroelectric projects to partially offset the energy importation requirements of the country. To date only 7 hydropower generation schemes have been constructed in the eastern highlands, with power output ranging from 8 kW to 700 kW. One scheme with 700kW power generation is connected to the national grid. Tables 1&2 give minihydro potential on dams and perennial rivers.

Table 1: Feasible SHP sites on existing dams

DAM	CAPACITY (MW)	CAPACITY (GWh)	LOCATION
Condo	100.0	650.0	Manicaland
Gairezi	35.0	230.0	Manicaland
Tsanga	5.0	32.0	Manicaland
Osborne	3.0	20.0	Manicaland
Rusitu	0.7	4.6	Manicaland
Clearmont	0.3	1.6	Manicaland
Muturikwi (Kyle)	5.0	3.7	Manicaland
Bangala	1.0	9.0	Manicaland
Ngezi (Palawan)	0.3	2.0	Zvishavane / Midlands
Ruti	3.0	4.0	
Siya	0.6	5.0	
Manyuchi	0.7	5.0	Masvingo

Biogas

Methane produced by anaerobic digestion of organic waste matter such as animal waste and agricultural waste

The Government has built biogas plants as demonstration projects at institutions, communities and exhibition centres; others are also in use on commercial farms. It is envisaged that biogas will play a major role in providing alternative source of energy in smallholder farming areas, commercial farms, boarding schools and similar rural institutions for cooking, lighting and refrigeration. Currently the country has more than 400 biogas digesters scattered countrywide. Focus is on smallholder farmers and resettled areas. Constraints in the dissemination of the technology are to do with lack of end-user financing, limited number of trained builders compared to the demand for digesters.

Recently NGOs have shown a lack of willingness to finance projects on bio-digesters owing to high levels of failures in many of the installed bio-digesters.

Municipalities of some towns such as Harare have bio-digesters for anaerobic sludge treatment where a small proportion of the gas is used for heating sludge and most of the gas produced is just flared into the atmosphere. There is need for municipalities to install combined heat and electricity generating plant to maximise producer gas use.

Solar Energy in Zimbabwe

The country's solar energy potential of 16–20MJ/m²/day is greatly underexploited. At 3,000 hours a year, this can produce 10,000GWh of electrical energy per year. Donor-funded solar PV (photovoltaic) installations have been installed in many homes, businesses, schools and health centres since the launch of the Global Environment Fund initiative in the early 1990s. In addition to the Rural Electrification Agency (REA), there are a lot of small and medium enterprises now involved in importing and installing solar home systems for individuals who can afford buying the equipment.

Solar PV water pumping systems are also becoming a big area of interest. Solar water heaters present an attractive alternative technology for heating water both for domestic and industrial applications. The electricity saved by displacing electric water heating systems results in less pressure on the national grid and lower electricity bills for heating purposes. The electricity so saved can also be diverted to more productive uses in industry. Solar water heating technology is now a common technology in both urban and rural areas. Mining establishments with financial resources (e.g. Mimosa Mining Company in Zvishavane) have installed Solar Water Heaters in many of its staff houses.

Other types of solar thermal applications such as drying of vegetables and fruit, pasteurization of liquid foodstuffs, water desalination, cooking and water heating are also common.

Image 1: Solar refrigeration
Image 2: Solar water heater (evacuated tube solar geyser)
Image 3: Solar milk pasteurizer
Image 4: Solar crop dryer

Pros and Cons of Solar

Advantages of Solar PV Technology

1. **Solar PV provides clean – green energy.** During electricity generation with Solar PV there are no harmful greenhouse gases that are emitted thus it becomes environmentally friendly.
2. **Solar energy is energy supplied by nature** – it is thus free and abundant!
3. **Solar energy can be made available** almost anywhere there is sunlight
4. **Solar PV technology has indeed a highly promising future** both for economical viability and environmental sustainability.
5. **Photovoltaic panels,** through photoelectric phenomenon, produce electricity in a direct electricity generation way.
6. **Operating and maintenance costs** for PV panels are considered to be low, almost negligible, compared to costs of other renewable energy systems.
7. **PV panels have no mechanically moving parts,** except in cases of sun-tracking mechanical bases; in addition they have less breakages and require less maintenance than other renewable energy systems (for example wind turbines).
8. **PV panels do not produce any noise at all.**

Disadvantages of Solar PV

1. **As in all renewable energy sources,** solar energy has is not always available, there is no sun shining at night, during cloudy and rainy days.
2. **Consequently, intermittency and unpredictability** of solar energy makes solar energy panels less reliable a solution.
3. **Solar energy panels require additional equipment** (inverters) to convert direct electricity (DC) to alternating electricity (AC) in order to be used on the power network.
4. **For a continuous supply of electric power,** especially for on-grid connections, Photovoltaic panels require not only Inverters but also storage batteries; thus increasing the investment cost for PV panels considerably
5. **In case of land-mounted PV panel installations,** they require relatively large areas for deployment; usually the land space is committed for this purpose for a period of 15-20 years – or even longer.
6. **Solar panels efficiency levels are relatively low** (between 14%-25%) compared to the efficiency levels of other renewable energy systems.
7. **Though PV panels have no considerable maintenance** or operating costs, they are fragile and can be damaged relatively easily; additional insurance costs are therefore of ultimate importance to safeguard a PV investment.

Summary of Pros & Cons of Solar

PROS

Reliability	Even in harsh conditions, PV systems will continue to generate power, preventing costly power failures where continuous operation is critical (e.g. solar refrigeration in a butchery)
Durability	Most modules are guaranteed from the manufacturer to produce power for 25 years and will keep producing well beyond that timeframe
Low Maintenance Costs	PV systems only require periodic inspection and occasional low cost maintenance such as dust removal on panels.
No fuel costs	No fuel required therefore there are no costs associated with purchase, storage and transportation of fuel.
Reduced sound pollution	PV systems do not have moving parts and therefore operate silently
Flexibility due to modularity	Modules can be added incrementally to increase power available from the system
Safety	PV systems do not require combustible fuels and therefore are safe when properly designed and installed
Independence	Independence from unreliable grid supplied power
Grid decentralisation	Small scale decentralised power stations reduce the possibility of outages on the electricity grid
High altitude performance	Increased insolation at high altitudes leads to optimised power output. In contrast, generators need to be de-rated at high altitudes.

CONS

Initial cost	Higher installation costs compared with generators. Prices are however, coming down
Variability	Weather can affect the power output of solar based systems
Energy storage	The need for batteries increases the size, cost and complexity of systems. In addition energy storage technology still needs to develop further
Efficiency improvements	A cost-effective use of PV requires use of energy efficient appliances which may require replacement of inefficient appliances
Education	Uptake of PV technology needs to go hand in had with user education as the technology is new to most in rural areas.

Exercises

1. **Define** the following terms:
   a. Biofuels
   b. Small hydro power
   c. Biogas

2. Name **three** non-renewable sources of energy.

3. Name **three** renewable sources of energy.

4. What energy source is used to meet the highest proportion of energy demand in Zimbabwe?

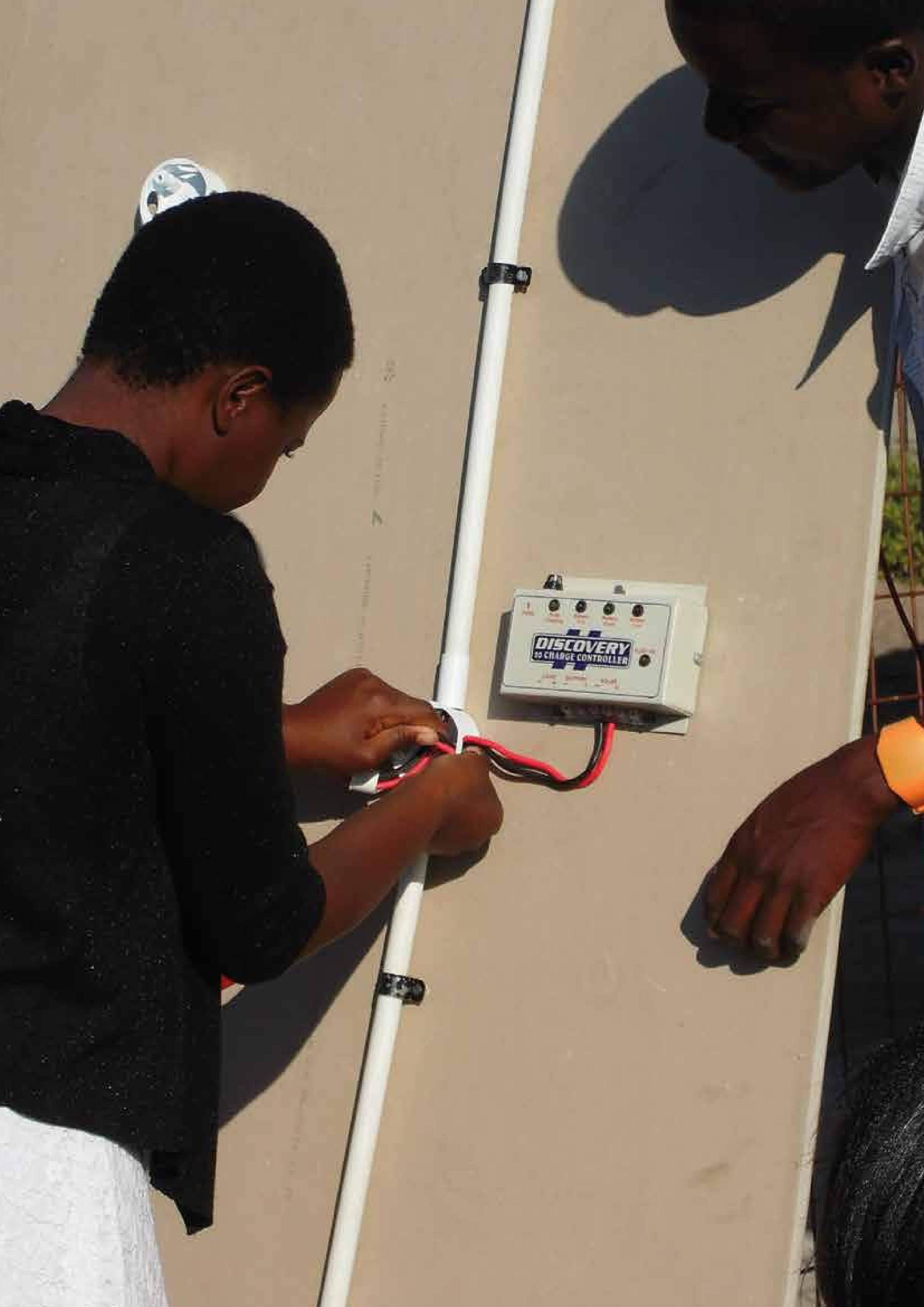
5. List **four applications** of solar technology in Zimbabwe.

6. What is the main barrier to the development of renewable energy in Zimbabwe?

7. Why is solar energy an appropriate technology for Zimbabwe? **List four reasons.**

Practical Exercise:

Over the next week, identify, take note and take photographs (if possible) of solar technology at work around your everyday environs. This will aid in your appreciation of the application of the technology.


DISCOVERY
CHARGE CONTROLLER

UNIT 2:

Solar Energy – The Basic Physics

Learning Outcomes

By completing this unit, trainees will have basic understanding of:

i. The basics of electricity – voltage, current, resistance, power and energy
ii. Describe solar energy
iii. The earth's energy budget
iv. The technology enabling the capture and use of solar power (solar PV and solar thermal)

In this Unit

- A Brief Introduction to Electricity
- The Solar Resource
- Solar Energy Conversion

A Brief Introduction to Electricity

What is Electricity?

The term electricity is used generically in reference to four related physical states as follows:

1. **Electric charge:** the build up of electrical energy measured in coulombs. Naturally it occurs as static electricity. Batteries store electric charge.
2. **Electric current:** the rate of flow of electric charge measured in amperes
3. **Electric potential:** the potential difference in electrical energy between two points e.g. between the positive and negative terminals of a battery. It is measured in volts.
4. **Electromagnetism:** the relationship between electricity and magnetism, which enables electrical energy to be generated from mechanical energy (as in a generator) and vice versa (as in a motor).

Measuring Electricity

- **Power (P):** **the rate of energy** conversion measured in ***Watts***
- **Voltage (V):** **the potential difference** in electrical charge between two points measured in ***Volts***
- **Current (I):** **the flow of electrons** in a circuit/wire between two points measured in ***Amperes***
- **Resistance (R):** **the opposition to the flow** of electrical current in the material through which it is passing measured in ***Ohms***
- **Energy (E):** **refers to the capacity for work** i.e. the power used over time, measured in ***Watt hours***

The following equations show the relationship between the above parameters:

Power = Volts x Current	P = V X I	Watts
Volts = Power ÷ Current	V = P ÷ I	Volts
Current = Power ÷ Volts	I = P ÷ V	Amperes
Resistance = Volts ÷ Current	R = V ÷ I	Ohms
Energy = Power x Time	E = P x t	Watt-Hours

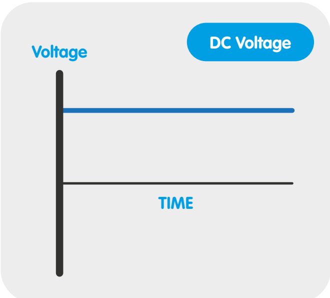
Types of Current

In electricity generation there are two distinct types of electrical current - **direct current (DC)** and **alternating current (AC)**.

Alternating current is the type of current most commonly used in households to power electrical appliances (for example TVs, refrigerators, radios and computers). Grid supplied electricity is alternating current.

Direct current is produced by PV modules and stored in batteries.

It is possible to convert direct current to alternating current and vice versa using an adapter (e.g. cell phone charger) or an inverter (see Unit 3). Some key differences between AC and DC are shown in *Table 2* below.



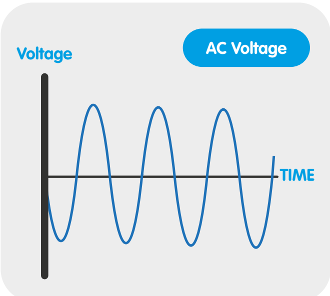
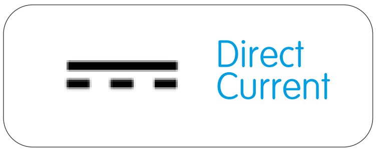


Figure 1:
Visual Representation of the difference between AC and DC

	Alternating Current	Direct Current
Amount of energy that can be carried	Safe to transfer over longer distances and can provide more power.	Cannot travel very far until voltage drop will start to affect, hence there will be loss of energy.
Frequency	The frequency of alternating current is 50Hz or 60Hz, as indicated on most appliances	The frequency is zero.
Direction	Reverses its direction at frequent, regular intervals while flowing in a circuit.	Flows in one direction in a circuit.
Current	It is the current of magnitude varying with time	It is the current of constant magnitude.
Flow of electrons	Electrons keep switching directions - forward and backward.	Electrons move steadily in one direction or 'forward'.
Obtained from	A.C Generator and mains.	Cell or Battery.
Storage	Cannot be stored	Can be stored in batteries.



Electrical Circuits

An electrical circuit is the continuous path through which electrical current flows from a voltage source (e.g. battery or PV module), through a conductor (wire) to a load and back to the source. Figure 2 to the right shows a simple schematic drawing of a circuit.

The switch in the circuit controls the flow of current. When the switch is turned off (an open circuit) the load is disconnected. When it is turned on (a closed circuit) the load is connected.

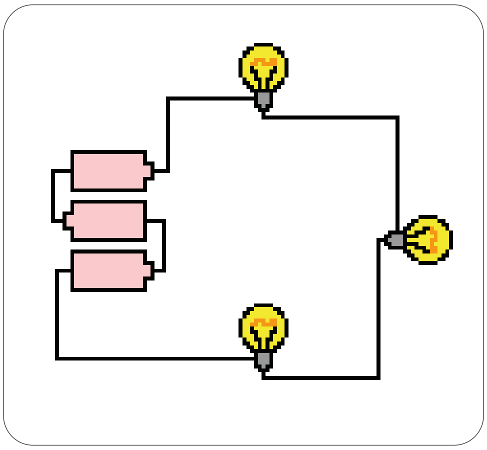


Figure 2:
Simple Schematic
Drawing of a Circuit

Loads and power sources in a circuit can be connected in ***series*** or ***parallel***.

Series wiring connections are made at the positive end of one load/power source to the negative end of another. When loads/power sources are connected in series the VOLTAGE INCREASES. Series wiring does not increase current. Figure 3 below illustrates power sources and loads connected in series respectively.

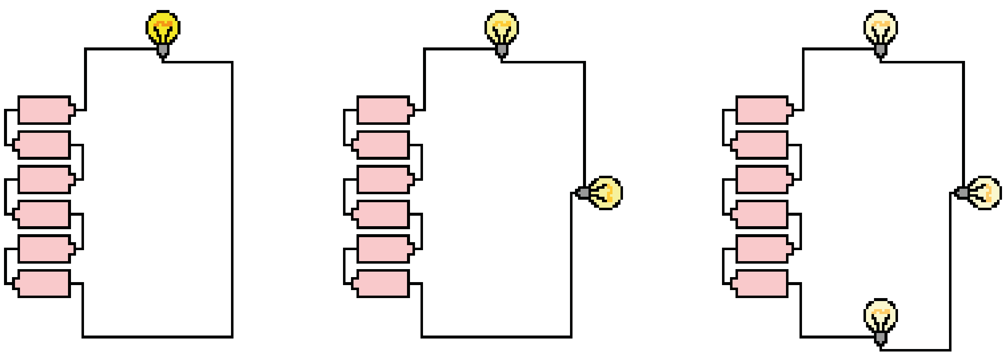


Figure 3:
Series Connection
Schematic

Parallel wiring connections are made from the positive to positive ends and negative to negative ends between loads/power sources. When loads/power sources are connected in parallel the CURRENT INCREASES. Voltage is not affected. Figure 4 below illustrates power sources and loads connected in parallel respectively.

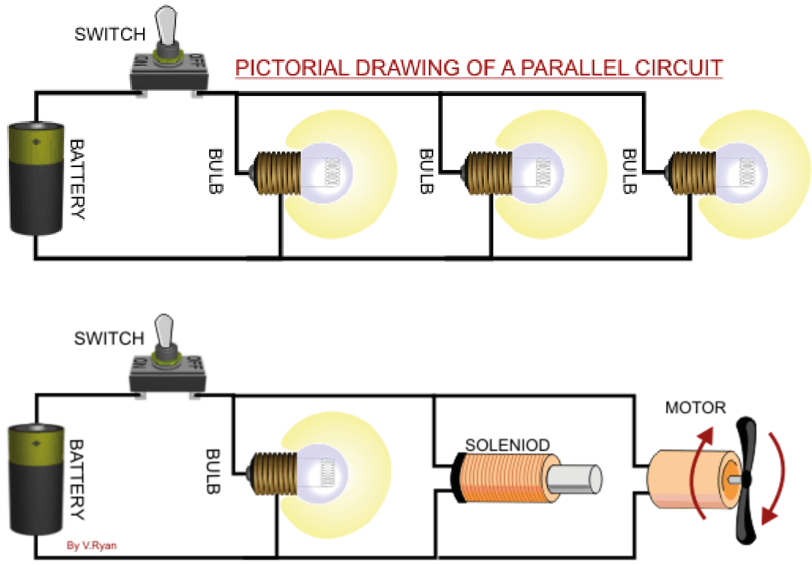


Figure 4: Parallel Connection Schematic

Systems may use a mix of series and parallel wiring to achieve the required voltages and amperages.

The Solar Resource

The term “Solar Energy” refers to radiant heat and light from the sun. This energy travels over 93 million miles from the sun to the earth. As solar energy travels through the atmosphere to the earth’s surface, not all of the energy reaches the earth’s crust. The following diagram shows how solar energy travels through the atmosphere to the earth where it can be utilised.

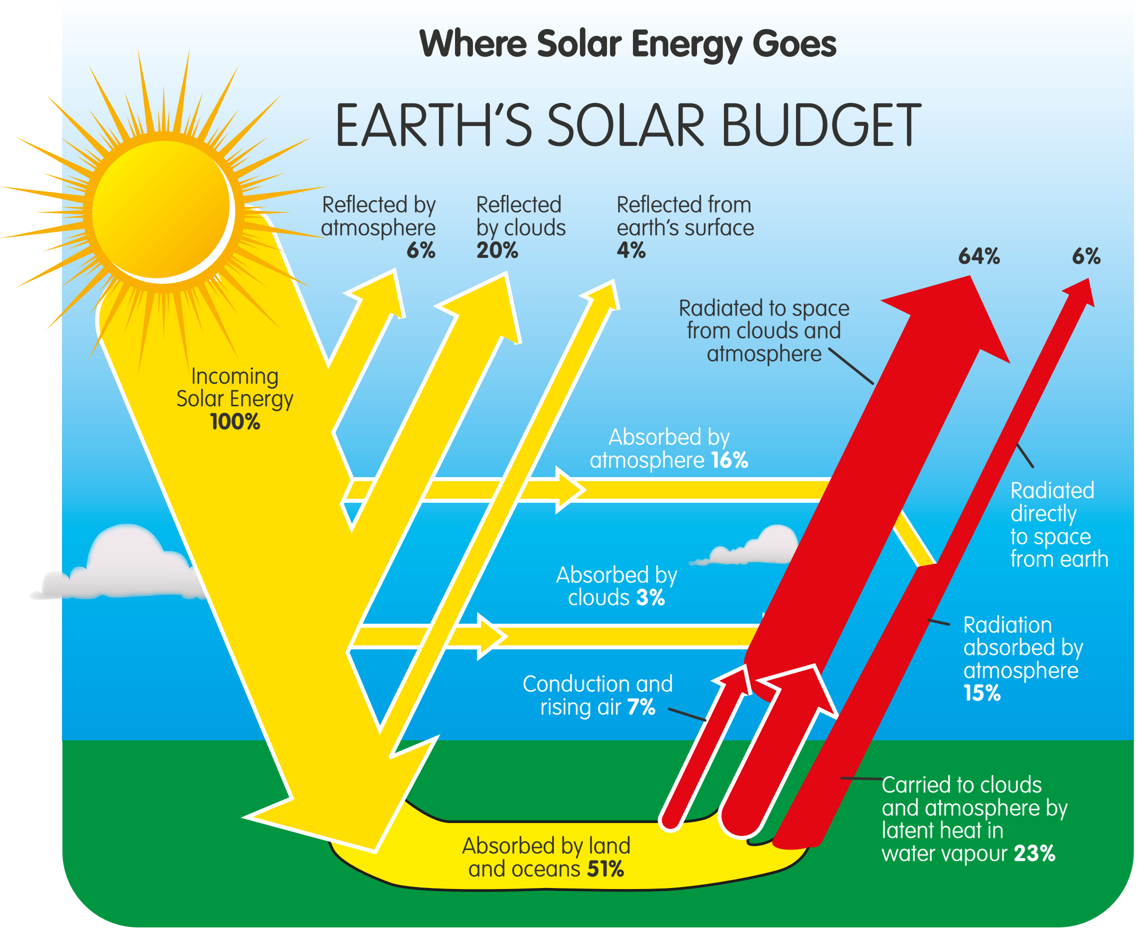


Illustration 1:
Earth’s Solar Budget

In addition to the factors shown in the illustration above, the amount of solar energy (insolation) available at a particular location on the earth’s surface is affected by:

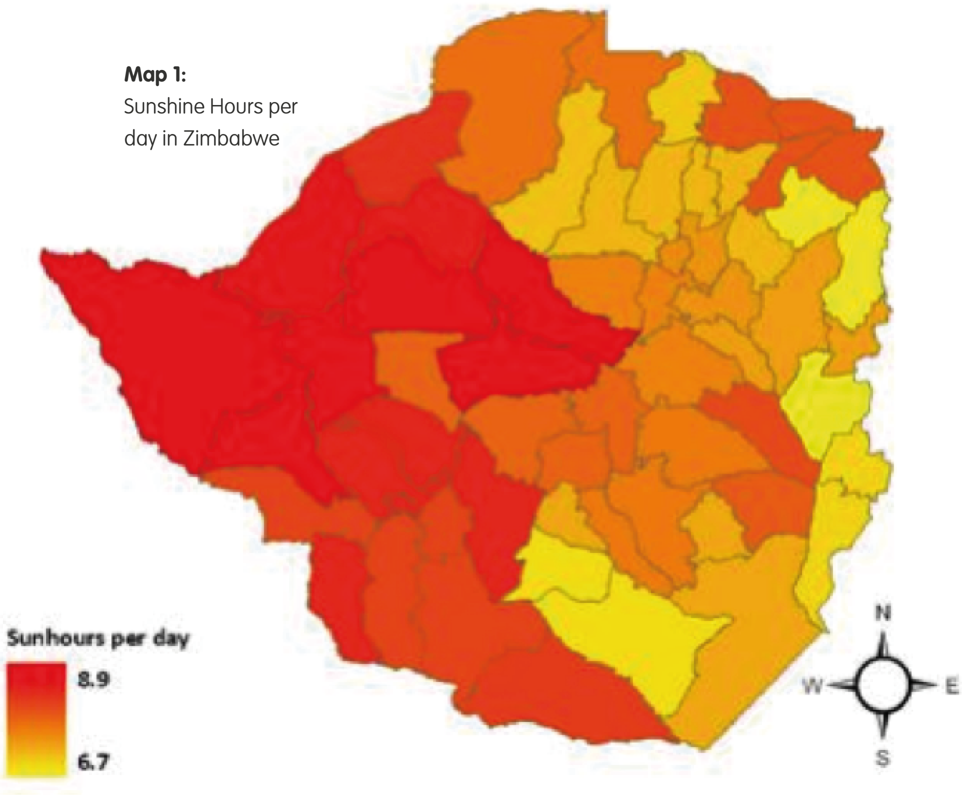
- Latitude (the location’s distance north or south of the equator),
- The earth’s tilt, and
- Time of year

The average insolation for a particular location is known as irradiance and is measured in Watts per square meter (W/m^2).

In addition to irradiance, sunshine hours are also used to determine the availability of viable solar resource. Zimbabwe has an annual average of sunshine hours per day of approximately 4.5 and 8.9 Map X.

The western part of the country gets the most sunshine of an average of up to 8.9 hours per day. The eastern part gets less sunshine to as low as an average of approximately 4.5 - 6.7 hours per day. The difference of the sunshine hours is explained by the difference in climatic conditions.

Map 1:
Sunshine Hours per day in Zimbabwe



Solar Energy Conversion

Solar Energy is harnessed and converted to heat or electricity using various technologies. Below is a description of the basic technologies.

Solar Energy to Electricity

The term photovoltaic means electricity from the sun. Photovoltaic technology is used to convert light energy into electrical energy. This technology has been developed on the basis that some semiconductor materials such as silicon generate voltage and current when exposed to light.

A thin wafer consisting of an ultra-thin layer of N-type silicon on top of a thicker layer of P-type silicon (where N – Negative and P – Positive) will have an electrical field where these two materials are in contact, called the P-N junction. When sunlight strikes the surface of the wafer, it causes the electrical field to provide momentum and direction to light-stimulated electrons, resulting in a flow of electrical current to any electrical load connected. Figure X below illustrates this principle.

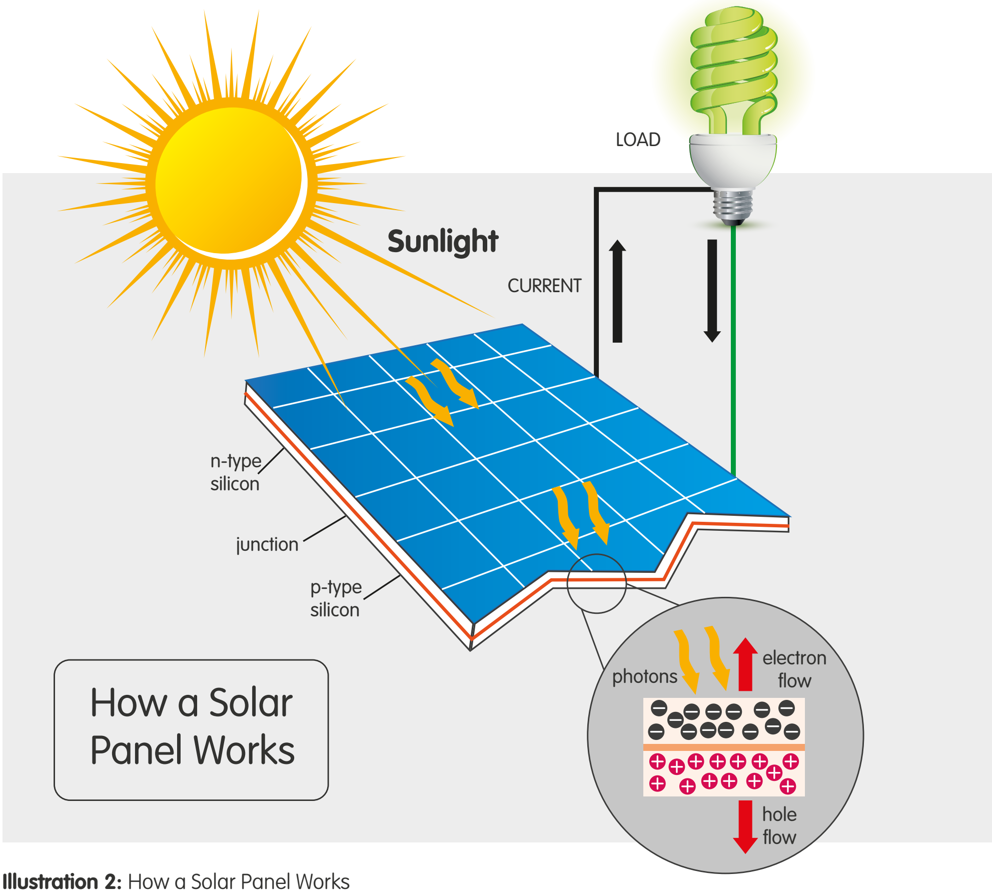


Illustration 2: How a Solar Panel Works

Solar Energy to Thermal Energy

Solar thermal systems operate when radiation/heat from the sun is directed to a device which captures and concentrates the heat to a carrying media (air or water). The fluid gains heat from the pipes/fins installed within the system and delivers it through an outlet either as warm or hot. Figure X below illustrates the concept using water as the medium.

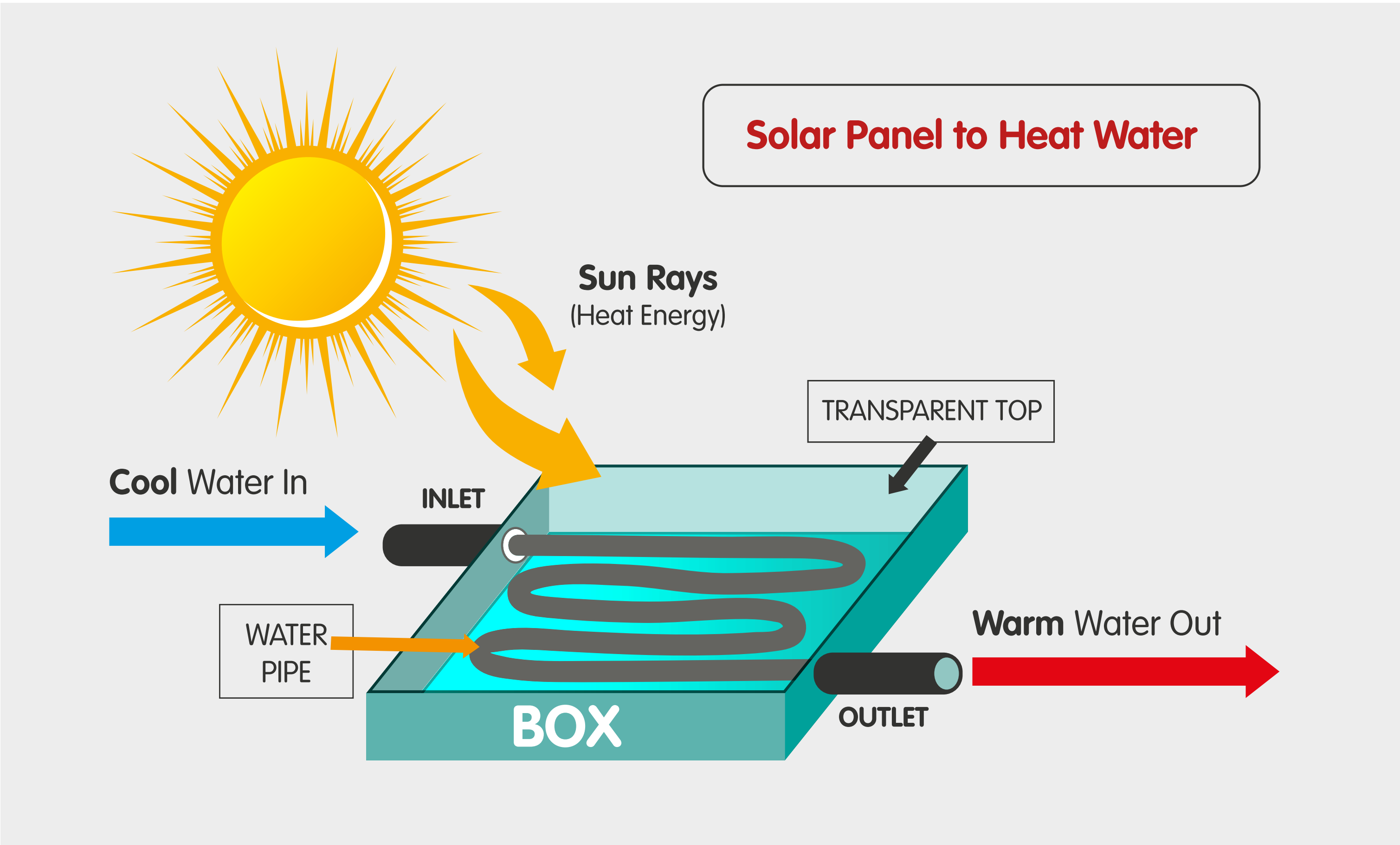


Illustration 3: Solar Panel to Heat Water

Exercises

1. **Define** the following terms providing equations:
    a. Voltage
    b. Current
    c. Resistance
    d. Power

2. How much electrical energy is consumed if a 100-watt light bulb is used for 10 hours?

3. When **four** 1.5V DC batteries are connected in series, what is the resulting voltage?

4. How would you wire the **sixteen** 12V batteries to achieve a 48V power source?

5. State four differences between AC and DC.

6. What percentage of the total incoming solar energy makes it to the earth's crust?

7. What is the basis of photovoltaic technology?

8. What media can be used to capture heat radiation from the sun?

Practical Exercise:

Make a list of electrical gadgets in your home and note the following for each one:

- Voltage rating
- Power rating
- Whether it utilises DC or AC

This information will be used in Unit X for sizing a system.

UNIT 3:

Photovoltaic Systems

Learning Outcomes

By completing this unit, trainees will have basic understanding of:

i. The standard, basic components of a PV system, including their function and operation
ii. Range in size/scale of PV systems/applications
iii. The basic connections of a solar home system

In this Unit

- From Micro PV to utility scale
- PV system Components
- Solar lanterns
- Solar Home Systems

From Micro PV to Utility Scale

The application of PV technology now ranges from calculators to utility scale power generation. In between you have solar lanterns, PV lighting systems, water pumping systems and community scale micro-grids. As scale increases so does the complexity of the system.

This Unit highlights the variation in scale by discussing solar lanterns and solar home systems along with their system components.

Image 5:

Solar Calculator versus Large Scale Solar farm

PV System Components

Photovoltaic systems consist of some or all of the following components:

- PV Panel
- Load
- Wiring
- Inverter
- Charge controller
- Battery

Whether a system has some or all of these components is dependent on factors such as the size, the type of load powered, required current (AC or DC or both) and how it is used (all day or a few hours a day).

PV Panel

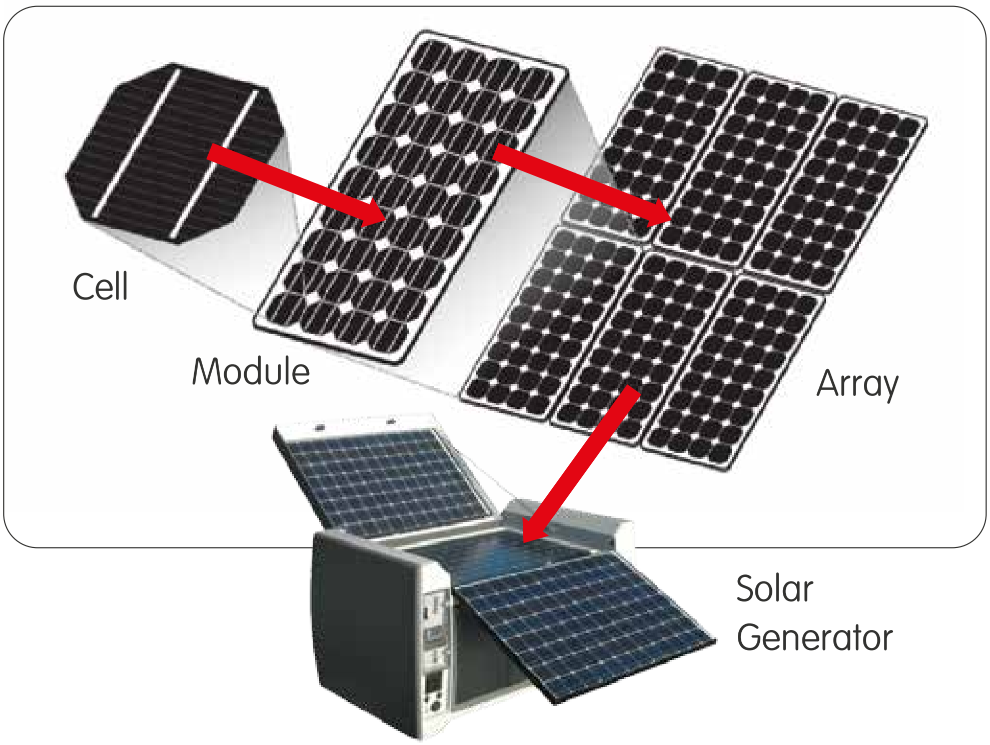
Photovoltaics (PV) or solar cells are the building blocks of solar panels. They are made of semiconductor materials as described in Unit 2. They convert sunlight into direct current (DC) electricity.

In practice a typical silicon PV cell produces voltage of 0.5 – 0.6 DC under open-circuit, no-load conditions. The current (and power) output of a PV cell depends on its efficiency and size (surface area), and is proportional to the intensity of sunlight striking the surface of the cell. For example, under peak sunlight conditions a typical commercial PV cell with a surface area of 160cm² will produce about 2 watts peak power.

Image 6: Typical Solar Cell

Groups of PV cells are electrically configured into modules/panels which can be connected into arrays to achieve desired power and voltage outputs. Photovoltaic modules consist of PV cell circuits sealed in an environmentally protective laminate, while panels include one or more PV modules assembled as a pre-wired, field-installable unit. A photovoltaic array is the complete power-generating unit, consisting of any number of PV modules and panels.

Figure 5: Solar cell, module, array and solar generator



The performance of PV modules and arrays is generally rated according to the maximum DC power output and current (to produce watts) under Standard Test Conditions (STC). Since these conditions are not always typical of how PV modules and arrays operate in the field, actual performance is usually 85 to 90 % of the STC rating.

Standard Test Conditions are defined by a module (cell)

- Operating temperature of 25o C, and...
- Incident solar irradiance level of 1000 W/m² and...
- Under Air Mass 1.5 spectral distributions.

In practice each and every solar panel has a distinct rated power output which is determined by the voltage and current that the solar panel can produce. In general, solar panels produce either 12 or 24 volts. The amount of current that the solar panel produces determines the amount of power produced by the solar panel. Figure X below shows an extract from the name plate of a solar panel.

Reading a Solar Panel Name Plate

Maximum Power means it can deliver maximum 100 Watts electricity.

Maximum Voltage means its maximum output voltage is 18.0V.

Open Circuit Voltage means the voltage without load.

Maximum Current means the maximum output current.

Short Circuit Current means the current of short circuit of solar panel.

Maximum System Voltage means that, when we connect solar panel in series then **Maximum Voltage Limit** is 1000V.

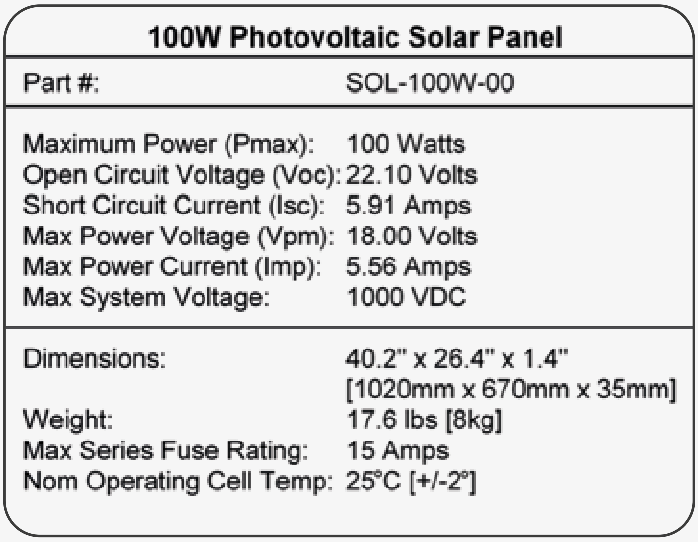


Figure 6: The picture above shows an extract of a name plate of a solar panel

Charge Controller / Charge Regulator

The solar charge regulator/ charge controller is basically a voltage and/or current regulator which is connected between the solar panel and the battery and load. Its main function is to manage the charge and discharge of the battery and keep the battery pack in good condition.

The charge controller regulates the voltage and current flowing from the solar panel(s) to the battery since most solar panels can produce more than the rated voltage (for example a solar panel rated 12 volts can produce up to 20 volts).

Without the regulation the battery will be damaged due to overcharging. This is so because maximum voltage for most batteries is between 14 and 15 volts.

The figure below shows a typical solar charge controller. However, they come in various forms and designs depending on the application and manufacturer. They vary in terms of their working voltage or system voltage and the current that they are supposed to handle during operation.

Image 7:
Charge Controller / Regulator

Other Examples of Charge Controllers / Regulators

Images 8, 9 & 10:
Other examples of Charge Controllers

Advantages of Using a Charge Controller

- It monitors the battery voltage, stops charge when the battery is fully charged
- Extends battery life
- Regulates power from the solar panels, protecting the battery from overcharging
- The charge controller ALSO protects our gadgets

Disadvantages of NOT Using a Charge Controller

- Damage of batteries since there is no regulation of power
- Damage of Electrical gadgets
- Damage of the solar panel due to reverse flow of voltage

Connections on a Charge Regulator / Controller

Basically, the charge regulator/controller is connected to the solar panel(s), battery and DC Loads.

The diagram shows the terminals where these components are connected. Most charge regulators/ controllers have some pictures or icons which indicate the component to be connected as indicated in the diagram.

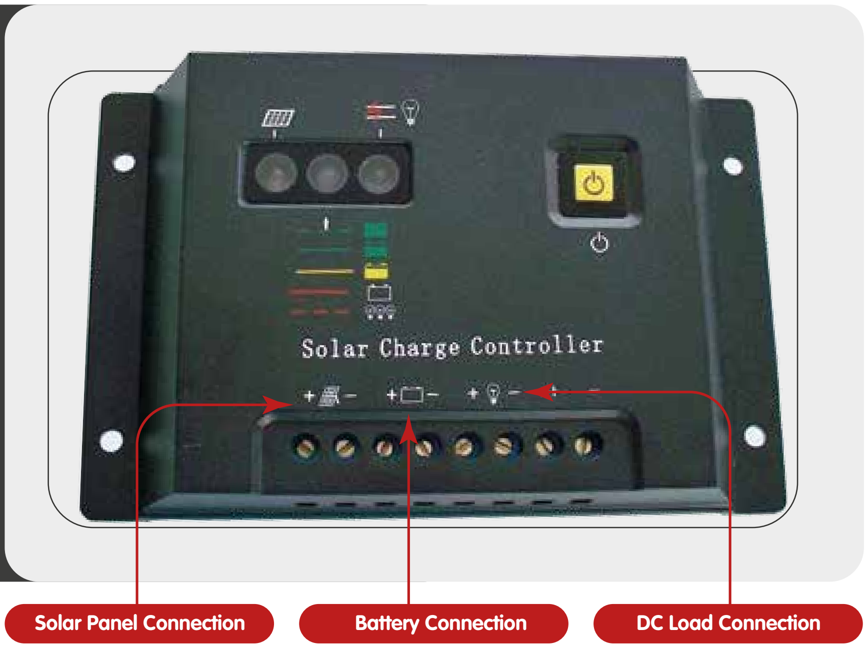


Figure 7:
Connections on a Charge Controller

Solar Batteries

Solar batteries are available in various forms and designs depending on the use and also on the manufacturer. Basically, a solar battery must be able to withstand constant and frequent charging whilst it delivers the required power/voltage output. A solar battery is not expected to fail in a short space of time (when it is properly used).

The primary functions of a storage battery in a PV system are:

1. **Energy Storage Capacity and Autonomy:** to store electrical energy when it is produced by the PV array and to supply energy to electrical loads as needed by the system or on demand.
2. **Voltage and Current Stabilization:** to supply power to electrical loads at stable voltages and currents, by suppressing or 'smoothing out' transients that may occur in PV systems.
3. **Supply Surge Currents:** to supply surge or high peak operating currents to electrical loads or appliances.

Types of Solar Batteries

Solar systems require use of deep cycle batteries. These differ from standard car batteries in that deep cycle batteries have been developed for frequent discharge and slow recharge. Car batteries are therefore not suitable for use in solar systems.

Why Not Use the Car Battery?

- Its capacity is too small for continuous charging so they would not last very long.
- It might seem like a good idea in the beginning because of cost, but you'll pay for it in 9 months or so.
- Car type batteries discharge too quickly and don't last very long. In addition, after they get discharged to a certain extent they don't work well at all.

Conclusion: **DO NOT USE CAR BATTERIES ON YOUR SOLAR SYSTEM**

Deep cycle batteries are either wet/flooded or sealed. There are three types of batteries within these categories suitable for use in solar systems:

Flooded Type

- This is a lead acid type battery.
- While these are good batteries, this type **needs to be stored outside of your home** or in an area with lots of air as they emit gas and can be dangerous in your home if not handled carefully.
- This type of battery is economical and will last for years if maintained properly.
- The most popular brands of this type of battery are **Trojan, Surrette** and **Deka**.
- Make sure to ventilate this type of battery if in an enclosure.

Gel Type

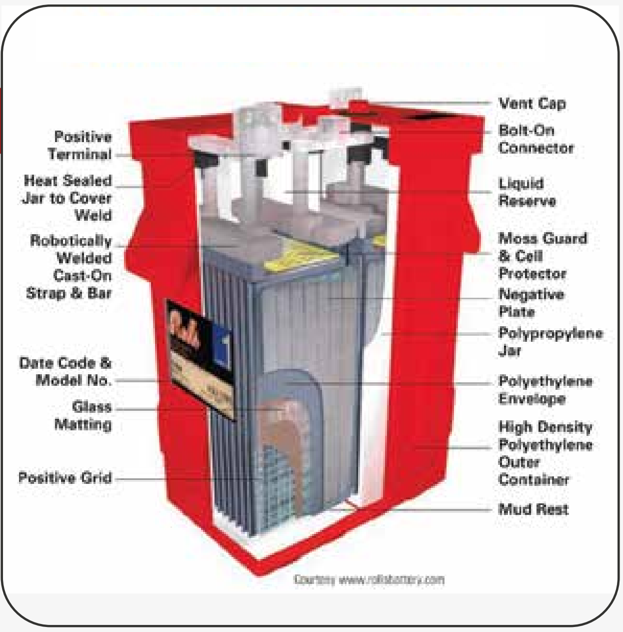
- This type of battery does not have vents and will not emit gas so it is is safe to use indoors.
- Being able to use it where the temperature is ata constant is definitely a plus because it helps the battery to perform better and last longer.
- Although this is a good battery for solar applications, it takes a low charge to recharge which may cost you more.

Absorbed Glass Mat (AGM) Type

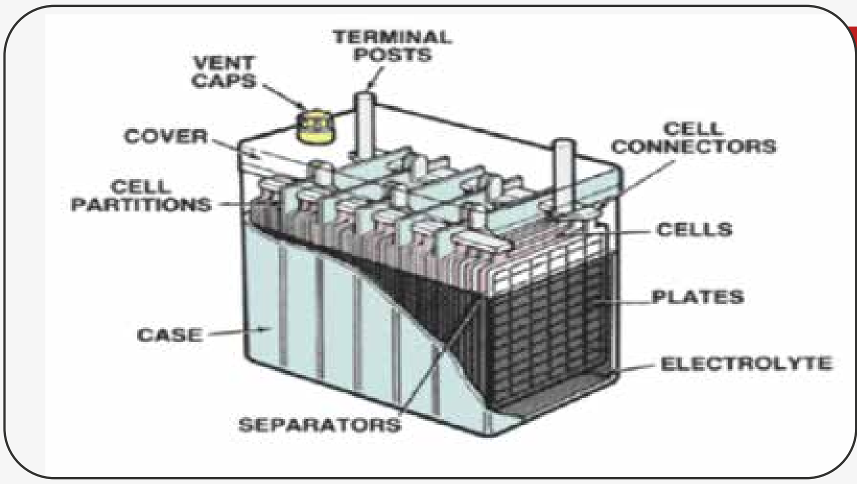
- This type of battery has a woven glass mat in between cells to help sustain charging longer.
- This type is considered by most solar users to be the best as it holds charges for longer and the battery lasts longer.
- They are leak proof, spill proof and do not emit gas, making them the safest and most easy to maintain.
- Even though this type is more expensive it is worth it.
- These types of batteries are used in airplanes, hospitals and remote communication centres.
- The most sought after brand of this type are the **Sun Xtender** and **the Concorde**.

Dissected Batteries

Flooded Type



Gel Type



Absorbed Glass Mat (AGM) Type

Flooded lead-acid batteries are the most commonly used in Zimbabwe and are readily available from local battery manufacturers. Regular monitoring and maintenance will ensure the system functions properly and the batteries last much longer. However, if the deep cycle batteries are being used in a remote area where regular maintenance is not possible, sealed batteries are a better option. Sealed batteries are also suitable for situations with space constraints that require storage of batteries in unusual orientations or where venting is not possible.

Rated Storage Capacity

The amount of energy that a battery can store is called its capacity. The capacity of a battery is measured in ampere-hours. This indicates the amount of energy that can be drawn from the battery before it is completely discharged. For example a battery of 100Ah should ideally give a Current of 2 Amps for 50 hours. The rated storage capacity however is not an indication of the exact measurement as capacity changes with a battery's age and condition and the rate at which power is drawn from it. If current is drawn from the battery at a higher rate its capacity is reduced.

Self Discharge

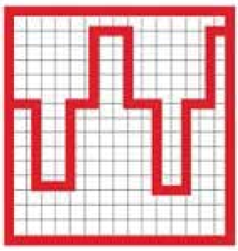
If a batteries are left standing uncharged they loose charge slowly by a process called self discharge this occurs because of reaction within the cells of the battery. The rate which batteries loose their charge depends on the temperature, type of batteries, their age and condition. As a battery gets older their rate of discharge goes up. As well dirty batteries (those with a higher accumulation of acid mist on their surface) tend to have higher self discharge rates. Also warmer weather increases the rate of self discharge.

How to Avoid Higher Self Discharge Rates

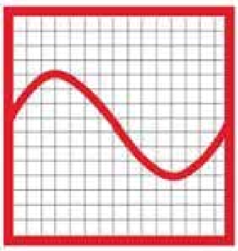
1. Store batteries off the floor in a wooden box or non metallic tray
2. Keep the top surface of the battery clean
3. Keep the terminals clean and greased

Measuring of the State of Charge

The instrument that you can use is a hydrometer or a voltmeter. A hydrometer is more accurate than the voltmeter. When measuring the state of charge check the electrolyte level in each cell to make sure that it has not fallen too low.



Modified Sine Wave



Pure Sine Wave

Inverter

This is a device that converts DC electricity into AC electricity, allowing the PV system to be used for appliances that require AC current. Inverters come in various forms and designs, there are however 3 basic types of inverters which are:

1. Square wave
2. Modified (quasi) square wave
3. Sine wave

Each of these inverters has a specific purpose where it can be used.

Image 11: Pure Sine Wave Inverter

Connecting the Inverter

- The inverter is connected to the charge controller at the terminals indicated in the image belowe (+) and (-).
- The terminals are loosened and the cable from the inverter is fitted with the same polarity:

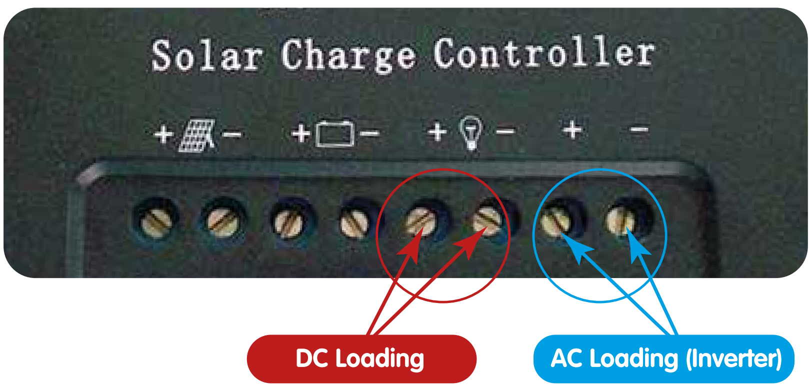


Image 12: Location of DC & AC Loading Terminals

Comparision of AC & DC

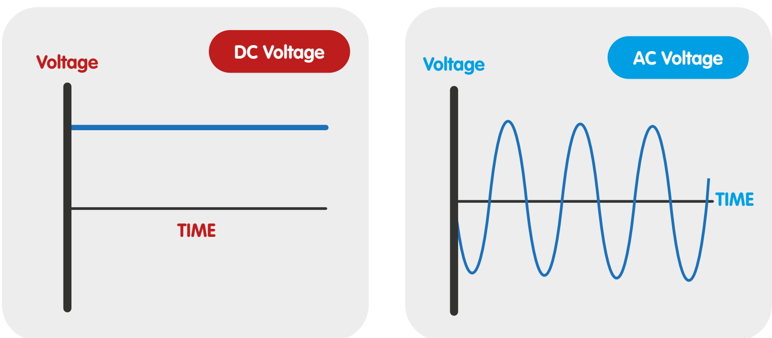
In electricity generation there are two distinct types of electricity which are **direct current electricity (DC)** and **alternating current electricity (AC)**.

Direct Current (DC) is used mostly in houses that are not connected to the grid, and are running with batteries.
Alternating Current lectricity (AC) is the type of current most commonly used in households that are connected to the grid to power electrical appliances (for example TVs, refrigerators, radios, lighting and many others).

Loading or the Load

- This is where the electrical energy is to be used.
- Solar energy can power both DC and AC appliances or gadgets.
- **DC loads include:**
  - Radios
  - Light bulbs
- **AC Loads include:**
  - Refrigerators
  - Televisions
  - Computers

A bad installation can cause problems to the entire electrical system.



Visual Representation difference between AC & DC

On some electrical devices DC and AC Voltage are represented by signs as follows (these are the signs that are used on most multimeters to indicate the two voltages):

Direct Current

Alternating Current

Solar Lanterns

These are portable lighting systems. They can be classified into classic and multifunctional. Classic systems provide lighting only and multifunctional provide lighting as well as facilities for mobile phone charging and radios.

There 3 main types of solar lanterns:

Simple Light-Only Lanterns

This is a solar lantern that has one light that will provide 8 hours of bright light when fully charged. It can be used for working, studying, cooking, walking and socialising, it is portable and gives 360 degrees illumination. It comes with a solar panel that is fitted to the casing of the light such that during charging the whole unit must be in the sun. The solar lantern has its battery fitted together with the unit (cannot be detached)

General Specifications		
	Approximate Cost	USD 10.00
	Wattage	3 Watts
	Battery Charging Time to Full Capacity	10 Hours
	Hours of Light	4-8 Hours

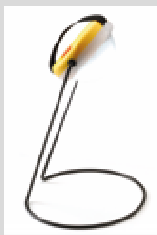
Light and Mobile Charging Solar Lanterns

This is a solar lantern that can provide 12 hours of bright light when fully charged. It also has facilities for mobile phone charging for approximately 2 hours per day. The lantern has an integrated battery and lamp system. It also has a separate solar panel that can be connected to the lamp charging unit during the hours of charging such that the whole unit does not need to be in direct sunlight except for the panel only.

General Specifications		
	Approximate Cost	USD 25.00
	Wattage	3-5 Watts
	Battery Charging Time to Full Capacity	10 Hours
	Hours of Light	12 Hours

Adjustable Brightness Solar Lanterns

These solar lanterns can provide different brightness with varying light lumens ranging from 20 – 100 lumens. The difference in light brightness determines the number of hours of light (for example 20 Lumens can last for 15 – 30 hours, 40 Lumens can last for 8 – 15 hours, 100 Lumens can last for 3 – 6 hours) when fully charged. It also has facilities for mobile phone charging for approximately 2 hours per day. The lantern has an integrated battery and lamp system. It also has a separate solar panel that can be connected to the lamp charging unit during the hours of charging such that the whole unit does not need to be in direct sunlight except for the panel only.



General Specifications		
	Approximate Cost	USD 40.00
	Wattage	3-5 Watts
	Battery Charging Time to Full Capacity	10 Hours
	Hours of Light	8-30 Hours

Basic Components of the Solar Lantern System

- Solar panel
- Battery for electricity storage (often integrated in the lamp)
- Lamp
- Mobile Phone charging Unit
- FM Radio

The figure below shows the schematic layout of a solar lantern.

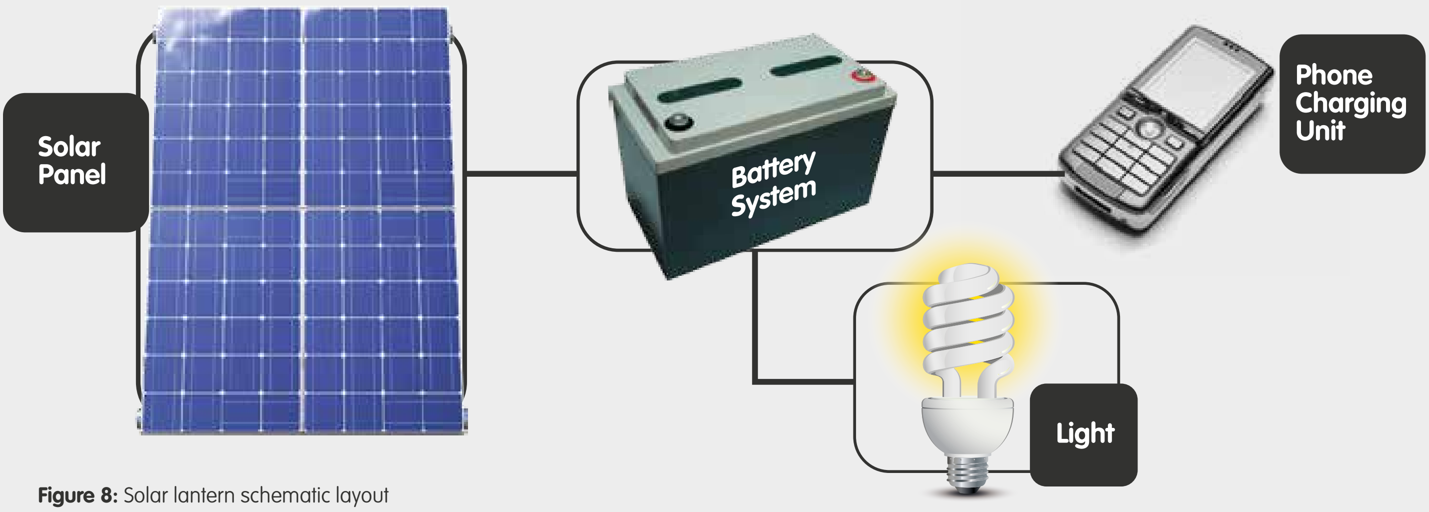


Figure 8: Solar lantern schematic layout

Main uses of Solar Lanterns

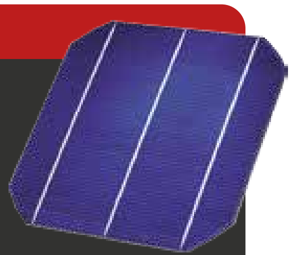
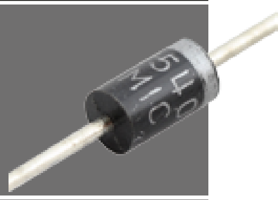
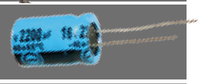
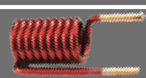
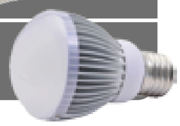
- To enlighten one single room
- Recreational uses
- Mobile phone charger (depending on the model)
- Radio (depending on the model)

Advantages of Solar Lanterns

- Loads can be carried elsewhere without the panel
- Replacing traditional light (kerosene/ paraffin lamps and candles)
- Easy installation (Plug & Play)
- User-friendly application
- Low investment costs
- Little maintenance required (Refer to maintenance section)
- The prices are generally within the payment capacity of most rural people in developing countries.

Solar Lantern Component Assembly

A solar lantern as described earlier is made up of components that can be assembled together. This section demonstrates how the basic components of a solar lantern can be assembled.

Component	Description
Photovoltaic Cells	The photovoltaic cells make up the solar panel that can be used as receiver of energy. The PV cells can be connected in parallel and or in series to attain a desired voltage. (From a dismantled panel cells are tested for voltage output using a multimeter). 
Diode	A diode is an electronic device which allows current to flow in one direction and avoid the reverse. The electricity from the PVs goes through a diode into the rest of the circuit. The diode prevents energy from flowing back into the PV array. 
Resistors	A resistor is a component which resists the flow of current in a circuit. 
Capacitor	An electrical device which stores energy and is measured in Farads. 
Inductor Coil	It is an electrical device which limits current in a circuit and it can also be called a choke. 
Transistors	An electrical device which acts as a valve or a switch in a circuit. 
LEDs	These are light producing diodes. 

The combination of these electrical components makes up a circuit. They can be seen on circuit boards. (Participants should be able to identify the different components on the circuit board of a solar lantern).

Solar Home Systems

Solar Home Systems (SHS) can either be independent of the utility grid (stand alone) or connected to the utility grid (grid connected). This manual only considers the stand alone systems.

Stand-alone PV systems are designed to operate independent of the electric utility grid, and are generally designed and sized to supply certain DC loads. The simplest type of stand-alone PV system is a direct-coupled system, where the DC output of a PV module or array is directly connected to a DC load (as illustrated below). Since there is no electrical energy storage (batteries) in direct-coupled systems, the load only operates during sunlight hours, making these designs suitable for common applications such as ventilation fans, water pumps, and small circulation pumps for solar thermal water heating systems.

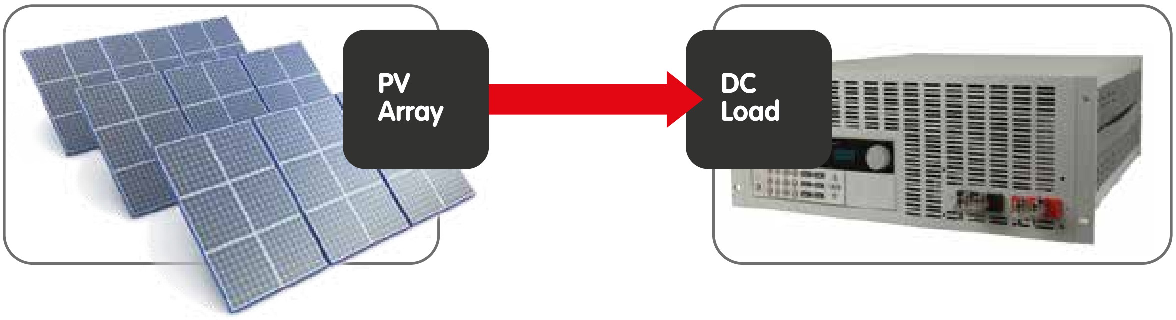


Figure 9:
PV Array to DC Load

In many stand-alone PV systems, batteries are used for energy storage. Figure X below shows a schematic of a typical stand-alone PV system powering DC and AC loads.

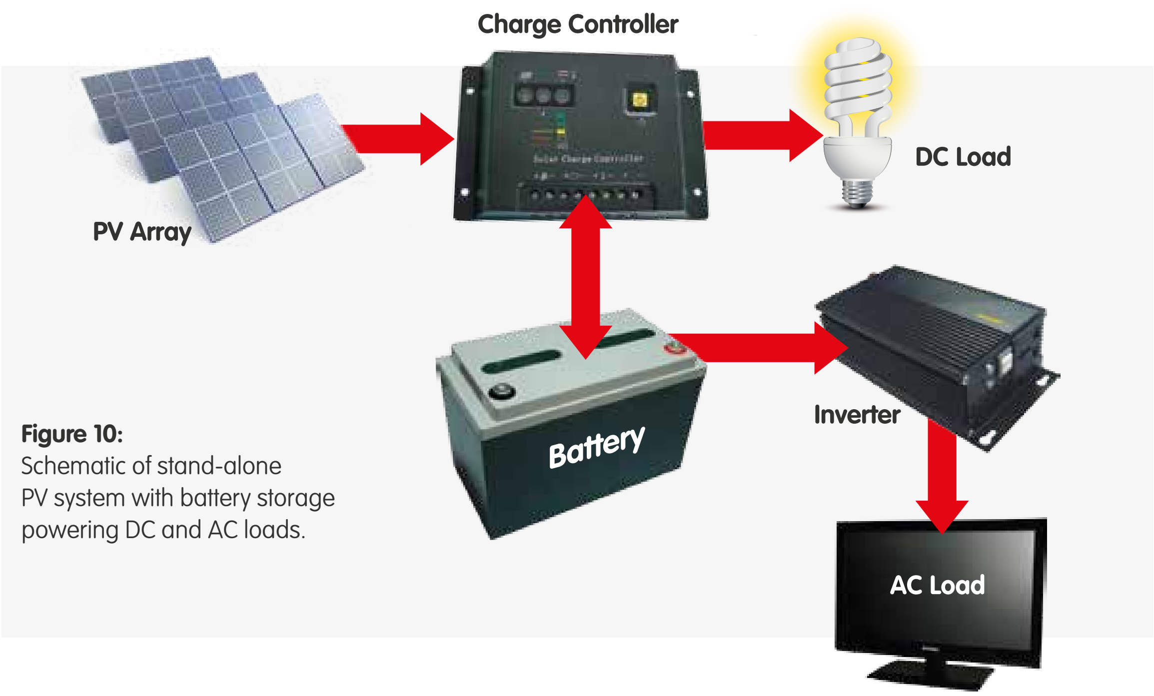


Figure 10:
Schematic of stand-alone PV system with battery storage powering DC and AC loads.

Exercises

1. List **three reasons** why a car battery is not suitable for use in a PV system.

2. List the **four key components** in a solar home system.

3. Name the **two common categories** of battery types.

4. **Define** the terms storage capacity and self discharge

Practical Exercise 1: Solar Panel Output

This practical exercise will demonstrate how current and voltage are related in coming up with the solar panel power output.

Use a Multimeter to Test Voltage Output

- Set the multimeter to correct scale and voltage range (Solar panels produce Direct Current)
- Ensure that the collector is on a secured place and where there is enough sunshine
- Connect the multimeter terminals to the positive and negative terminals of the solar panel
- Read and note the voltage
- Compare the tested output voltage and the one written on the solar panel
- If there is a difference then the solar panel is not a good product

Use a Multimeter to Test Current Output

- Set the multimeter to correct scale and current range (Note that on some multimeters you need to change the probes to the correct range)
- Ensure that the collector is on a secured place and where there is enough sunshine
- Connect the multimeter terminals to the positive and negative terminals of the solar panel.
- Read and note the current recorded on the meter
- Compare the tested output current and the one written on the solar panel
- If there is a significant difference then the solar panel is not a good product

Practical Exercise 2: Check for Polarity of a Solar Panel

- Place the solar panel outdoors with the monocrystaline side facing up in a sunlit location.
- This will produce a test voltage for you to measure.
- Set the multimeter to the DC voltage range capable of measuring up to 24VDC.
- Connect the positive side of the multimeter to one terminal of the solar panel and the positive side of the multimeter to the other side.
- If the reading is positive this is the positive side of the solar panel.
- If the reading is negative the terminal markings are incorrect and should be marked correctly.

Practical Exercise 3: Inverter Demonstration

Demonstrations from a broken down inverter by identifying the components of the inverter: capacitors, resistors, inductors, diodes transistors on the printed circuit board.

Practical Exercise 4: Battery Voltage Testing

1. Voltage is tested using a multimeter
2. Set the multimeter to the correct scale (for DC)
3. Connect the multimeter to the positive and negative terminals of the battery
4. Read and record the voltage as indicated on the multimeter.
5. Note that if there is a negative reading it means there is reverse polarity

UNIT 4:

Solar Home System Sizing

Learning Outcomes

By completing this unit, trainees will have basic understanding of the basic steps in system sizing.

In this Unit

- Introduction to system sizing
- A sample design situation
- Steps in System Sizing Process
- Sunshine Hours Method

Introduction to System Sizing

Proper Planning Prevents Poor Photovoltaic Performance

This is the six P's principle of PV system design.

Sizing a stand-alone system is not particularly complex. This Unit outlines the design process that must be completed before the purchase and installation of any PV system components. The process includes the following steps:

1. Estimating electric loads
2. Sizing and specifying PV modules
3. Sizing and specifying batteries
4. Specifying a charge controller
5. Sizing and specifying an inverter
6. Sizing system wiring

This method is not biased toward any product, but will result in generic product specifications for the system. Each step is described in the following sections based on the following design situation.

Design Situation Information

Design Situation: Design a Stand Alone PV System for the following household electrical appliances:	• 29 Inch Colour TV • Multichoice Decoder • 2×15 W light bulbs
Location: Mutare, Zimbabwe	**Geographical Coordinates:** 19.0°S, 32.7°E

Table 2: Design Situation Information

Table 3: Mutare Average Monthly Daily Insolation and Earth Temperature

MONTH	DAILY SOLAR INSOLATION (kW/m²)	EARTH TEMPERATURE (°C)
January	6.06	24.5
February	5.88	23.8
March	5.69	23.1
April	5.47	21.8
May	5.00	20.0
June	4.53	18.2
July	4.73	18.6
August	5.59	21.9
September	6.38	26.1
October	6.51	27.4
November	6.25	26.8
December	5.84	24.6
ANNUAL	**5.66**	**23.0**

Steps in System Sizing Process

Step 1: Load Assessment

The PV System is designed to operate the loads as given in the table below. Four hours of operation per day have been assumed for the colour TV, Multichoice decoder and the flourescent lamps.

For the purpose of minimizing the panel size as well as the battery capacity, the TV and the decoder should not be left in standby mode.

Table 4: Load Assessment

LOADS	QUANTITY	WATTS	HRS/DAY	WATT-HOURS PER DAY
29 inch Colour TV	1	120	4	480
Multichoice Decoder	1	15	4	60
Fluorescent Lamp 15W	2	30	4	120
TOTAL		**165**		**660**

Step 2: PV Module Sizing

The module sizing is based on the month of June with the lowest figure for daily solar insolation.

$$\text{PV Module Size} = \frac{\text{Total Daily Watt Hours}}{\text{Average Daily Solar Insolation}}$$

$$\text{PV Module Size} = \frac{660}{4.53} = 145.7 \text{ Watts}$$

Figure 11:
PV Module Size Formula

Taking into consideration the temperature losses, battery efficiency and wiring losses, the **145.7 W** should be increased according to typical loss percentages in a PV System as follows:

Typical percentages of the losses in a PV System are:

- **90%** for temperature loss
- **85%** for battery losses
- **97%** for wiring losses

$$\text{Total Losses} = 0.90 \times 0.85 \times 0.97 = 0.74$$

Final PV Module Size Calculation

$$\text{PV Module Size} = \frac{145.7}{0.74} = 196.9 \text{ Watts}$$

200 Watts

Figure 12:
PV Module Size Final Calculation

Table 5: Typical 200W PV Module Characteristics

Typical 200W PV Module Characteristics - Sharp ND 200 U1	
PV Module lifetime	**25 Years**
No of cells and connections	**60 in series**
Open Circuit Voltage **(Voc)**	**35.5 V**
Max Power Voltage **(Vpm)**	**28.5 V**
Short Circuit current **(Isc)**	**7.82 Amps**
Maximum Power Current **(Ipm)**	**7.02 Amps**
Max Power **(Pm)**	**200 W**
Module Efficiency	**12.3%**

Step 3: Battery Sizing

In standalone PV Systems, the electrical energy produced by the PV array cannot always be used when it is produced, because the demand for energy does not always coincide with production. As such, electrical storage batteries are commonly used in PV Systems. **When sizing the battery, the following factors have been taken into consideration:**

- **Battery Efficiency**
  Most batteries have an efficiency of about 85%

- **Allowable Depth of Discharge**
  The maximum percentage of full rated capacity that can be withdrawn from a battery is known as its Allowable Depth of Discharge. The allowable depth of discharge for a Lead Acid Battery is 80%

- **Days with no sunshine/number of days of autonomy**
  Generally expressed as the days of storage in a PV System, autonomy refers to the time a fully charged battery can supply energy to the systems loads when there is no energy supplied by the PV modules. Number of days of autonomy typically ranges from 2 to 6.

3 days has been used as a good approximation for the number of no sun days in sizing the battery for this PV System.

$$\text{Battery Capacity} = \frac{\text{Daily Load}}{\text{Battery Effificiency}}$$

$$\frac{660}{0.85} = 776.5 \text{ Watts}$$

Multiplying by 3 (number of sun days)

Battery Capacity = 776.5 x 3 = 2,329.3 Watt Hrs

Multiplying by 80% depth of discharge

Battery Capacity = 2,329.3 × 0.8 = 1,863.4 Watt Hrs

Figure 13: Battery Capacity Calculations

However, batteries are usually rated in amp-hours:

$$\text{Amp Hours} = \frac{\text{Watt Hours}}{\text{Volts}}$$

$$\text{Battery Capacity} = \frac{1{,}863.4}{12} = 155.3 \text{ Ah}$$

Final Total = 160 Ah

Step 4: Charge Controller Sizing

The primary function of a battery charge controller in a stand alone PV System is to maintain the battery at highest possible state of charge while protecting it from overcharge by the array and from over discharge by the loads.

A charge controller with a higher current rating than the maximum PV System and load current should be selected.

Module Current = 7.02 A

The assumed load current drawn by the TV, decoder and lights should not exceed 7A.

Therefore, a 10A charge controller is selected for the stand alone PV System.

Step 5: Inverter Sizing

An inverter is a piece of equipment that converts DC electricity into AC electricity, allowing the PV system to be used for appliances that require AC.

Most inverters have a DC to AC conversion efficiency of 85%.

A DC to AC inverter should be selected to match the PV system with the following characteristics (as calculated above):

- **Peak Power** = 165W
- **System Voltage** = 12V
- **Inverter Power Rating** = 165W

Dividing by 0.85 for Inverter Efficiency

$$\frac{165}{0.85} = 194.1\ W$$

Final Total = 200 W

Figure 14:
Inverter Sizing Calculations

A 200 W 12V DC to 240 V AC sine wave inverter is desirable for the PV System.

Step 6: Wire Sizing

The wiring is what carries the electricity from the panels through the charge controller to the batteries and from the batteries through the charge controller out to the loads. Two main considerations are the wire size and the terminations to avoid too much resistance to the flow of electricity.

A properly designed wiring system should have a voltage drop of not more than 5%, and, therefore, on a 12V system, voltage loss should not be more than 0.6V.

The wire-sizing chart below should be used to select the correct wire cross section for a given current and length of wire. The voltage loss values given in the table are for 100m length of wire at a given current. The table can be used for lengths of wire that are less than 100m by first dividing the selected length by 100 and multiplying by the corresponding voltage drop given in the table to get the correct voltage drop. The wire cross section that gives a voltage drop of less than 0.6V will be the most appropriate.

Wire Sizing

Whenever current passes through a wire, voltage is lost as a result of the resistance in the copper wire(s). In low voltage systems like the 12 Volt system, voltage loss is of significant importance. For example losing 2 volts on a 240V system only represents less than 1% of the voltage lost to resistance, but losing 2 volts on a 12V system represents almost 17% which is quite significant. The amount of voltage that is lost for a given wire size and current flow is based on how much wire there is, or the length of the wire.

A wire sizing chart is used to determine the wire size for a solar system.

It must be noted that voltage losses in the table are theoretical, calculated using Ohm's Law. As such the state of wires must be considered.

Table 6: Wire Sizing Chart

Voltage loss per 100m of wire run (volts per 200m of wire)			
	Wire Cross Section (mm²)		
Flow (Amps)	**1.5**	**2.5**	**4.0**
0.1	0.21	0.14	0.08
0.2	0.43	0.27	0.17
0.3	0.64	0.41	0.25
0.4	0.86	0.54	0.34
0.5	1.07	0.68	0.42
0.6	1.29	0.81	0.51
0.7	1.50	0.95	0.59
0.8	1.72	1.08	0.68
0.9	1.93	1.22	0.76
1.0	2.15	1.35	0.85
2.0	4.29	2.70	1.69
3.0	6.44	4.05	2.40
4.0	8.58	5.41	3.38
5.0	10.73	6.76	4.23
6.0	12.87	8.11	5.08
7.0	15.02	9.46	5.92
8.0	17.16	10.81	6.77
9.0	19.31	12.16	7.62
10.0	21.45	13.51	8.46

Sunshine Hours Method

Steps to follow when Estimating SHS Size

Step 1. Determine the load:
Determine the energy load required in watt-hours (Wh) per day. Multiply the number of watts the load will consume by the hours per day the load will operate. Multiply your result by 1.5.

Total Wh per day required: _______Wh

Example:

Description	Wattage (Watts)	Hours of Operation	Watt-hours
Radio	20	9	(20 x 9) = 180
Light	11	6	(11 x 6) = 66
		Total Wh/day	**180 + 66 = 246**

Load = 246 Watt-hours

Step 2. Determine the available Sunlight Hours:
Determine the hours per day of available sunlight at the site.

Total available sunlight: ______ hrs/day

Note that for Zimbabwe the avarage available sunshine hours used are **6.5 hours**.

Step 3: Determine the PV array size (Solar Panel size):
Determine the PV array size needed. Divide the energy needed (Step 1) by the number of available sun hours per day (Step 2). **PV array means two or more solar panels.**

Total array size required: ______ Watts

From our example:

$$\frac{246}{6.5} = 37.85 \text{ Watts}$$

Step 4: Determine the size of the battery bank:
Determine the size of the battery bank.
Multiply the load (Step 1) by 3 (result is watt-hours, Wh).
The 3 is the number of days without sunshine.
Then divide by the battery voltage (for example, 12 volts) to get the amp-hour (Ah) rating of the battery bank.

Total Battery Bank Required: ______ Ah

From our example:

Load = 246 Watt-hours

246 Wh x 3 days = 738 Watt-hours

$$\frac{738Wh}{12V} = 61.5\ Ah$$

Step 5: Determine the size of the solar charge controller:
Solar charge controller rating is given by the total short circuit current of PV array (solar panel). The short circuit current is indicated at the back of the solar panel. Where two or more panels are used, the short circuit current rating of each will be added together to determine the size of the solar charge controller.

Step 6: Determine the size of the Inverter to be used:
The input rating of the inverter should never be lower than the total watt of appliances. The inverter must have the same nominal voltage as your battery. The inverter size should be 30% bigger than total Watts of appliances.

From our example:

Load = 246 Watt-hours

The size of the inverter will be given by **246 x 1.3 = 319.8 Watts**

The conclusion therefore is that:

A 400Watt inverter can be used

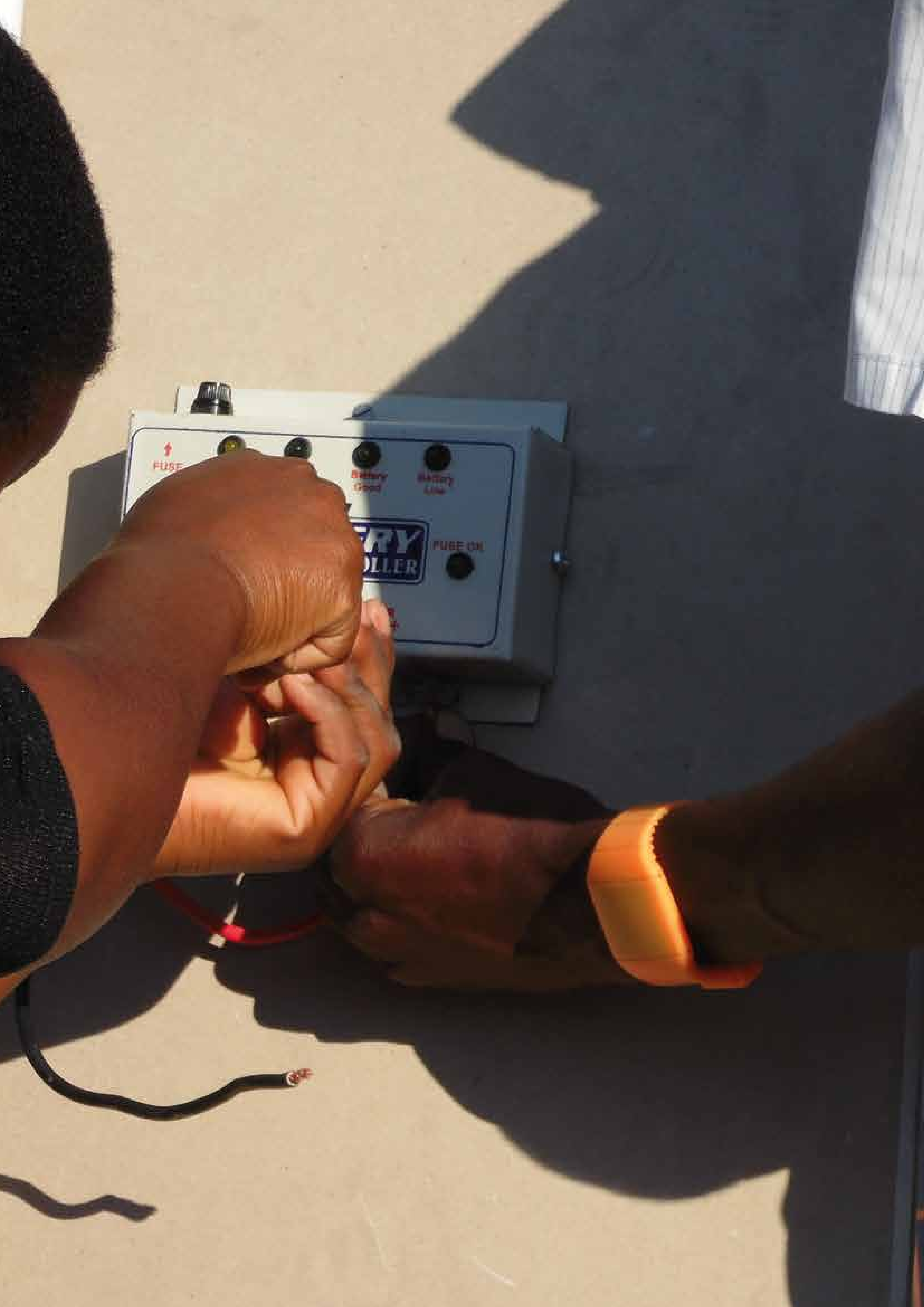
Exercises

1. What is the **Six P's Principle** in system sizing and design?
2. List the **six steps** in the system sizing process.
3. What **three loss factors** must be taken into account in designing the process?
4. What is the **alternative system sizing** method to the standard one?
5. **Size a system** for the following (providing specifications for the PV panels, charge controller, battery and inverter):

Location: Gweru, Zimbabwe

LOAD:

Appliance	Rating (Wh)
TV	**80**
Satellite TV decoder	**25**
Radio	**15**
Refrigerator	**350**
5 energy saving light bulbs	**55**
Laptop	**45**
Microwave	**900**


FUSE
Battery Good
Battery Low
FUSE OK

UNIT 5:

PV System Installation

Learning Outcomes

By completing this unit, trainees will have basic understanding of:

i. The basic steps in system installation
ii. The necessary tools for quality installation
iii. The key factors to consider when carrying out a site assessment
iv. The main considerations when installing the system components
v. How to check the quality of an installation

In this Unit

- Site Assessment
- Preparation for installation
- PV Array Installation
- Connection of the Charge Controller
- Battery Installation
- Installation Assessment and Final Checklist

Site Assessment

An initial visit to the site is critical in the system design process. It serves to confirm feasibility of the installation and aids in planning of the system installation. In carrying out the site visit, the following factors need to be checked/confirmed/assessed:

1. Space availability
2. Presence of obstacles – trees or buildings
3. Site layout
4. Site orientation

It helps to sketch a rough site map on which the position of the panels and other system components can be drawn.

What You Will Need

- Notepad and pen
- Map
- Compass
- Protractor
- Tape measure
- Spirit level

Preparation for Installation

In addition to the system components, the following are common tools used in home solar electric installations:

Safety Equipment:

- Hardhats
- Safety glasses
- Safety shoes
- Gloves
- Fall protection equipment

Basic Tools:

- Ladders
- Flashlights
- Mirrors
- Magnifying glasses
- Tape measures
- Compasses
- Levels
- Protractors
- Solar shading calculators
- Voltmeters
- Ammeters
- Watt & Watt-hour meters
- Power quality equalizers
- Multimeters
- Graph paper
- Calculator
- Drills
- Wire stripper
- Impact drivers
- Utility knife
- Screwdrivers
- Hammers
- Pliers

PV Array Installation

Firstly, the position of the array needs to be determined. Solar panels produce the most electricity when they are perpendicular to the sun. Since the sun moves all day, it is not practical to keep moving the panel all day to keep it perpendicular to the sun (unless a tracking system is used but it is expensive).

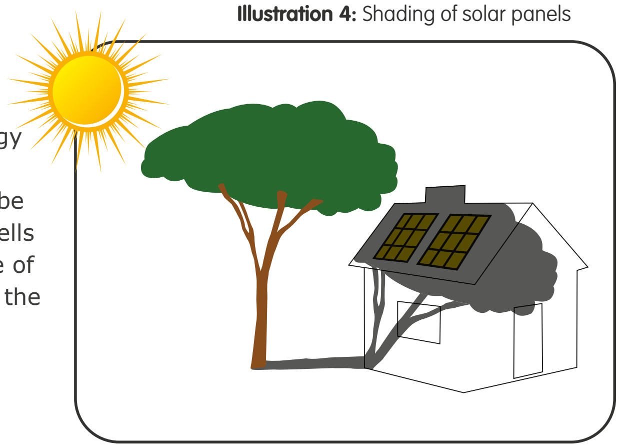
Three factors will influence the performance of the array:

Shading

When a solar panel is shaded in whole or part, for example, by tree branches and or a building, it captures less energy from the sun thus its performance is reduced. Less voltage and current will be produced. This is because most solar cells are connected in series such that if one of the cells is not producing some energy the output will be reduced.

Even minor shading can result in significant loss of energy!

Illustration 4: Shading of solar panels



It is recommended that the PV System be installed on rooftop so as to minimize the effects of shading from the buildings and trees.

Orientation

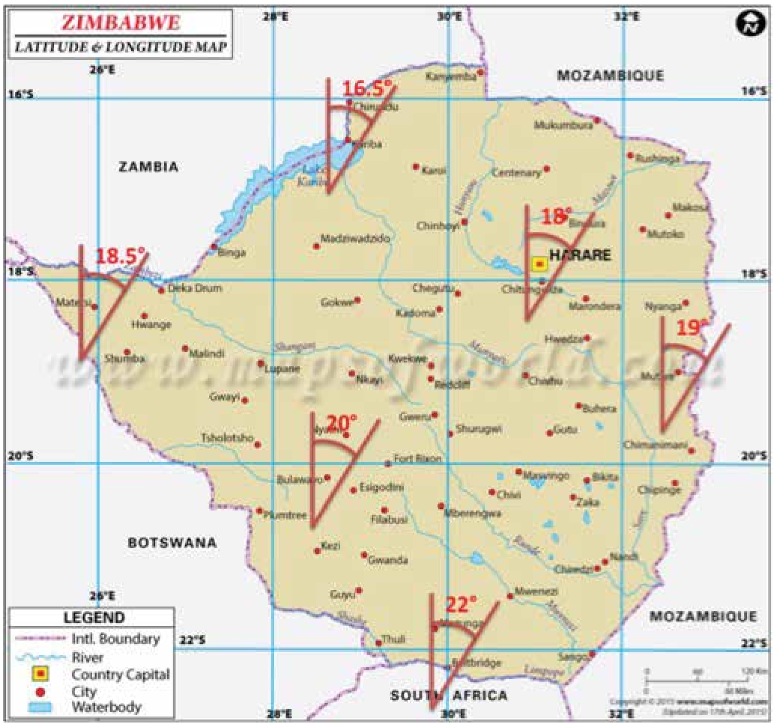
In the Southern Hemisphere, due North is the best possible orientation. If the PV is to be mounted on vertical walls the orientation should preferably be between North East and North West. If the PV is to be mounted at a tilt a wider range of orientations will still give a reasonable energy yield.

South facing orientations should be avoided.

Tilt

A tilted array will receive more light than a vertical array. Any angle between vertical and 15° off horizontal can be used. For self cleansing, a minimum tilt of 15° to the horizontal is recommended to allow the rain to wash dust off the solar panels. For a north facing panels the recommended tilt angle is between 30° - 60° (Southern Africa which is the same for Zimbabwe). The solar module has to be installed at a tilt angle approximately equal to the latitude of the area e.g. the tilt angle for a site in Mutare would, therefore, be about 19° as shown in the following figure.

Tilt Angles for Locations in Zimbabwe



Map 2:
Visual Representation of the difference between AC and DC

Series Connection of Solar Panels

For increased voltage and amperage solar panels can be connected either in series or in parallel. Series wiring is used to increase the total system voltage being produced by the panels, however the current remains the same. This connection can be employed where a higher voltage is required.

Series type connection is shown in the diagram below.

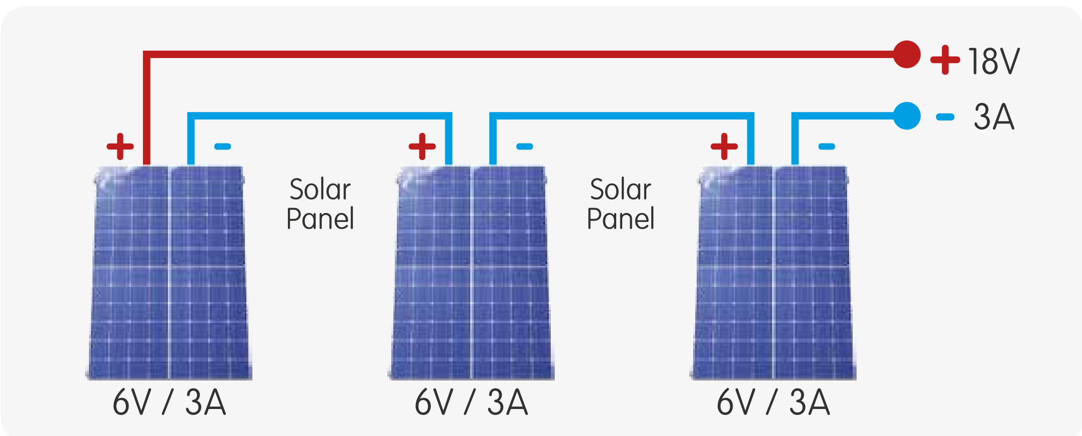


Figure 15:
Series type connection of solar panels

From the diagram 3 (6 volts/3 amps each) solar panels are connected in series. The negative of the first solar panel is connected to the positive of the next solar panel, and the following panels follow suit. The terminals at the end comprise of the positive terminal of the first panel and the negative terminal of the last panel. In this connection voltages add up.

6 + 6 + 6 = 18 Volts

It must be noted that for a series connection and a parallel connection the solar panels have to be IDENTICAL to enable the system to function properly.

Parallel Connection of Solar Panels

In parallel connection of solar panels the voltage output would remain the same but the amperage would increase. This connection is employed where high current is required.

A parallel connection is shown in the diagram below.

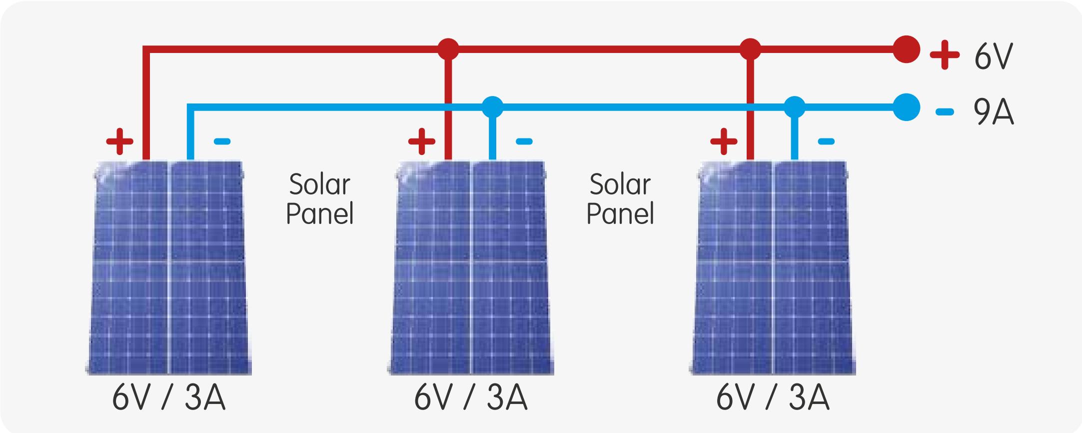


Figure 16: Parallel connection of solar panels

From the diagram 3 (6 volts/3 amps each) solar panels are connected in parallel. The negative of the first solar panel is connected to the negative of the next solar panel, and the following panels follow suit. The terminals at the end comprise of the positive terminals of all panels and the negative terminals of all the panels. In this connection current add up and voltage remains the same.

3 + 3 + 3 = 9 Amps

Connection of the Charge Controller

The charge controller is connected to the solar panel(s), battery and DC Loads. The figure below shows the terminals were these components are connected. Most charge regulators / controllers have some pictures or icons which indicate the component to be connected.

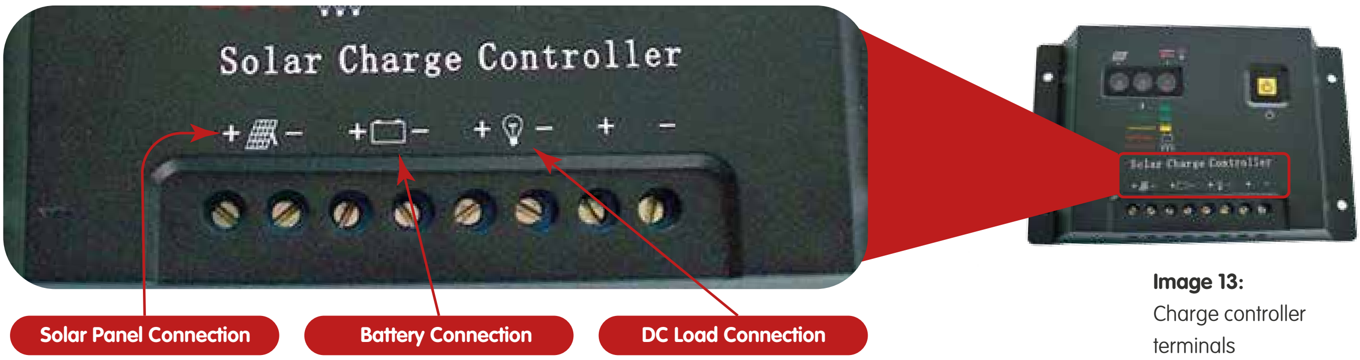


Image 13:
Charge controller terminals

Figure 14 below illustrates how the solar panel, charge controller and battery are connected. The charge controller forms the central unit to connect the battery to the panel. The solar panel should not be connected directly to the battery; this reduces the battery life and eventually damages the battery.

It must be noted that the nominal voltage of the solar panel must match with the charge controller's voltage rating (for example for a 12 V charge controller, only a 12 V nominal solar module with an open circuit voltage of 30 V must be used).

Warning:

When connecting a charge controller, **you should connect the battery first before** connecting the cables from the solar panel, so as to avoid damaging the charge controller.

Solar Panel Terminals & Screws

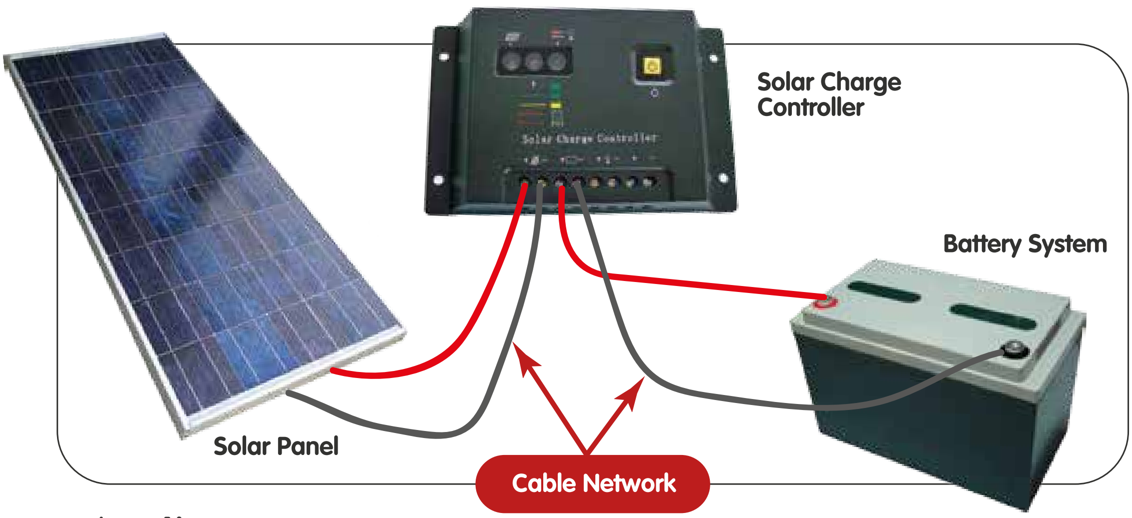


Image 14:
Charge controller connections

Connecting a Battery to a Solar System (Practical Exercise)

Safety precautions have to be prioritised when performing these connections since there is high risk of electrical shock.

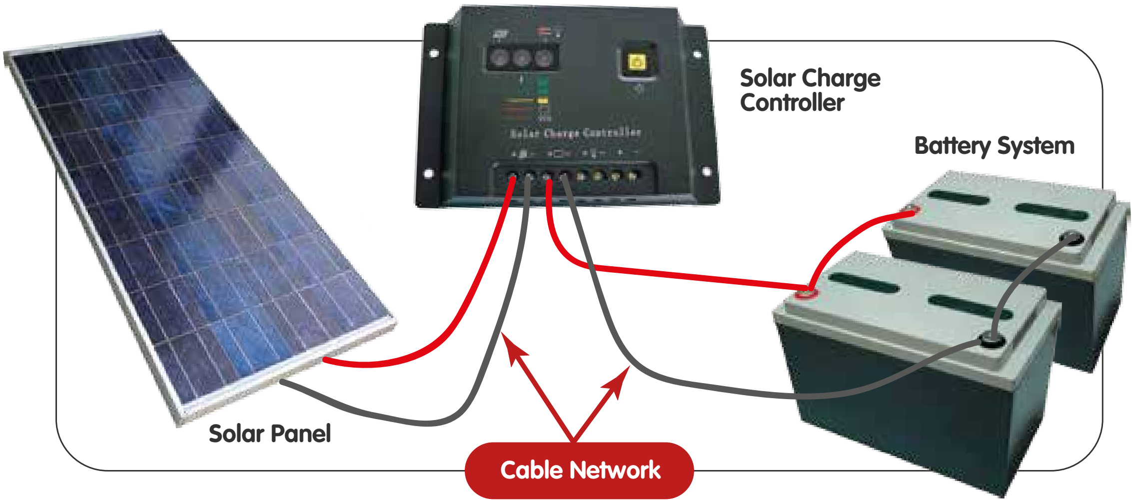


Figure 17: Schematic of battery connected to a solar system

- Taking into account all safety precautions and using the right tools loosen the screws for the battery connections on the battery section as indicated below.

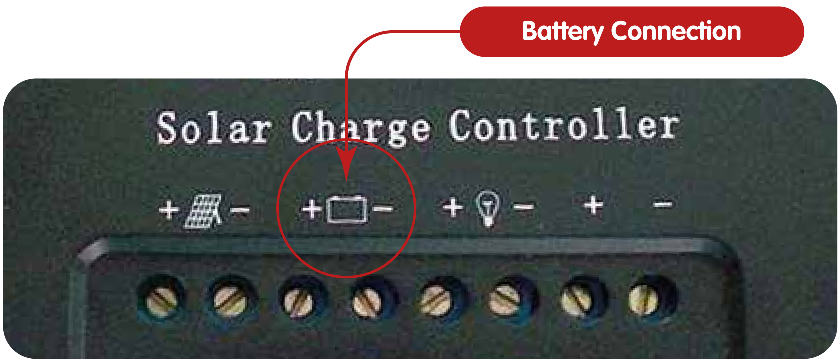


Image 15: Battery connection termianl

- Fit the cable to the positive terminal of the charge controller and to positive terminal of the battery.
- Fit the cable to the negative terminal of the charge controller and to the negative terminal of the battery.
- Ensure that the fitted cables are secured tightly on the terminals and that there are no naked wires.
- The connections are shown in the figure above.

Steps to Connect the Charge Controller to the Solar Panel

- Ensure that the collector (the solar panel) is shaded, avoid the risk of electric shock.

- Using the right tools loosen the screws at the terminals where there is a solar panel picture as in the figure below:

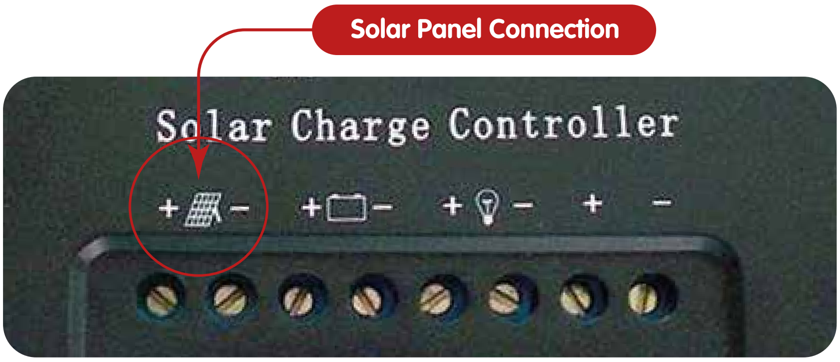


Image 16: Solar Panel connection terminal

- Fit the positive electrical cable from the solar panel to the positive terminal of the charge controller.

- **Some have colour coding:**

RED is postive (+)

Connect the **Positive** (Solar Panel) to the **Positive** (Charge Controller)

AND

BLACK is negative (-)

Connect the **Negative** (Solar Panel) to **Negative** (Charge Controller)

Battery Installation

Key considerations when installing batteries are as follows:

- **Refresher Charge:** Before commissioning the batteries, they require a refresher charge. This can be done either by using a battery charger before installation or leaving the panels to charge the batteries for at least 24hrs before commissioning.

- **Positioning:** Batteries need to be positioned so they are upright, cannot fall over, away from members of the public or children and away from sources of ignition. For insulation and heating purposes, batteries should not be stood directly on a concrete floor.

- **Insulation:** Styrofoam sheets or old blankets can be used underneath and around the side of the batteries to keep them insulated. DO NOT INSULATE THE TOP OF THE BATTERIES as this will prevent the batteries from venting properly.

- **Ventilation:** Flooded lead-acid batteries vent hydrogen oxide which is lighter than air and rises up. If the battery storage area has no ventilation, ventilation must be installed.

- **Access:** it is important that the battery area is easily accessible for maintenance purposes.

- **Connections:** Connect the batteries to make a complete battery pack as set out below. Once connected use a multi-meter to check that the pack has the correct voltage. Use petroleum jelly around the terminals to protect from moisture.

Series Connection of Batteries

In this connection the positive terminal of one battery is connected to the negative terminal of the second battery thus the remaining two terminals of the batteries are left loose to be connected to the load as indicated by 1 and 2 below.

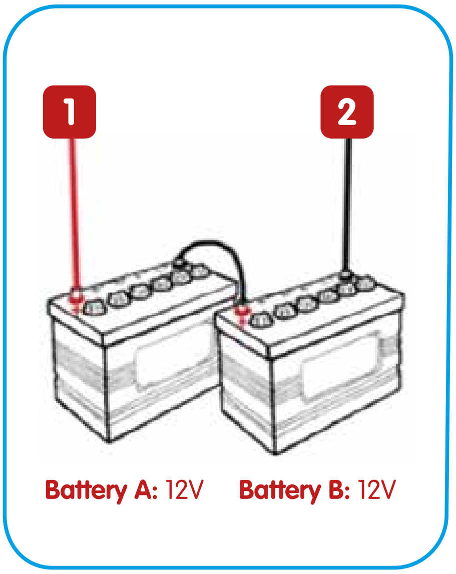


Figure 18: Series Connection of Batteries

When batteries are connected in series the voltages add up.

As indicated in the diagram above Battery A and Battery B are connected in series, the output voltage at the positive terminal (1) of battery A and the negative terminal (2) of Battery B is given by adding the voltages:

12 + 12 = 24 Volts

Parallel Connection of Batteries

In this connection the positive terminal of one battery is connected to the positive terminal of the second battery thus the batteries are connected together and the load is connected at points indicated by 3 and 4 below.

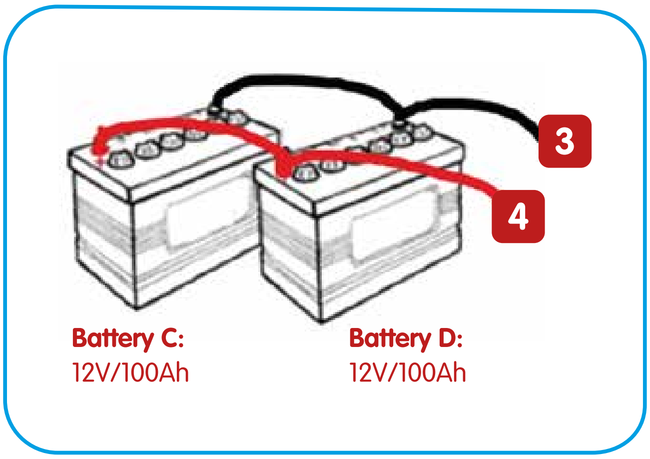


Figure 19: Parallel Connection of Batteries

When batteries are connected in parallel the voltage remains the same but their capacity is doubled.

This means that the system will last twice as much as compared to using a single battery. As indicated in the diagram above Battery C and Battery D are connected in parallel, the output voltage at the negative terminal (3) and the positive terminal (4) is the same at 12 volts. However, the capacity adds up and is given by adding the individual capacities:

100 + 100 = 200 Ampere – hours

Exercises

1. **A solar system is to be installed at a local clinic in your area.** The system voltage is to be 12 Volts and the machinery required need a total of 12 Amps as current. You are supplied with 4 x 12 Volt/4 Amp Solar panels. Draw the layout of the system.

2. **A small fan is to be operated by 24 Volts of DC.** You are supplied with 4 x 6 Volt batteries, draw how the connection will look like in order to power the fan.

Practical Exercise: Performance of a Solar Panel in a Shade

Can be done using connected solar water pumping system or using a multimeter in the following procedure.

1. Ensure that the multimeter is at the correct scale within the range of the solar panel voltage.
2. Place the collector in a position that it can receive maximum radiation.
3. Connect the multimeter on the positive and negative terminals of the solar panel.
4. Note the voltage and record it.
5. Do not remove the multimeter from the terminals.
6. Shade the solar panel starting from one end to the other.
7. Take note of the voltage change until the solar panel is fully shaded.

UNIT 6:

Solar Water Pumping

Learning Outcomes

By completing this unit, trainees will have basic understanding of:

i. Solar water pumping applications
ii. The main components of a solar water pumping system
iii. The steps in the process of specifying a solar water pumping system.

In this Unit

- Introduction to basic solar water pumping
- Applications of solar water pumping
- Main Components of the Solar Water Pumping System
- Sizing & Designing a Solar Water Pumping System
- Installation

Introduction to Basic Solar Water Pumping

Solar water pumping involves the use of solar energy to pump water to desired places either on surface or from a well. Solar water pumps are widely used on farms and remote areas to supply borehole and surface sourced water to livestock. In Zimbabwe, the use of solar water pumping has been gaining popularity on commercial farms due to the energy challenges the country has faced. Once a very expensive technology, prices have dropped in recent years.

Solar water pumping is simple as compared to windmills which have been used widely to pump water for agricultural purposes. The time taken to build a solar water pumping system is significantly shorter as compared to that taken to build a windmill.

In addition, maintenance of a windmill is tiresome because of the height that is involved, so solar water pumping can be a perfect substitute for windmills. Thus, solar water pumping is reliable and simple. Most PV water pumps rarely exceed 2 horsepower in size. Well installed quality PV water pumping systems can provide over 20 years of reliable and continuous service.

Typical Solar Pumping System

Example: For a certain water pumping system, the type of pump used is a submersible pump, the Well is 35 m deep, a combined PV array power output of 900 watt, it is an active Tracker with a daily volume of $36m^3$/day.

Image 17:
Solar water pumping system

Applications of Solar Water Pumping

Solar water pumping can be used for:

- Domestic purposes – water that is pumped can be used at households and or in communities
- Agricultural Purposes – for irrigation, animal rearing
- Pond management

Main Components of the Solar Water Pumping System

The Water Source:

Water sources can be deep drilled wells, boreholes, streams, springs, ponds, rivers, etc. The main variables, in addition to initial cost, that factor into system design are the recharge rate of the source and the volume of the source reservoir. If the pump takes water away faster than the source can recharge, the reservoir can run dry causing the pump to run dry which should be avoided to prevent damage to the pump. When volume is lacking, there is the potential for the pump to "suck" the reservoir dry before the sun sets and the reservoir recharges overnight.

The Pump

This is the heart of the solar water pumping system.

There are two main types of pumps:

- Displacement pumps use diaphragms, vanes or pistons to seal water in a chamber and force it through a discharge outlet.
- Centrifugal pumps use a spinning impeller that adds energy to the water and pushes into the system, similar to a water wheel.

Pumps can either be submersible or operate from the surface of the water source. Submersible pumps are placed below the surface of the water source and are submerged in the reservoir. They are highly reliable as they are not exposed to freezing temperatures, do not need special protection from the elements, and do not require priming.

Surface pumps, located at or near the water surface, are used primarily for moving water through a pipeline. Some surface pumps can develop high heads and are suitable for moving water long distances or to high elevations.

Surface and **Submersible** Pumps

- Solar pumps are rated according to the voltage of electricity that should be supplied. A 12 Volt pump is a small one, 24 Volt is more the norm, while 48 Volts and upwards will require more power and might pump more water.
- In most cases these solar water pumps come with specifications of vertical lift or head.
- The manufacturer or distributor will usually specify what is required; it is important to always refer to product manuals when operating these pumps.
- DC water pumps in general use one-third to one-half the energy of conventional AC (alternating current) pumps.

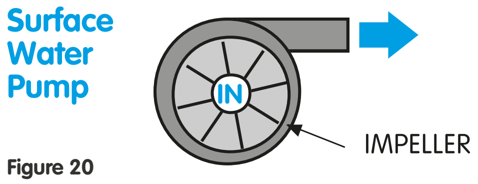


Figure 20

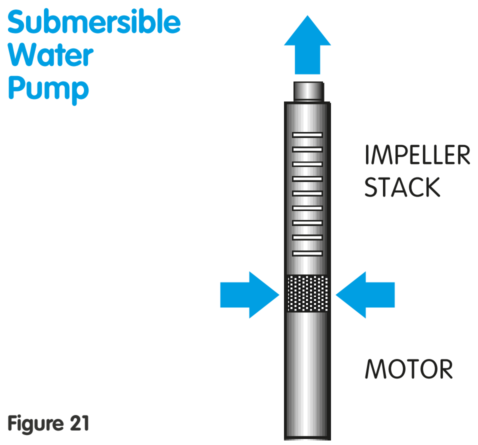


Figure 21

Surface Water Pump System

Submersible Water Pump System

Images 18 & 19: Examples of surface and submersible water pumps

PV Panels

The panels provide power to the pump and the pump rated voltage must match with that of the solar panels. Having a larger solar panel (in terms of power output) allows the pump to turn on earlier and later in the day and also in relatively lower light conditions. Essentially, the large panel surface area acts as a linear current booster and may eliminate the need for one.

Storage

Battery-Coupled Solar Water Pumping Systems

Battery-coupled water pumping systems consist of photovoltaic (PV) panels, a charge control regulator, batteries, pump controller, pressure switch and tank and DC water pump (as shown in Figure X below). The electric current produced by PV panels during daylight hours charges the batteries, and the batteries in turn supply power to the pump anytime water is needed.

The use of batteries spreads the pumping over a longer period of time by providing a steady operating voltage to the DC motor of the pump. Thus, during the night and low light periods, the system can still deliver a constant source of water for livestock.

However, the use of batteries has its drawbacks:

- Batteries can reduce the efficiency of the overall system because the operating voltage is dictated by the batteries and not the PV panels.
- Depending on their temperature and how well the batteries are charged, the voltage supplied by the batteries can be one to four volts lower than the voltage produced by the panels during maximum sunlight conditions.
- This reduced efficiency can be minimized with the use of an appropriate pump controller that boosts the battery voltage supplied to the pump.

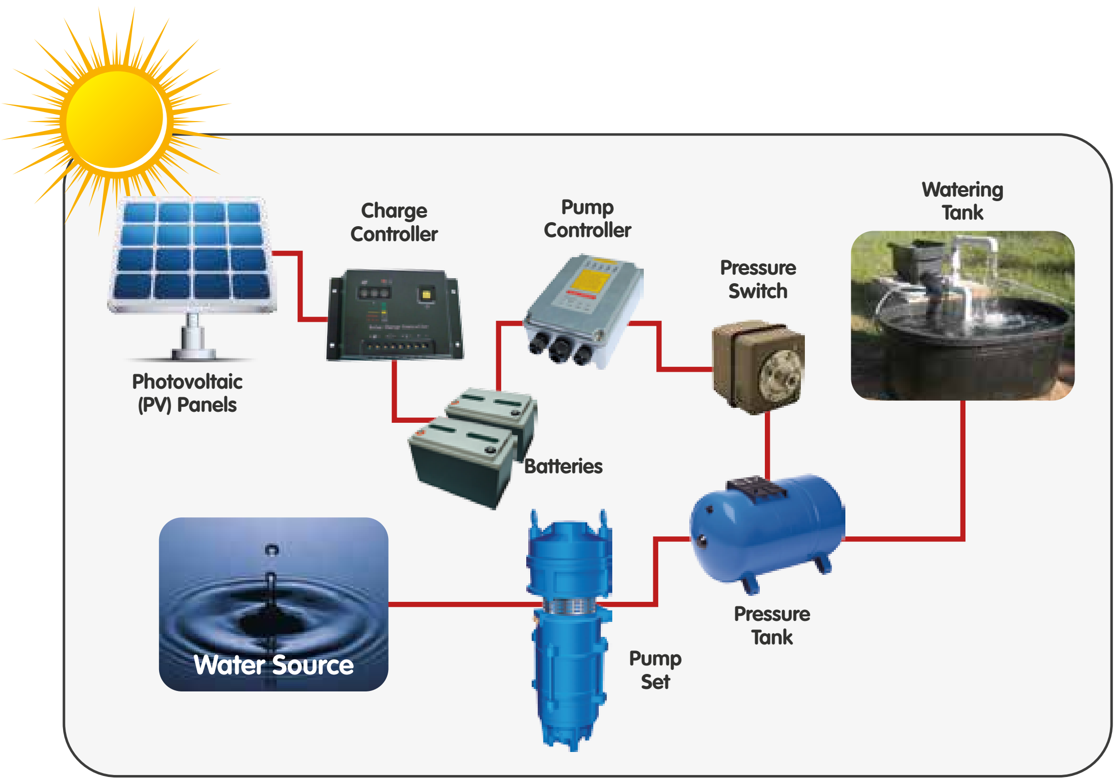


Figure 22: Battery-Coupled Solar Water Pumping System

Direct-Coupled Solar Water Pumping System

In direct-coupled pumping systems, electricity from the PV modules is sent directly to the pump, which in turn pumps water through a pipe to where it is needed (see Figure X below). This system is designed to pump water only during the day. The amount of water pumped is totally dependent on the amount of sunlight hitting the PV panels and the type of pump.

As the intensity of the sun and the angle at which it strikes the PV panel changes throughout the day, the amount of water pumped by this system changes throughout the day. For example, during most favourable sunlight periods (late morning to late afternoon on bright sunny days) the pump operates at or near 100 percent efficiency with maximum water flow. However, during early morning and late afternoon, pump efficiency may drop by as much as 25 percent or more under these low-light conditions. During cloudy days, pump efficiency will drop off even more. To compensate for these variable flow rates, a good match between the pump and PV module(s) is necessary to achieve efficient operation of the system.

Direct-coupled pumping systems are sized to store extra water on sunny days so it is available on cloudy days and at night. Water can be stored in a larger-than-needed watering tank or in a separate storage tank and then gravity-fed to smaller watering tanks. Water-storage capacity is important in this pumping system. Two to five days' storage may be required, depending on climate and pattern of water usage.

Storing water in tanks has its drawbacks:

- Considerable evaporation losses can occur if the water is stored in open tanks.
- Closed tanks big enough to store several days water supply can be expensive.
- Water in the storage tank may freeze during very cold weather.

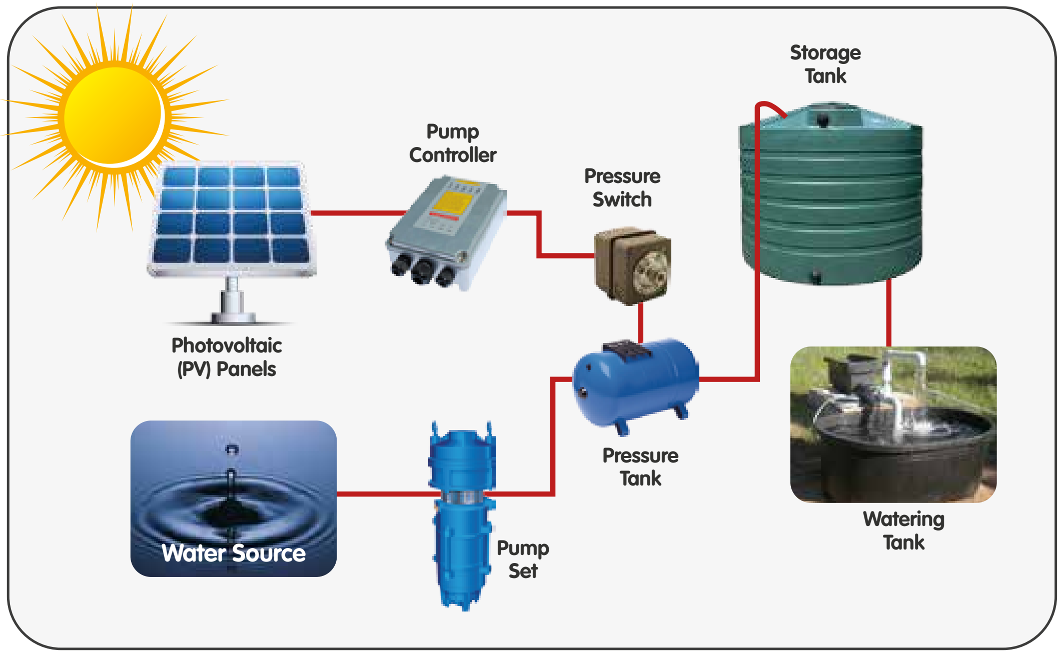


Figure 23: Direct-Coupled Solar Water Pumping System

Battery storage is not usually recommended for solar-powered livestock watering systems because it reduces the overall efficiency of the system and adds to the maintenance requirement and cost.

Controller or Inverter

The pump controller protects the pump from high- or low-voltage conditions and maximizes the amount of water pumped in less than ideal light conditions.

An AC pump requires an inverter, an electronic component that converts DC electricity from the solar panels into AC electricity to operate the pump.

Other Equipment

A float switch turns a pump on and off when filling the stock tank. It's similar to the float in a toilet tank but is wired to the pump controller.

Low water cut-off electrodes protect the pump from low water conditions in the water source.

Sizing & Designing a Solar Water Pumping System

In most cases the supplier of a solar water pumping system will size and design the system. They would require the information discussed below in order to do so.

Accurate sizing of a solar pump array is necessary to minimize the array size for a given duty and thereby to achieve the most cost-effective system possible. If there is doubt about the sizing, a technically acceptable approach is to use a larger than necessary system in order to guarantee an adequate output, but the cost will tend to increase in proportion with power rating; 10% over-size therefore means 10% more expense than necessary.

Solar pumps used for irrigation should be sized for the "critical month"; that is when the system is most heavily loaded in relation to energy available. This is usually the month of maximum irrigation water demand, which fortunately is rarely one of the least sunny months, since crop irrigation water demand and solar energy tend to be well correlated.

By contrast, a solar pump for drinking water supply is likely to need to deliver a constant daily water output, which would in this case make the least sunny month the critical month for sizing purposes.

The starting point in sizing a solar pump is the determination of:

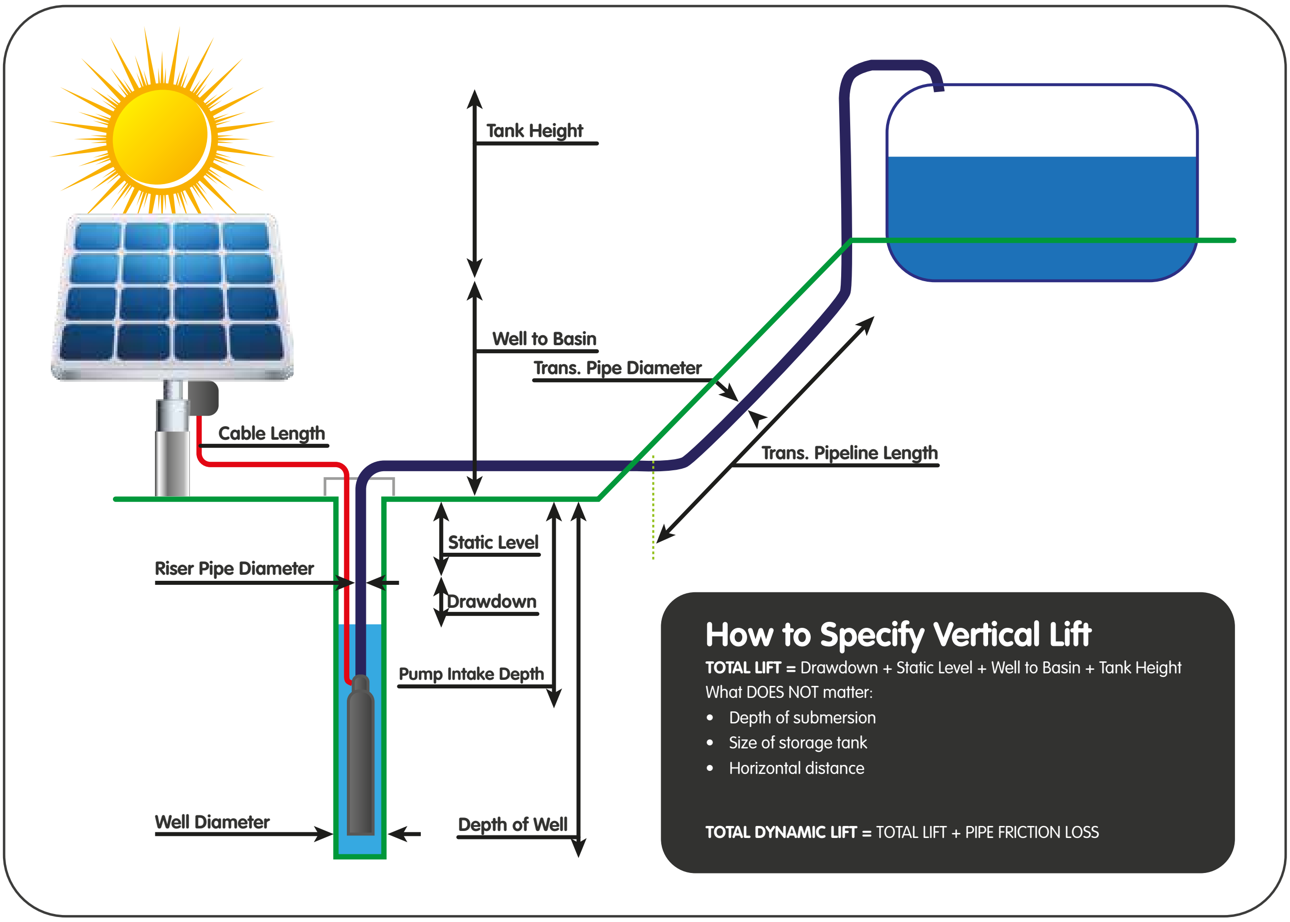
1. the critical month,
2. the mean daily water demand and
3. the mean daily solar irradiation for that month.

Solar pumps begin to be economically competitive for applications where:

a) the peak daily head-flow product is under 150m³m (e.g. 60m³/day through 2.5m head) and
b) the mean daily irradiation is greater than 4.2 kWh/m² (or 15MJ/m²) in the critical month.

In addition to the above information, the vertical lift will need to be specified. It is the maximum vertical distance from the pump intake depth up to the point where the water needs to be delivered. Figure X below illustrates how vertical lift is calculated.

Figure 24: Illustration of the Vertical Lift



Installation

Installing a solar pump is a difficult job, combining elements of electrical work, plumbing, and heavy construction (often including earthmoving, pouring concrete, and welding).

Written instructions are not always as complete as they should be. A backhoe or tractor with a front-end loader is almost a necessity for some larger projects.

Exercises

1. **List three applications** of solar water pumping technology.
2. Name the **two types of pumps** available and state how they function.
3. What are the **storage options** that can be used in solar pumping systems? State their drawbacks?
4. **List the three critical parameters** that need to be specified in order to size a system.

UNIT 7:

Safety Precautions, Basic Maintenance & Trouble Shooting of PV Systems

Learning Outcomes

By completing this unit, trainees will have basic understanding of:

i. The risks associated with PV system installation, operate and maintenance
ii. How to manage risks and the safety measures that need to be in place
iii. How to care for and maintain system components for trouble free operation
iv. How to troubleshoot some standard system faults / failures

In this Unit

- Site Risk and Hazard Assessment
- Safety Precautions
- Maintenance of System Components
- Troubleshooting Guidance

Site Risk & Hazard Assessment

What risks are there in on-site work?

Illustration 5:
Site Risks & hazard assessment

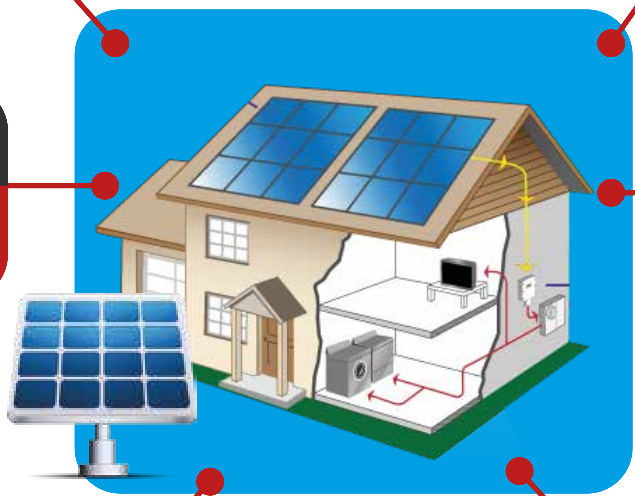
1. Photovoltaics (PV)

- Electrical shock
- Fire
- Fall of PV module
- Destruction of PV array
- Cut and bump

6. On-Site Work

- Electrical shock
- Falling from roof & ladder
- Cuts and bumps
- Fire
- Chemical burns
- Insects, snakes, etc

Your Solar Project



2. Charge Controller, Inverter

- Electrical shock
- Fire

5. Appliances

- Electrical shock
- Fire
- Burns

3. Batteries

- Electrical shock
- Fire
- Chemical burns
- Explosion

4. Cables

- Electrical shock
- Fire
- Cut

Hazards & How They Can Be Prevented

Hazard	Description	How to Prevent Injury
Exposure	• Sun damage • Symptoms of dehydration • Heat stroke	• *Wear a hat and long-sleeved clothes* • *Drink plenty of fluids, never alcohol* • *Take regular breaks in the shade*
Injury	• Falling from roof or ladder • Cut finger with sharp edge of metal and metal slivers • Bump head on the low beams and PV frame • Back strain by lifting and carrying heavy equipment • Burn caused by contacting hot metal	• *Wear comfortable shoes* • *Have a partner to hold the ladder and assist with handling equipment* • *Wear gloves* • *Wear a safety helmet*
Insects, Snakes	• Spiders and insects often move in and inhabit junction boxes and other enclosures.	--
Electrical Shock	• The human body acts like a resistor and allows current to pass. • The value of resistance varies with condition. (**Wet:** 1,000 Ω – **Dry:** 100,000 Ω) • The amount of current that will flow is determined by Voltage and Resistance in the current pass. • Current greater than 20mA may give a serious damage to the body.	• *Always check the voltage between any conductor and any other wires, and to ground.* • *Do not touch conductive part by wet hand*

Hazards & How They Can Be Prevented (continued)

Hazard	Description	How to Prevent Injury
Electrical Sparks and Burns	• Electric sparks are caused by short circuit, and it can lead to fire. Especially, short circuit of battery is extremely hazard. It may cause serious damage to person and PV system. • Loose connection increases resistance at the connecting part. The connecting part becomes the heating element and can cause a fire. • Insulation failure can cause electric leak and short circuit.	• *Use insulated tools (spanners etc).* • *Put covers over the battery terminals.* • *Install fuse.* • *Check contact and voltage drop at the connecting part.* • *Tighten up screw and clean up contact.* • *Check cable and terminal block periodically.*
Chemical Burns by Acid	• The lead-acid type battery uses sulfuric acid as the electrolyte. Sulfuric acid is extremely hazardous. Chemical burns will occur if the acid makes contact with an unprotected part of the body.	• *Wear non-absorbent gloves and protective glasses.* • *Wash out with plenty of water in case of contact.*
Gas Explosion	• Flooded lead-acid batteries release hydrogen gas as a result of the charging process. Hydrogen is flammable gas and has an explosion hazard.	• *The battery should be installed in a well-ventilated area.* • *All flames and equipment that could create a spark should be kept away from the battery.*

General Tips

01 You are responsible for your own safety and for the safety of others.

02 All accidents are preventable.

03 Do not take short cuts. Always follow the rules.

04 If you are not trained, don't do it.

05 Use the right tools and equipment and use them in the right way.

06 Assess the risks before you approach your work.

07 Never wear loose clothes or slippery footwear.

08 Do not indulge in horseplay while at work.

09 Practice good housekeeping.

10 Always wear proper protective gear.

Safety Management

Clothes: Wear proper clothes for on-site work and ambient environment (Long-sleeved clothes, Hat, Shoes etc.)

Safety Equipment: Prepare safety equipment (Gloves, Protective glasses, Safety helmet, Appropriate ladder, insulated tools, Proper measuring equipment etc.)

Work Plan: Check specification and diagram of PV system. Make work plan which reflect results of the risk assessment and inform the workers about work plan in advance.

Work at Site: Confirm risks and safety measures before starting work. Conduct work complying with work plan.

When dealing with any electrical installations it is better SAFE than SORRY.

Safety Precautions

1. Earthing: ensure your system is properly grounded

2. Do not attempt to disassemble the module, and do not remove any attached nameplates or components. Doing so will void the warranty.

3. Do not use mirrors or other hardware to artificially concentrate sunlight on the module.

4. Solar modules produce electrical energy when exposed to sunlight. DC voltages may exceed 30V on a single exposed module.

5. Only connect modules with the same rated output current in series. If modules are connected in series, the total voltage is equal to the sum of the individual module voltages.

6. Only connect modules or series combinations of modules with the same voltage in parallel. If modules are connected in parallel, the total current is equal to the sum of individual module or series combination currents.

7. Keep children well away from the system while transporting and installing mechanical and electrical components.

8. Completely cover all modules with an opaque material during installation to prevent electricity from being generated.

10. Do not wear metallic rings, watchbands, ear, nose, or lip rings or other metallic devices while installing or troubleshooting photovoltaic systems.

12. Use appropriate safety equipment (insulated tools, insulating gloves, etc) approved for use on electrical installations.

13. Observe the instructions and safety precautions for all other components used in the system, including wiring and cables, connectors, DC-breakers, mounting hardware, inverters, etc.

14. Use only equipment, connectors, wiring and mounting hardware suitable for use in a photovoltaic system.

15. Always use the same type of module within a particular photovoltaic system.

Maintenance of System Components

Solar Lanterns

- **Do not operate in explosive atmospheres,** such as in the presence of flammable liquids, gases, or dust. Electrical products create sparks which may ignite the dust or fumes.
- **Do not expose adapters to rain or wet conditions.** Water entering an adapter will increase the risk of electric shock.
- **Do not abuse the power cord.** Never use the power cord to carry the adapter or pull the plug from an outlet. Keep the power cord away from heat, oil, sharp edges, or moving parts. Replace damaged power cords immediately. Damaged power cords increase the risk of electric shock.
- Check for loose screws.
- **WARNING!** Make sure the **power switch** of the Solar Lantern is in its "OFF" position and that the Adapter is unplugged from its electrical outlet before performing any inspection, maintenance, or cleaning procedures.

Trouble Shooting for Solar Lanterns

Issue	Causes	Solutions
Battery only lasts a few hours	1. Solar Panel Dirty or in shade	1. Clean the solar panel, move the panel so it is not in shade
	2. Bad Connection	2. Check all wiring connections
	3. Cloudy Day	3. Recharge the battery on sunny days
	4. Old Battery	4. Test and replace battery
	5. Battery Misuse	5. Test and replace battery
Lamp does not work	1. Not switched on	1. Switch on the lamp
	2. Bad connection	2. Check all wiring connections
	3. Incorrect wiring	3. Check positive and negative connections
	4. Lamp broken	4. Replace lamp
Dim light	1. Solar panel not charging properly (dirt, shade)	1. Clean the solar panel and check if not shaded during charging
	2. Bad connection	2. Check the connections
	3. Battery misuse	3. Test the battery and replace it

Solar Lanterns

Shade

DO	DO NOT
• Make sure that all objects that may shade your panel are removed	• Concentrate artificial light on your solar panel
• Make sure that only direct sunlight falls on your panel	--

Cleaning

The solar panels must be clean at all times.

DO	DO NOT
• Inspect your solar panel regularly for dirt such as dust or bird droppings.	• Use soap or detergent
• Clean your solar panel once every three months (or when dirty) using clean water and a soft cloth.	--

Security

During installation, the solar panel was firmly fixed to roof of the house.

DO NOT
• Fix a wire mesh around it as it is already secure. This is because the wire mesh cast shadows making the panel produce less energy.

Safety

The solar panel consists of glass top which can easily break.

DO NOT
• Throw objects at the solar panel.
• Stand or step on the panel.
• Try to repair your solar panel if it breaks because once the panel is broken, it cannot be repaired.
• Carry out modifications on your system without technical guidance from your system supplier or a qualified technician.

Charge Controller

DO	DO NOT
• Ensure connections are firm. In case of a problem, consult your solar installer or supplier.	• Tamper with it.
--	• Place it were water can penetrate.

Wiring

DO	DO NOT
• Inspect the cable network every three to five years to ensure there are no exposed wires.	• Try to make connections when you are not sure. Seek expert advice and help.
• Protect your solar wiring from damage as this can result in the failure of your system.	--
• Avoid short circuiting your cables as this can lead to system damage.	--

Batteries

DO	DO NOT
• Keep the solar battery in a clean environment. Place the solar battery on a stable surface to prevent it from falling or tilting.	• Short-circuit the terminals of your solar battery. Your solar battery stores huge amounts of energy. If you connect the terminals directly, the stored energy will be released at one go causing the wires to melt or fire to occur. All power must be consumed through the installed regulator. This will protect your solar battery for a long time.
• Keep the solar battery safely inside a well-ventilated wooden box.	• Pour out the acid and fill with fresh acid as it damages the battery.
• Always check the level of electrolyte in every cell of your battery. If the level has gone down, add some distilled (or de-ionized) water.	• Add acid to your solar battery at any time.
• Top the solar battery with distilled water from a good source, never use tap or rain water since they have impurities, which may damage your battery.	• Accept advice on battery repairs from unauthorized persons. Rather, contact battery suppliers directly.
• Apply Vaseline, not grease or oil, on both battery terminals to prevent acid mist (a white substance) forming on them. Clean the terminals and battery's top surface regularly with hot water to prevent accumulation of acid mist which causes batteries to self discharge.	• Keep the solar battery near open flames as there is danger of explosion.
--	• Take your old batteries for repair.

Case 1

It has been sunny all day but there is not enough power in your solar battery.

Possible reasons:

- The television or radio may have been used during the day
- The lamps may have been left on during the day
- There could be some loose connections
- The panel may be faulty, dirty or shaded
- The battery may be old
- The electrolyte level in the battery could be low

Case 2

You were watching television and the rooms were well lit for several hours. Suddenly the television goes off and you are in total darkness.

Possible reasons:

- The charge regulator may have disconnected the loads because battery voltage was low.

Possible corrective measure:

- Check if the charge regulator shows" load off'. If the blackout is due to the regulator, turn off the main switch. It will reconnect the power on its own when the battery is recharged.
- If the charge regulator is not responsible for the blackout and the lights and television do not function at all the next evening, contact your solar electric system supplier.

Case 3

There are frequent power blackouts.

Possible reasons:

- The solar electric system may be too small for your demands
- The solar battery may be very old
- The solar battery may be damaged
- There may be loose or corroded connections in your solar electric system
- The electrolyte level in your battery could be low

Possible corrective measures

- Contact your solar electric system supplier
- Reduce the load demands on your system
- Upgrade your system
- Check the electrolyte level and top up if low

Case 4

During the cold and cloudy seasons the power supply is lower than usual.

Possible corrective measure:

- Continue using the solar electric system but exercise greater conservation of power. The power supply will rise to normal when the sunny season resumes.

Case 4

The solar battery acquires full charge earlier than normal and blackouts still occur.

Possible corrective measures:

- Test the battery's state of self discharge and if high, replace with a new one
- If the problem occurs and the battery is in working order, the charge regulator could be faulty.
- Check battery terminals for a possible loose connection

FAQs

Frequently
Asked
Questions

Frequently Asked Questions

Q1. Where can I get the solar lanterns?
Answer: Solar lanterns are sold and distributed by various solar supplier companies such as D-Light, Barefoot, One Degree Solar, Sun Transfer, and Sunlar among many others. In most cases, the solar supplier companies have offices or sales executives in major towns. In other cases, suppliers use courier companies or deliver orders to towns that are nearest to their retailers.

Q2. Where do I find the suppliers? Do I need to travel far to buy stock?
Answer: You do not need to travel to their offices or their distribution centres in order to place your order. You can use their sales executives on the ground to place the order.

Q3. Who are the best suppliers? Which are the fast moving products in the market?
Answer: A good supplier is one who meets your needs within the shortest time.
How fast a product moves will all depend on your: convincing power, marketing skills and avenues, positioning and networks and how well you understand your market and customers.

Q4. How do I deal with suppliers to ensure my orders are delivered on time?
Answer: Most suppliers will work hard to ensure you are served on time, and in case there is a delay, remember that they are only a call away.

Q5. How do I pay the suppliers when buying stock from them?
Answer: It is highly advisable that you pay for your order through the provided channels. Do not give cash to suppliers/agents on the ground.

Q6. How long should it take for the order to be delivered after I make the payment?
Answer: Most solar supplier companies will meet your order within 5 days.

Q7. In case delivery of the order takes longer than expected, how do I deal with the customers who keep asking for the lanterns?
Answer: Good customer care is important in such times. Understanding your customer, promising them what is possible, but also assuring them that you are taking care of their order is very important.

Q8. What are the wholesale prices of the various solar lanterns?
Answer: Most solar supplier companies will give you their price lists. They will give a wholesale price and a recommended retail price.

Q9. How do I price my solar lanterns to cover my costs and make a profit?
Answer: Solar Supplier companies will give a recommended retail price which guides you on the retail price and the margins. Ensure that you consider the following factors when you price: cater for the cost of the product, the expenses incurred to get the product to the customer and your profit margin.

Q10. How do I raise capital for the solar business?
Answer: Solar business is a business like any other. Capital for solar business is raised using sources that you have come across. These include: savings, donations from friends and relatives, loans among others.

Q11. If I were to get a loan from a financial institution to expand my solar business, what are some of the factors financial institutions would consider?
Answer: For you to access a bank loan to expand your business, your business must be bankable. It must meet the C 'S of Credit - Capacity, Capital, Character, Collateral, Cash Flow and Conditions.

Q12. Can I get the solar lanterns on credit and then pay after I have sold?
Answer:A few supplier companies will allow trade credit – where they supply portable lanterns on credit and allow you to pay them later. Most of them will have you pay before sending your order, making it very important for you to maintain a healthy cash flow in your solar business.

Q13. How do I market my solar lanterns?
Answer: There are many avenues that you can use to market solar lanterns. However, it is important to note that a market does not have to be physical. A market is a place with a buyer, a seller and a product, a place where a transaction can take place. This means that if a solar entrepreneur meets a potential buyer by a road side, it is a market. This makes personal selling a very effective way of selling solar lanterns. Different avenues can however be used to reach out to more customers:

- Self-help groups
- Institutions like schools and churches
- Financial institutions
- Using promoter model

Q14. How do I convince people to buy my solar lanterns whereas some have installed electricity?
Answer: It is always important to know the benefits of using solar energy in relation to other sources of energy. Ensure that you have the benefits at you finger tips. These include: low cost, readily available, green energy, no pollution. For example, during black-outs households using solar energy are well lit.

Q15. There are many types of solar lamps in the market, some are cheap - especially those from China. Why should I sell the ones that are more expensive?
Answer: Cheap at times can be very expensive. We advocate for products approved by Lighting Africa, a joint initiative of IFC and the World Bank that accelerates the development of markets for clean off-grid lighting products in Sub-Saharan Africa. These products have been tested over time. For these products, the supplier gives a warranty and in cases of default, the products can be returned and replaced during the warranty period.

Q16. How do I manage to maintain a healthy cash flow yet customers get the products on credit?
Answer:It is the work of the business manager to maintain a healthy cash flow for the business. Cash flow is the daily fuel that runs a business and without it, a business will die. Healthy cash flow enables a business person manage the daily operations of a business. Selling on credit denies a business the fuel to run the day to day operations of a business. If you keep selling all your solar lanterns on credit, you will soon be out of business.

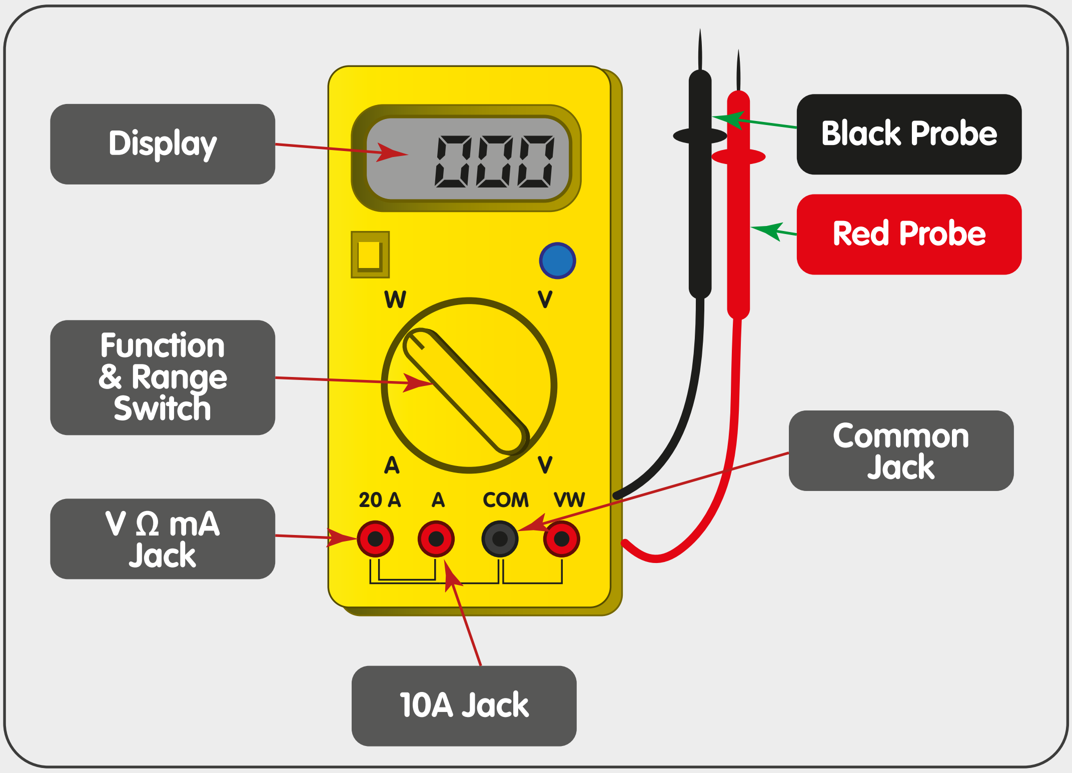
Q17. How do I deal with solar lanterns that have been returned by customers because they are not functioning?
Answer: Most Solar Lighting Africa approved products are sold on a warranty. A warranty is a representation made by a seller or company to a purchaser of a product or service that a refund, repair, or replacement will be made if the product or service proves defective or unsatisfactory, especially within a given time period. This means that a solar lantern that does not function well within the warranty period can be returned to the manufacturer and replaced at no extra cost. The defect should however not be caused by the purchaser.

Q18. Do I have to keep records of all the solar lanterns I sell? Isn't it a very hard job?
Answer: Record keeping is an important aspect of the business. It is only through record keeping that an entrepreneur can tell the performance of their business.

APPENDIX

Additional Notes & 'How To' Tests

i. Basic Anatomy of a Multimeter



Meter Leads

Red Meter Lead
• Is connected to voltage/ resistance or amerage port
• Is considered the **positive** connection

Black Meter Lead
• Is always connected to the common port
• Is considered the **negative** connection

Probe (Black & Red)
• Are the handles used to hold tip on the tested connection

Tips
• Are at the ends of the probes and provide a connection point

Examples of Multimeters

Digital

Analog

ii. How to Test Solar Panel Output

Using a multimeter:

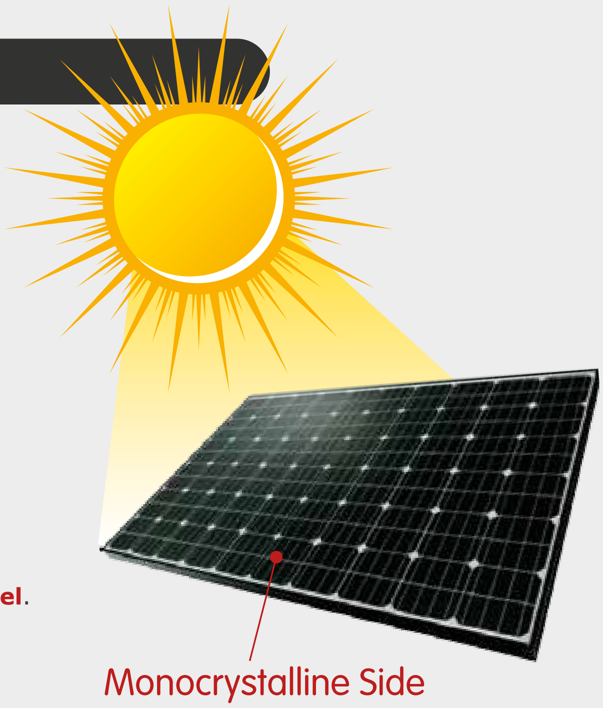
- Set the multimeter to the correct scale and voltage range.
  Solar panels produce Direct Current (DC).
- Ensure that the collector is on a secured place, where there is enough sunshine.
- Connect the multimeter terminals to the positive and negative terminals of the solar panel.
- Read and note the voltage.
- Compare the **tested output** voltage with the output voltage indicated on the solar panel.
- If there is a difference in the values, **then the solar panel is not a good product.**

It is ideal to test the solar panel when purchasing and before installing it to the system.

iii. How to Test a Solar Panel's Polarity

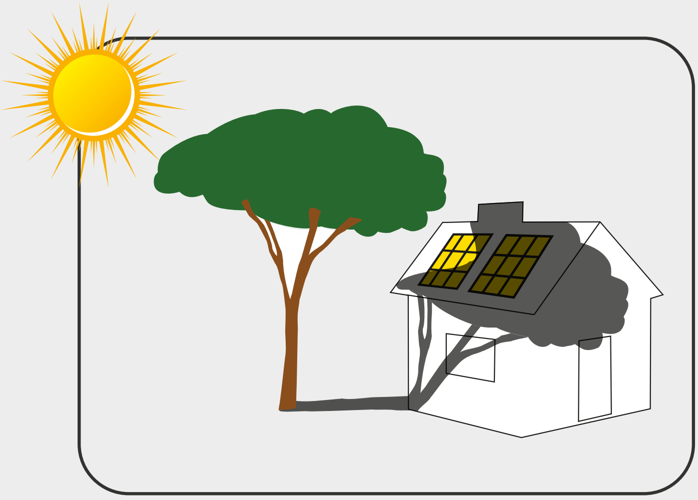
In order to check the polarity of the solar panel:

- Place the soalr panel outdoors with the monocrystalline side facing up in a sunlit location.
- This will produce a test voltage for you to measure.
- Set the multimeter to the DC (direct current) voltage range capable of measuring up to 24VDC.
- Connect the positive side of the multimeter to one terminal of the solar panel and the negative side of the multimeter to the otehr side.
- If the reading is **positive**, **this is the positive side of the panel**.
- If the reading is negative, the terminal markings are incorrect and should be re-marked correctly.



iv. How to Check the Voltage on a Solar Panel Affected by Shade

This can be done using a solar water pump or using a multimeter:



- Ensure that the multimeter is at the correct scale and within the range of the solar panel's voltage.
- Place the colector in a position that it can receive maximum radiation.
- Connect the multimeter on the **positive** and **negative** terminals of the solar panel.
- Note the voltage and recird it.
- Do not remove the multimeter from the terminals.
- Shade the solar panel, starting from one end to the other.
- Take note of the voltage change until the solar panel is fully shaded.

v. Battery Testing Using a Multimeter

- Use a multimeter.
- Set the multimeter to the correct scale (DC, direct current).
- Connect the multimeter to the positive and negative terminals of the battery.
- Read the voltage as indicated on the multimeter.

NOTES