ENERGY RESOURCE GUIDELINES

Prepared by:

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Foreword:

This document is intended to aid EWB-USA chapters when designing energy projects in developing countries. The initial chapter includes basic requirements needed during site assessments to determine the best source of energy for a sustainable project. The following chapters include more details in specific areas of energy design such as Photovoltaics, Wind and small Hydropower projects. This document is solely a guide and does not replace the need for an experienced Professional Electrical Engineer on the project.

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CHAPTER 1

INTRODUCTION

1.1 Energy Guidelines

These guidelines address alternative energy projects and designs for Engineers Without Borders primarily in developing countries. This document cannot provide all design criteria but seeks to provide guidance and resources for the evaluation, design and installation of small, renewable energy projects. Sustainable energy source technology has developed greatly in the past few decades to provide cost-effective, nonpolluting alternatives to the fossil fuel-based systems. These guidelines cover three important energy sources: solar, wind and small (micro) hydropower systems. Engineers Without Borders works primarily in rural areas where there is a need for energy to help run water pumps, provide lighting and electricity to small schools and offer back up power to clinics and vaccine refrigeration. These guidelines are intended as a general reference and will focus on energy solutions for small scale, stand-alone projects, typical of what is needed for developing countries.

1.2 Rural Electrification

More than half of the population in developing countries live in rural areas, and recent estimates indicate over two billion people live without electricity[1]. The most reasonable solution to poverty in rural areas is the increase of energy use, primarily through electrification. Renewable sources described in these guidelines are intended to help with the initial electrification of either specific activities (e.g., refrigeration of medical supplies) or the village. Renewable sources are economically viable for regions that have not been tied to a power utility grid. The democratic and equitable distribution and uses of the power are critical for the successful implementation of these projects. Specific and immediate concerns for electrification include the following:

- Water: Renewable energy sources can be especially valuable to pump water from wells with small power systems, freeing labor for schooling or other work.
- Cooking: Electrification can provide lighting in kitchen areas, perhaps allowing a more closed stove design. Beyond that, renewable energy from solar cookers could be evaluated, but these are not covered in these guidelines. Primary concerns with cooking include good stove design and perhaps consideration of biogas, also not covered in these guidelines.
- Medical: Electrical sources can provide power for refrigeration of medicines and lighting for hospitals and clinics.
- Education: Renewable electrical supplies can be used to light classrooms and power radios, TVs, and computers.

Due to the limited resources available to EWB, it may be necessary to prioritize electrification projects in a region based on immediate needs.

1.3 Special Considerations

As the project is being conceived or evaluated, the following factors should be considered:

- There should be adequate village size and need to justify the project.
- The project should involve community decisions of electrical use, system ownership, and system maintenance.
- The community should be allowed to choose from viable energy source options.
- Coordination, financing and/or approvals may be needed from local or regional government sources.
- The community must be trained to not only maintain the systems but also be able to coordinate future load demand issues, with organizations or processes for making future electrification decisions.

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[1] *Decentralised Rural Electrification: The Critical Success Factors,* Holland, et.al., ITDG

CHAPTER 2

ENERGY LOAD ANALYSIS

2.1 Energy Demands

A power system's success or failure depends on more than just the technical design of the system. It depends largely on what the users expect of the system and how this relates to their culture, geography, climate, and resources. Proper design of a power system includes evaluation of the community's energy demands. Rural areas in developing countries are not always accustomed to having electricity aside from disposable dry cell batteries. If power is available it is often expensive and not reliable so an alternative energy source may be required.

When determining the electrical loads it is necessary to have accurate data. For a stand alone power system loads need to be calculated. The following table lists the power consumption of some typical appliances.

Appliances	Specification	Power (W)
Fluorescent lamp	Circle	6, 8, 11, 15
Fluorescent lamp	Tube	15, 20, 40
Incandescent	A-19	60
LED Light bulbs	G-11 Edison Base	1.2
Fan	28 cm desk type	40
Fan	30 cm on floor	50
Refrigerator for vaccines	170 liter	130
Air conditioner	Cooling	900

Table 2 –1: Typical Power Consumption of Appliances

Note: LED light bulbs are becoming more widely used especially in developing world. The rated life of the bulbs are around 50,000 hours.

2.2 Power Measurement

Electrical power is measured in watts:

Volts x Amperes = Watts
Watts x Hours of Use = Watt hours

Most equipment will have a nameplate attached to it with the nominal voltage, amps and watts. If the voltage is reduced, the watts may not decrease, depending on the type of load. The amps may go up to adjust for total watts needed, based on the equipment loads.

The electrical load (use) can be determined by direct measurement of voltage applied and amps drawn by using a multimeter and clamp-on ammeter. Some loads are intermittent, like a refrigerator's compressor motor, and a daily average may be more appropriate for the load estimate.

If the power consumption to a piece of equipment is not known a "Power Analyzer" can be used to measure the power used by each piece of equipment on the circuit. Actual power consumption for each piece of equipment will enable higher accuracy in estimating power required by the generator.

2.3 Power load calculations

Generally the electricity supply for a village's hospital is the most important load. This might be followed by lighting, economic industry, and schools, with loads such as personal TV's being the least important. Having a high reliability power system that can supply electricity whenever it is needed will be more expensive than one that can supply electricity part or most of the time, but may not supply all of the loads during periods of low resource availability. Knowing the variation of the load throughout the year is also important in designing a power system. Power generated by wind turbines, hydro turbines, and photovoltaic cells will vary throughout the year, and must meet the critical loads during each time of the year. Many loads are relatively constant throughout the year, however some loads, such as water pumping loads, are much larger during the summer. Other loads, such as heating, may be much larger during the winter. The relative match between the seasonal variation of the load and the seasonal variation of the energy resource can determine the choice between different resources.

To size your alternative energy system, you must first know the energy needs, which is calculated by listing all the daily loads that would draw from the system. A load includes anything that uses electricity from your power source, such as lights, radios, or batteries. The Electric Load Estimation worksheet (See Appendix II) can be used to calculate average daily electrical energy use. It is calculated in watt-hours as well as the total connected watts. Some loads need electricity all the time, such as refrigerators, whereas others use electricity less often, such as lights. To determine the total energy consumption, multiply the wattage of the appliance by the number of hours it is used in a day.

Most electrical appliances in the United States are rated with wattage, a measure of energy consumption per unit of time. One watt delivered for one hour equals one watt-hour. Wattage is the product of current (amps) multiplied by voltage; watt = amps x volt. One amp delivered at 120 volts is the same amount of wattage as 10 amps delivered at 12 volts; 1 amp at 120 volts = 10 amps at 12 volts. Wattage is independent of voltage: 1 watt at 120 volts = 1 watt at 12 volts. To convert a battery's amp-hour capacity to watt-hours, multiply the amp-hours times the voltage. The product is watt-hours.

To figure out how much battery capacity it will require to run an appliance for a given time, multiply the appliance wattage times the number of hours it will run to yield the total watt-hours. Then divide by the battery voltage to get the amp hours. For example, running a 60-watt light bulb for one hour uses 60 watt-hours. If a 12-volt battery is running the light it will consume 5 amp-hours (60 watt-hours divided by 12 volts equals 5 amp-hours).

Some appliances do not give the wattage, so you may have to calculate the wattage by multiplying the amperes times the volts. After adding the totals for each appliance, you can decide what power output is needed. (For PV systems see Appendix III for sample PV worksheets).

There are some seasonal loads like pumps and fans. It is necessary to record and analyze all the loads in various seasons to rationally use the electricity generated by PV, wind or hydropower system. Additionally the proposed loads should be classified and prioritized, for example lighting, communications, and pumps for drinking water may be the top priorities. Refrigerator (unless used for vaccines) are typically lower priority, and fans or air conditioner for creature comfort would be lower priority. In accordance with solar conditions, the status of the generation, and batteries, the level of power during a specified season can be decided, or some loads can be cut off if necessary. Many electric loads that a designer would like to include may be cost prohibitive to power using an alternative energy system. Energy conservation should be included in all load calculations, considering available resources and sustainability of connecting the loads.

2.4 Load Growth

2.4.1 *Load Forecast*

A load forecast generally needs the following data:
□1□Load type and amount
□2□Load power and main electrical parameter
□3□The hours of electricity use each day
□4□Electricity amount consumed each day
□5□Load simultaneity (diversity) ratio (the ratio of loads running at the same time)

Section 2.3 discusses how to calculate total power and average power use each day according to system load.

2.4.2 *Evaluate Load Increases*

Generally loads increase faster in the first year after the power system is installed, then increases as the number of users increase and the standard of living improves, but the rate of increase slows. When designing the system, the load increase must be considered, usually, the scale of the power system should depend on the expectation of the load increase in the first 3 years after installation. For different villages and areas, the ratio of load increasing is not the same. So be careful to estimate this increasing speed.

One way of dealing with the uncertainty of load increase is to adopt a system structure that can be expanded easily. PV modules and wind power are easy to add to a system, but the storage battery and electronic equipment are not so easy to expand. (The new storage batteries cannot be used with the old ones). If the power system needs expansion, the first method is to increase the capacity of the storage battery, electronic equipment, and transmission line on the base of the original system, when the PV/wind hybrid system needs expansion. The second method is to divide the village into several parts and supply power for each one, when expanding the original station. The new station should supply power to different areas independently. The third method is to juxtapose electrical nets and supply power, which means connecting the original station with the new station, which requires an inverter that can be connected in a network instead of supplying power alone.

The system should be designed to account for moderate load growth if it is financially feasible. The energy system must be used and managed economically and efficiently, within the means of the community. Load can be managed by setting higher tariffs for high-demand users or by appointing a person from the village be the power system operator and power monitor. Education of users is critical; they need to understand what kinds of appliances are suitable for renewable energy systems (for example electric heaters, rice cookers and incandescent light bulbs are not suitable). When end users do not understand that the power from a system is limited, they tend to overuse the system, which can damage and even destroy the batteries.

2.5 System Voltage and Distribution

Based on the load estimates and provisions for future load growth, a decision should be made on the use of DC versus AC for the project. For smaller, specific tasks or loads, DC can be used efficiently from PV systems due to the PV output in DC voltage, removing the need for the DC-AC inverter. If the loads are greater, or if loads are expected to increase, an AC system should be installed. Many appliances are now available for using DC power, but many voltages are available and existing loads must match the new source voltage. For AC systems, the frequency and voltage of the community's region should be considered. Most regions of the world operate at 50 hertz versus the 60 hertz in the U.S.

Distribution of the power generated should be carefully considered. This should be considered from several aspects, including:

- Distribution voltage. The higher the voltage, the more economical the distribution, but the greater the safety risks.
- Control of the number of circuits connected.

- Wiring methods – the wiring must be secure from damage and vandalism, and safe.
- Visual impacts to the village.
- Replacement and repair parts.

CHAPTER 3

CHOOSING AN ALTERNATIVE ENERGY SOURCE

3.1 Introduction

3.2 Factors Involved

Mineral resources, coal, and petroleum are unequally distributed in most regions of the world. Electricity can be easily transmitted, but it needs high-voltage lines to reach remote areas. Residents cannot afford the cost of installing transmissions lines. Locally generated power like wind and solar energy can help to solve the energy supply problems in such areas. The use of renewable sources can make a huge contribution to savings and environmental issues compared to use of exhaustible energy sources. Each 600 kWh of electricity generated with a renewable source is equivalent to 1 barrel of oil, assuming an efficiency of 38 % for the conversion of oil into electricity.

A major factor in determining the most sustainable and appropriate source of energy to use in a given community is determining what technologies are available in the country or area of the community. For an energy project to be sustainable the parts for maintenance of the project must be available within an acceptable range of transportation.
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An evaluation of the regional resources, followed by an assessment trip, should be conducted to determine the resources available and to determine the appropriate technologies. The designers must determine if sufficient sun, wind or water sources are available for the project to supply appropriate energy for the requested community.

3.2.1 *Characteristics of Solar Energy Resources*

Advantages of Solar Energy

(1) It is widely distributed. Solar power is the most widely available power source in the world. Direct solar radiation can provide efficient power in virtually all regions, particularly in the third world.
(2) It can be sized to match available load and if planned well it can easily be expanded.
(3) It has no moving parts. Maintenance is very low and easy. Regular battery maintenance is needed if they are included in the system.
(4) Systems are modular and fairly easy to install. With an adequate roof, the system requires virtually no superstructures and relatively easy mounting.
(5) The cost of the power does not increase. Because there is no fuel cost, renewable energy cost/kilowatt hour remains the same.

(6) It Does Not Pollute, and Is Environmentally Friendly. The use of fossil fuels releases many harmful substances. In many rural communities a great deal of wood is consumed, which damages forests and erodes the soil. The development and use of renewable energy sources (solar, wind, hydropower) energy will not pollute the air or destroy the ecological system. It is clean and safe.
(7) It Is Renewable. Renewable energy can be generated and supplied regularly. Coal, petroleum, and natural gas deposits have taken billions of years to form. Once they are exploited and used, they cannot be readily regenerated. Thus, solar and wind energy should be developed and used.

<u>*Disadvantages of Solar Energy*</u>

(1) High initial cost. The cost of the solar panels and inverter can be beyond the means of rural communities in third world countries.
(2) Production and spare parts are not readily available. Solar systems are currently manufactured in modernized areas - capacity needs to be developed in smaller countries.
(3) It is unsteady. Solar energy is only available during daylight hours and is vulnerable to the weather. Although solar energy can be characterized for average solar irradiance, its intensity changes based on cloud cover.

3.2.2 *Characteristics of Wind Energy Resources*

<u>*Advantages of Wind Energy*</u>

(1). It is widely distributed
Wind energy that is higher than 10 m and has a density of 150–200 W/m^2 may be usable in about two-thirds of the world. It is somewhat localized, but compared to fossil fuels, hydropower, and geothermal energy, wind is widely distributed. A wind-powered electrical system can be big or small, so it is easy to develop locally.
(2). It does not pollute, and is environmentally friendly, as noted for solar.
(3). It is renewable, as noted for solar.

<u>*Disadvantages of Wind Energy*</u>

(1). It has low energy density
The density of air is just 1/773 of that of water. The energy density of wind at 3 m/s is 0.02 kW/m^2; water's energy density is 20 kW/m^2 at the same speed. To get the same power from wind energy as from water energy, the wind wheel should be 26.8 times bigger than water wheel.

(2). It is unsteady
Wind energy is vulnerable to weather and climate and as such is random energy. Though wind energy can be characterized for average wind speed energy in a specific area over a long time, its intensity changes from minute to minute. The unsteadiness of wind energy makes its development and use difficult.

3.2.3 *Characteristics of Hydropower Resources*

Hydropower is a clean source of energy but it may have impacts on water use patterns, fisheries, and land area consumed by the storage reservoir. It does not consume the water, it only uses the water. After release, the water is available for other purposes at the downstream location. The conversion of the potential energy of water into mechanical energy is a technology with a high efficiency (in most cases double that of conventional thermal power stations).

Advantages of Hydropower

- Power is usually continuously available on demand,
- Given a reasonable head, it is a concentrated energy source,
- The energy available is predictable,
- Limited maintenance is required, so running costs are low (compared with diesel power).
- In many cases, the power replaces energy imported, to the benefit of the local economy,
- It is a long-lasting and robust technology; systems can last for 50 years or more without major new investments.

Disadvantages of Hydropower

- It is a site specific technology. Sites that are well suited to the harnessing of water power and are close to a community where the power can be economically exploited are not very common.
- There is a maximum useful power output available from a given hydropower site, which may limit future load growth.
- River flows often vary considerably with the seasons, especially where there are monsoon-type climates and this can limit the firm power output to quite a small fraction of the possible peak output,
- Lack of familiarity with the technology and how to apply it inhibits the exploitation of hydro resources in some areas.

3.2.4 *Analyze the data*

(See ‘Project Model’ under each main section for solar, wind and hydropower).

3.2.5 *Develop feasible options*

Developing feasible options helps focus the community on the advantages and disadvantages of differing systems. Community involvement in the selection improves the likelihood the system will become sustainable. Without alternative energy system designs to select from, there is not much of a decision for the community to make.

3.2.6 *Hold discussions with the community*

Discussions should be held with the community on proposed technology options. Each option should be discussed with special focus on the long-term management of each system. Any adjustments to the design can be selected. The persons responsible for the power system installation, management/operation, maintenance should be defined.

CHAPTER 4

PHOTOVOLTAIC ENERGY

4.1 Principles Photovoltaics

Photovoltaic (PV) panels are semiconductor devices that convert sunlight into direct current (DC) electricity. Small isolated loads can be powered directly with DC voltage. With the appropriate power conversion equipment, PV systems can produce alternating current (AC) compatible with any conventional appliances. AC systems can be stand-alone or interconnected to the local utility grid.

A typical silicon PV cell is composed of a thin wafer consisting of an ultra-thin layer of phosphorus-doped (N-type) silicon on top of a thicker layer of boron-doped (P-type) silicon (Figure 4-1). An electrical field is created near the top surface of the cell where these two materials are in contact, called the P-N junction. When sunlight strikes the surface of a PV cell, this electrical field provides momentum and direction to light-stimulated electrons, resulting in a flow of current when the solar cell is connected to an electrical load.

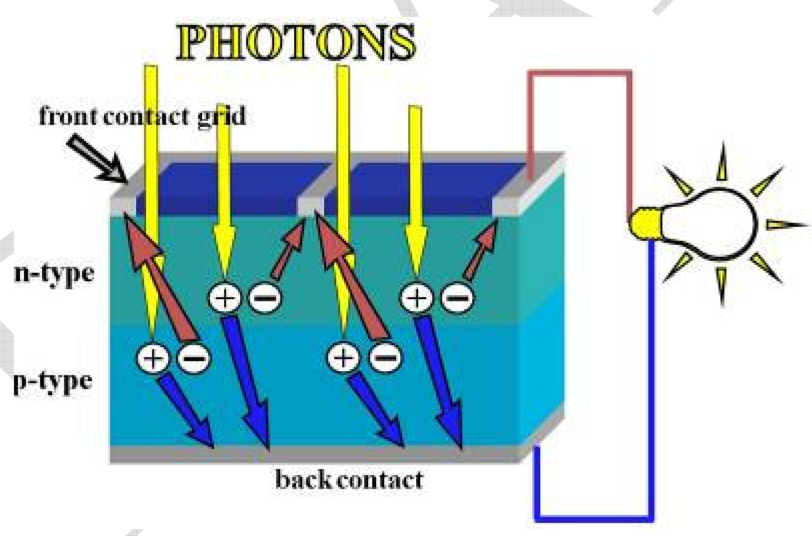

Figure 4-1. Diagram of photovoltaic cell

Regardless of size, a typical silicon PV cell produces about 0.5 – 0.6 volt 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 25 in^2 will produce about 2 watts peak power. If the sunlight intensity were 40 percent of peak, this cell would produce about 0.8 watts.

PV systems can be classified into two general categories: flat-plate systems or concentrator systems. These guidelines focus exclusively on flat-plate systems as they are the most common array design. Several PV cells are interconnected into a single PV panel that has external wiring, ready for connection to other panels. The panels (or modules) in these systems can either be fixed in place or allowed to track the movement of the sun. They respond to sunlight that is either direct or diffuse. Even in clear skies, the diffuse component of sunlight accounts for between 10% and 20% of the total solar radiation on a horizontal surface. On partly sunny days, up to 50% of that radiation is diffuse. And on cloudy days, 100% of the radiation is diffuse.

One typical flat-plate module design uses a substrate of metal, glass, or plastic to provide structural support in the back; an encapsulant material to protect the cells; and a transparent cover of plastic or glass (Figure 4-2).

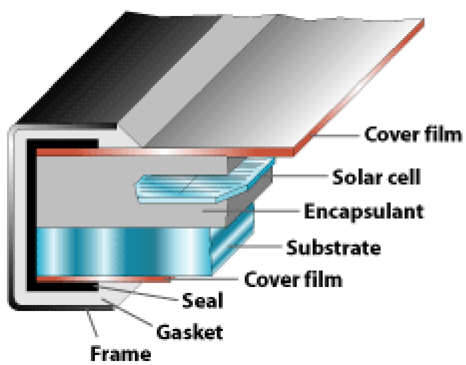

Figure 4-2. Flat-plate system

Simply put, PV systems are like any other electrical power generating systems; just the equipment used is different than that used for conventional electromechanical generating systems. However, the principles of operation and interfacing with other electrical systems remain the same, and are guided by a well-established body of electrical codes and standards.

4.2 Site Analysis – Photovoltaic Energy

4.2.1 *Siting the System*

Because even a small amount of shade can drastically reduce output, PV panels generally are installed in a "solar window" - an outside area that receives no shade from 9 a.m. to 3 p.m. To effectively access this solar window; PV modules can be mounted on a roof or a pole, or on a rack that is set on the ground. Another option is to use newer building-integrated PV (BIPV) arrays, which are integrated into the roof or applied to the existing building's exterior. These thin-film panels are less sensitive to shading.

The simplest PV array consists of flat-plate PV panels in a fixed position. The advantages of fixed arrays are that they lack moving parts, there is virtually no need for extra equipment, and they are relatively lightweight. These features make them suitable for many locations, including most residential roofs. Because the panels are fixed in place, their orientation to the sun is usually at an angle that practically speaking is less than optimal. Therefore, less energy per unit area of array is collected compared with that from a tracking array. However, this drawback must be balanced against the higher cost of the tracking system.

Pole-mounted PV systems have the advantage of being able to be connected to a tracking mechanism that follows the sun from east to west (and, in the case of dual-axis trackers, from horizon to sky). Tracking systems can increase the amount of power a PV system annually produces by up to 25 percent. Although trackers are well-suited for applications such as a batteryless water pumping system, which can use solar energy the second the sun comes up, for many applications it's more economical to add another panel or two than to invest in a tracker. There are also pole-mounted systems that can be manually adjusted throughout the day and year; to capture the most from the sun adjust the tilt of the panels to different sun angles throughout the year; to follow the sun's arc through the sky, daily reposition the panels.

4.3 Equipment: System Components

Although a PV panel produces power when exposed to sunlight, a number of other components, referred to as balance-of-system (BOS) equipment, is required to properly conduct, control, convert, distribute, and store the energy produced by the array. Depending on the functional and operational requirements of the system, the major components may include the battery charge controller(s), batteries, inverters (for loads requiring alternating current), wire (conductors), conduit, a grounding circuit, fuses, over-current protection, safety disconnects, metal structures for supporting the modules, and any additional components that are part of the PV system.

Combining modules with the BOS components creates an entire PV system. This system is usually everything needed to meet a particular energy demand, such as powering a water pump, appliances and lights in a home, or, if the PV system is large enough, all the electrical requirements of a whole community.

Note that in many systems the cost of BOS equipment can equal or exceed the cost of the PV modules. When examining the costs of PV modules, remember that these costs do not include the cost of BOS equipment.

4.3.1 *PV Modules: Cells, Modules, & Arrays*

The basic photovoltaic or solar cell typically produces only a small amount of power. To produce more power, cells can be interconnected to form modules, which can in turn be connected into arrays to produce yet more power. Because of this modularity, PV

systems can be designed to meet any electrical requirement, no matter how large or how small.
Photovoltaic cells are connected electrically in series and/or parallel circuits to produce higher voltages, currents and power levels. Photovoltaic modules consist of PV cell circuits sealed in an environmentally protective laminate, and are the fundamental building block of PV systems. Photovoltaic 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, Figure4-3.

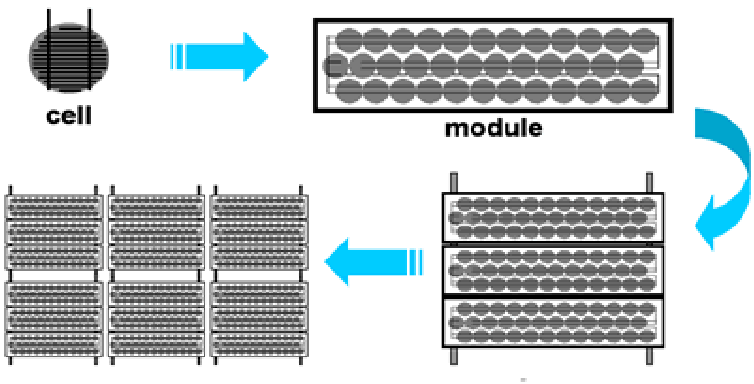

Figure4-3. Photovoltaic cells, modules, panels and arrays

4.3.2 *Batteries*

Batteries are often used in PV systems for the purpose of storing energy produced by the PV array during the day, and to supply it to electrical loads as needed (during the night and periods of cloudy weather). Other reasons batteries are used in PV systems are to operate the PV array near its maximum power point, to power electrical loads at stable voltages, and to supply surge currents to electrical loads and inverters. In most cases, a battery charge controller is used in these systems to protect the battery from over charge and over discharge.

The battery's capacity for holding energy is rated in amp-hours: 1 amp delivered for 1 hour = 1 amp-hour. Battery capacity is listed in amp-hours at a given voltage, e.g., 220 amp-hours at 6 volts. Manufacturers typically rate storage batteries at a 20-hour rate: 220 amp-hour battery will deliver 11 amps for 20 hrs.

This rating is designed only as a means to compare different batteries to the same standard and is not to be taken as a performance guarantee. Batteries are electrochemical devices sensitive to climate, charge/discharge cycle history, temperature, and age. The performance of your battery depends on climate, location and usage patterns. For every 1.0 amp-hour you remove from your battery, you will need to pump about 1.25 amp-hours back in to return the battery to the same state of charge. This figure also varies with temperature, battery type and age.

4.3.3 *Power Conditioning*

Power conditioners process the electricity produced by a PV system so it will meet the specific demands of the load. Although most equipment is standard, it is very important to select equipment that matches the characteristics of the load. Power conditioners may have these functions:

- Limit current and voltage to maximize power output
- Convert DC power to AC
- Match the converted AC electricity to a utility's electrical network
- Have safeguards that protect utility personnel and the network from harm during repairs

Specific requirements of power conditioners depend on the type of PV system they are used with and the applications of that system. For DC applications, power conditioning is often done with regulators, which control output at some constant level of voltage and current to maximize output. For AC loads, power conditioning must include an inverter that converts the direct current generated by the PV array into alternating current. Many simple devices—for example, ones that run on batteries—use DC electricity. However, AC electricity, which is what is generated by utilities, is needed to run most modern appliances and electronic devices.

4.3.4 *Inverters*

Inverters are the main brain to a power system. Photovoltaic panels create Direct Current (DC) electricity from the sun's light. Inverters convert this DC electricity into Alternating Current (AC) electricity. AC systems require an inverter, which changes the DC electricity produced by PV modules and stored in batteries into AC electricity. Different types of inverters produce a different "quality" of electricity. For example, lights, radios, and power tools can operate on lower-quality electricity, but computers, laser printers, and other sophisticated electronic equipment require the highest-quality electricity. So, you must match the power quality required by your loads with the power quality produced by the inverter.

Inverters for most stand-alone applications (i.e., those systems not connected to the utility grid) cost less than $1 per rated output watt. The cost is affected by several factors, including the quality of the electricity it needs to produce; the incoming DC, the number of AC watts your loads require when they are operating normally; the amount of extra surge power your AC loads need for short periods; and whether the inverter has any additional features such as meters and indicator lights. Always anticipate growth of load in inverter size selection. If building additions or adding electrical loads is likely, consider purchasing an inverter with a larger input and output rating than you currently need. This may be less costly than replacing it with a larger one later.

Sine and Modified Sine Wave Inverters

Both sine wave and modified sine wave inverters are used for off-gird systems; each of which has a good use and a proper place. Advantages and disadvantages are as follows:

- Modified sine wave units typically are more basic, and do not have some of the nicer control and monitoring features of a good sine wave unit. Trace brand sine wave units have all components built-in for direct interface to the utility (in most cases), automatic starting of generators, and automatic control of other equipment.

- Modified sine wave units are always smaller and lighter than an equally sized sine wave model.

- Motors may use more power and get hotter during operation on a modified sine wave unit than they normally do.

- Transformer based units have the capability to handle high "surge" requirements. Surges happen when a large load (refrigerator or well pump motor) starts. A high load is created for a fraction of a second. A transformer based inverter can typically surge instantaneously to about 2.5 times its normal rating. A high frequency unit typically has little or no surge capacity beyond its continuous rating nameplate.

- For equal nameplate sizes, modified sine wave units typically have higher surge capacity than sine wave units.

Batteries and Inverters

- Inverters that operate without a battery bank (Batteryless Systems) allow generation of electric power with no routine maintenance. They are also more efficient than units that require batteries, due to battery loses and charging limitations with batteries.

- All equipment in a batteryless system can be placed outside.

- Without a battery bank, no power is available when the utility grid fails. The batteryless units must have utility power to operate.

- Costs saved by eliminating the batteries allow either a reduction in overall cost, or more PV panels to be installed for the same cost.

Micro Inverter Versus Central Inverter

- Micro inverters allow sizing the inverter to exactly match the PV panels.

- Micro inverters allow purchase of a lower cost small system, since a large central inverter is not required.

- Central inverters are less expensive for larger systems.

- Central inverters are typically more efficient.

- Micro inverters are easier to install, since only AC wiring is required.

<u>Price Comparison</u>

In terms of price, the different types typically come out as follows:

- The sine wave units are more expensive than the modified sine wave units.
- The transformer based modified sine wave units are more expensive than the high frequency ones. Both types of sine wave units are similar in cost.
- Micro inverters are more expensive per watt than central inverters, but are less expensive overall for smaller systems since the inverter is not oversized.
- Batteryless systems are less expensive overall than systems with batteries.

4.3.5 *Controllers*

A charge controller regulates the flow of electricity from the PV modules to the battery and the load. The charge controller protects the battery (the electricity storage device) from overcharging and also excessive discharge. Most batteries must be protected from overcharge and excessive discharge, which can cause electrolyte loss and even damage or ruin the battery plates. Most charge controllers also have a mechanism that prevents current from flowing from the battery back into the array at night.

When the load is drawing power, the controller allows charge to flow from the modules into the battery, the load, or both. When the controller senses that the battery is fully charged, it stops the flow of charge from the modules. Many controllers will also sense when loads have taken too much electricity from batteries and will stop the flow until sufficient charge is restored to the batteries. This last feature can greatly extend the battery's lifetime.

Controllers generally cost between $20 and $400, depending on the ampere capacity at which your PV system will operate and the monitoring features you want. When selecting a controller, make sure it has the features you need; cost should be a secondary consideration.

4.3.6 *Generators*

Currently these guidelines focus on stand alone PV systems that are not integrated with other sources of power generation, such as wind, hydro or engine generators. EWB will develop guidelines for these integrated systems at a later date.

4.4 Project Model: Photovoltaic

The two principle classifications of PV systems are grid-connected (utility-tied) and stand-alone systems. These guidelines deal exclusively with stand-alone systems to provide DC and/or AC power service. .

4.4.1 *Tilted Irradiance Calculation*

The solar constant, which is defined as the average energy flux incident on a unit area perpendicular to the solar beam outside the Earth's atmosphere has been measured to be S = 1.367 kW/m^2

The solar radiation incident on a collector on the Earth's surface is affected by a number of mechanisms, as shown in Figure 5. Part of the incident energy is removed by *scattering* or absorption by air molecules, clouds and other particles in the atmosphere. The radiation that is not reflected or scattered and reaches the surface directly is called **beam radiation**. The scattered radiation which reaches the ground is called **diffuse radiation**. Some of the radiation is reflected from the ground onto the receiver; this is called **albedo radiation**. The total radiation consisting of these three components is called **global radiation**. Although it varies significantly, a solar irradiance value of 1 kW/m^2 has been accepted as the standard for the Earth's surface. The spectral distribution of this standard radiation is called Global AM 1.5 solar spectrum, where AM stands for Air Mass and AM 1.5 indicates that the direct beam path of the sun's rays travels through 1.5 times the thickness of the atmosphere in a typical situation.

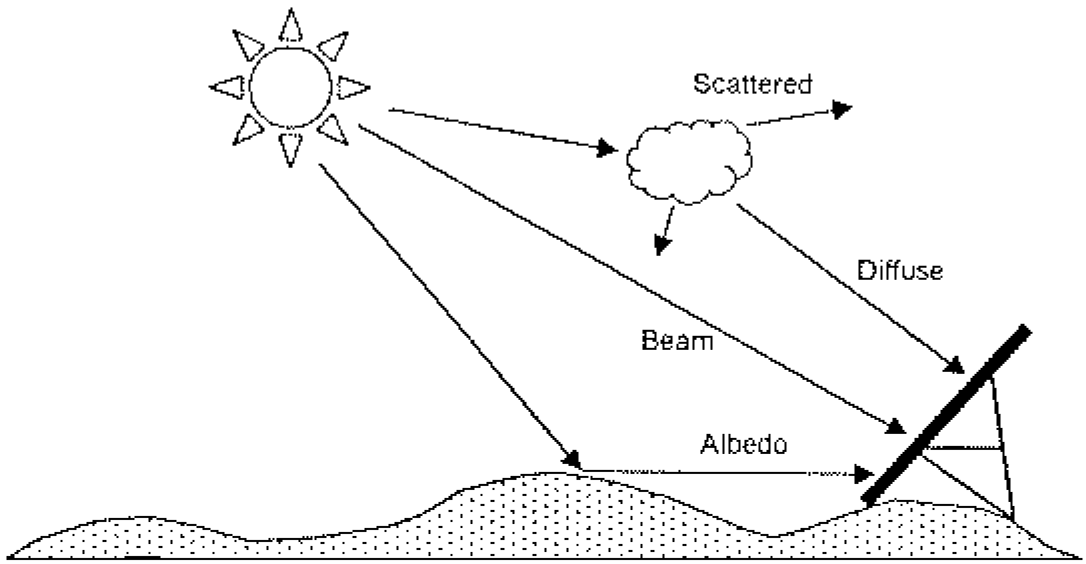

Figure4-5. Solar radiation

Calculation of the incident radiation for a particular site from theoretical methods is extremely difficult as it is highly dependent on variables such as local weather conditions, the composition of the atmosphere above the site, and the reflectivity of surrounding land. For this reason, the design of a photovoltaic system relies on the input of experimental data measured as close as possible to the site of the installation.

This data is generally given in the form of *global irradiation on a horizontal surface* for each day at a particular location, or for a representative day of every month. Since solar panels are usually tilted, a manipulation of the experimental data is necessary.

Solar irradiance integrated over a period of time is called *solar irradiation*. Of particular significance in solar panel design is the irradiation over a day. The process of determining the total irradiation incident on a tilted plane over one day consists of calculating the equivalent radiation outside of the atmosphere, comparing this with experimental data measured on a horizontal surface at the site to determine the relative components of beam and diffuse, then adjusting them for the panel angle and including the albedo radiation.

Links to determine hours of sunshine in your area.
http://www.arachnoid.com/lutusp/sunrise/index.html
http://www.ncdc.noaa.gov/oa/ncdc.html
http://eosweb.larc.nasa.gov/cgi-bin/sse/register.cgi?email=&task=login&next_url=/cgi-bin/sse/ion-p&page=globe_main.ion&app=gri
http://rredc.nrel.gov/solar/pubs/redbook/
http://www.wattsun.com/resources/calculators/photovoltaic_tilt.html

4.4.2 *PV Array Model –Off Grid Model Only*

Stand-alone PV systems may be powered by a PV array only, or may use wind, an engine-generator or utility power as an auxiliary power source in what is called a PV-hybrid system. 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 (Figure 4-6). 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. Matching the impedance of the electrical load to the maximum power output of the PV array is a critical part of designing well-performing direct-coupled system. For certain loads such as positive-displacement water pumps, a type of electronic DC-DC converter, called a maximum power point tracker (MPPT) is used between the array and load to help better utilize the available array maximum power output.

In many stand-alone PV systems, batteries are used for energy storage. Figure 4-7 shows a diagram of a typical stand-alone PV system powering DC and AC loads. Figure 4-8 shows how a typical PV hybrid system might be configured although these systems are not currently addressed in the guidelines.

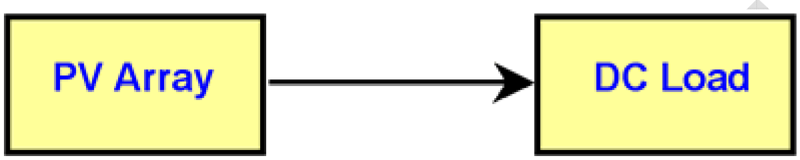

Figure4- 6. Direct-coupled PV system

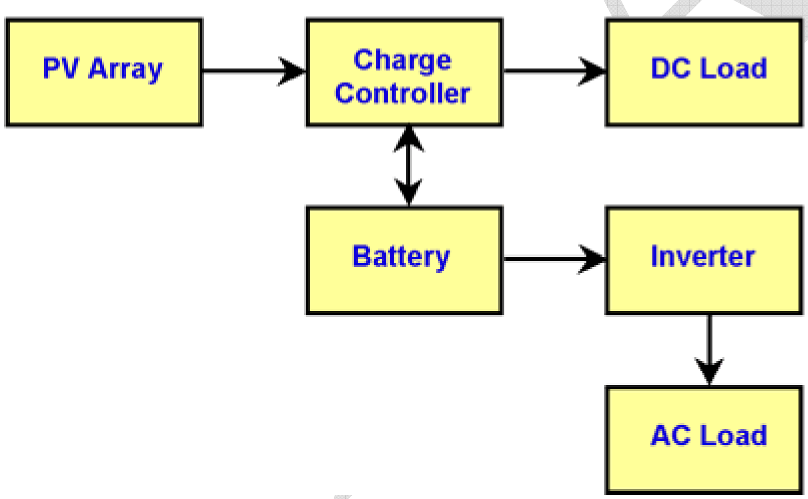

Figure4-7. Diagram of stand-alone PV system with battery storage powering DC and AC loads

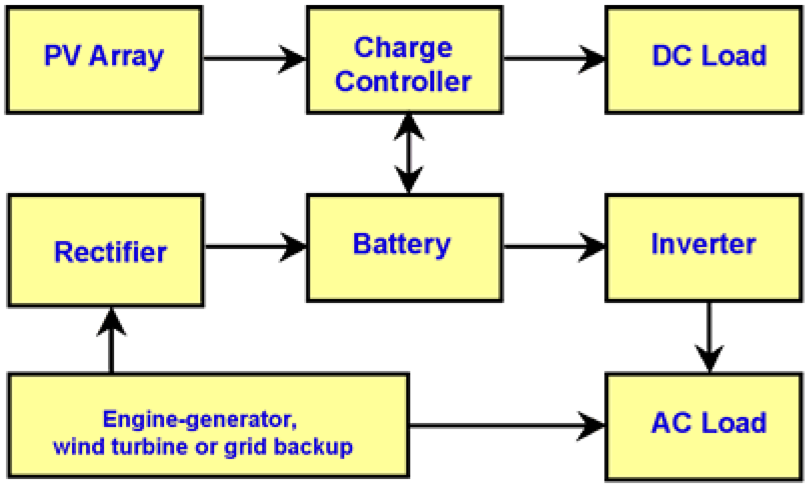

Figure4-8. Diagram of photovoltaic hybrid system

4.4.3 *Design Example*

Stand-Alone Photovoltaic Systems: A Handbook of Recommended Design Practices (Sandia National Laboratories publication SAND87-7023[1]) details the design of complete photovoltaic systems. This simplified example gives an idea of what is involved. Initial steps in the process include:

- Determining the load (energy, not power)
- Calculating the battery size, if one is needed
- Calculating the number of photovoltaic modules required
- Assessing the need for any back-up energy of flexibility for load growth

A SIMPLE EXAMPLE

The following example uses a back-of-the-envelope technique, useful to see how reasonable a particular application for photovoltaic would be or about the estimated cost for a system. It does not account for such design-specific details as the percent the system will be available. For example, a critical communication link might require 99.999% availability, whereas a streetlight might be fine at 90%. This technique will hit pretty close to the 98% mark.

[1] Sandia National Laboratories has produced numerous publications that might be useful to your project. Check out the following web site http://www.sandia.gov/pv/docs/DOC/Order%20Form.doc

The sample system is for a streetlight. The light is 30 watts and will be expected to run all night year-round. Low-wattage, high-efficiency fixtures and lamps make sense for PV systems. To see the effect of differing climates, we have designed a system for San Diego and another for Seattle.

FIRST: Design for Worst Case
For this example, the worst case is easy to determine. The load is greatest in the winter, which is the worst case for the load, and the sun shines least at this time, the worst case for the resource. In some instance, the worst case for the load is the summer and worst case for the resource is the winter, requiring you to perform two designs and then to select the one system that will carry the load through both summer and winter. We assume that the lights are needed for sixteen hours a day in winter. Therefore, the total daily energy requirement is 30 x 16=480 watt-hours a day.

SECOND: Throw in a Fudge Factor
We multiply the load by 1.5 to account for several factors that would be handled individually in a detailed design, such as all the system inefficiencies, including wiring losses, battery charging and discharging cycle, and for extra capacity for the photovoltaic system to recharge the batteries after they have been drained to keep the load going in bad weather. The load is figured to be 480 x 1.5=720 watt hours.

THIRD: Determine the Hours of Available Sunlight
Most solar resource data are given in terms of energy per surface area per day. No matter the original unit used, it can be converted into kWh/m2/day. Because of a few convenient factors, this can be read directly as "sun-hours a day." For example, in the publication A Comparison of Typical Meteorological Year Solar Radiation Information with the SOLMET Data Base (Albuquerque: Sandia National Laboratories, SAND87-2379), San Diego is shown to receive 4.6 kWh/m2/day in December on a fixed surface at latitude tilt (that is, tilted 32.73o up from horizontal). This information is available in other publications and is in the often-referenced typical meteorological year (TMY) database. What it means is that the referenced titled surface will receive the equivalent of an average of 4.6 full sun-hours in December. For the sake of comparison, we also look at Seattle, where the corresponding number is 1.2 sun-hours a day.

As an aside, capturing energy in winter can be enhanced by tilting the surface at a higher angle than latitude. A latitude tilt gives the best energy capture for the entire year, but circumstances may dictate that a different tilt be used. A few figures for San Diego illustrate this point. At latitude tilt, insolation for December, January, and February averages 4.94 sun-hours a day, the summer months average 6.35, and the annual average is 5.79 sun-hours a day. If the tilt is increased 15°, the winter energy increased to 5.29, summer drops to 5.73, and annual drops to 5.68. Similarly, if the tilt is reduced by 15°, the winter energy drops to 4.31, summer is increased to 6.67, and the annual drops to 5.62.

Two points should be remembered: changing the tilt of the array can enhance the energy collection for a certain season, with a decrease in the opposite season; and, second, although changing the tilt does affect the annual amount of energy collected, it is not as great a change as one might think. Note that a 15° tilt change only results in a 3% drop in the annual production of energy.

FOURTH: Determine the Size of the Array
The size of the array is determined by the daily energy requirement divided by the sun-hours per day. For San Diego, the size of the array is 720 divided by 4.6 or 156 watts. For Seattle, the equivalent is 720 divided by 1.2 or 600 watts. This is the minimum size of the array, and must be modified to the next higher size by the size of the modules used. If 60-watt modules are used, then you will wind up with 180 watts in San Diego. Remember, when converting calculated array to actual modules, **always round up.**

FIFTH: Determine the Size of the Battery
Most batteries will last substantially longer if they are shallow cycled, that is, discharged only by about 20% of their capacity, rather than being deep-cycled daily. Deep discharge or cycling means that a battery is discharged by as much as 80% of its capacity. A conservative design will save the deep cycling for occasional duty, and the daily discharge should be about 20% of capacity. This implies that the capacity of the battery should be about five times the daily load. To know the daily load, go back to the original load number before the fudge factor—that is, 480 watt hours. Add to this a battery fudge factor of about 50% to account for the efficiency of the battery discharge, the fact that only 80% of the battery's capacity is available, and the loss in efficiency because photovoltaic systems rarely operate at the battery design temperature.
The end result is that the battery design load is 480 times 1.5 or 720, which is coincidentally the same as the array's design load, but for different reasons. This is the daily energy drawn out of the battery, which is now multiplied by five to ensure 20% daily discharge: 720 times five or 3,600 watt hours. This is the battery capacity, which is usually given in ampere-hours so it must be divided by the voltage of the system; 3,600 divided by 12 or 300 ampere hours. Notice that the discussion of the battery's size is independent of the size of the array or the solar resource. In other words, the same battery size works both for San Diego and Seattle because both loads are the same and both arrays are sized to produce the same daily energy.

4.4.4 *Summary of Recommended Design Practices*

The following recommendations come from experienced PV system designers and installers. The best are based on common sense.

Keep it simple. Complexity lowers reliability and increases the need for technical support and maintenance. For example, the costs and maintenance requirements for tracking collectors are usually not justified. Battery systems are more complicated and require higher maintenance (many batteries only last 5 years before their capacity is significantly diminished).

Understand system availability. Achieving 99+ percent availability with any energy system is expensive. In many cases it is better to meet only part of the load with solar electric and rely on the local utility, battery or generator backup for the rest. Size your system to give the optimal economic benefits, not to completely eliminate the utility bill or to completely cover a roof with solar electric modules.

Be thorough but realistic when estimating the load. Many system disappointments have been the result of underestimated loads. Watch out for "phantom" loads. Consider the inevitable efficiency losses in inverters, wires, collector soiling and battery charging. Because of these losses, even well-designed and installed systems operate at about 70% of their rated capacity, even under peak conditions.

Check local weather sources and seasonal shading conditions. Errors in solar resources estimation can cause disappointing system performance. Microclimates can have a big impact on actual solar insulation. For example, morning fog in many San Francisco-area locations means that systems should be designed to optimize afternoon energy collection.

Know what solar electric hardware is available and at what cost. Tradeoffs are inevitable, and alternatives can frequently save a lot of money. The more you know about hardware, the better you can make decisions. Shop for bargains, talk to dealers, and ask questions.
Unless your available PV module area is severely constrained, it is usually best to install solar electric modules that have the lowest cost per watt -- instead of the highest output per square foot.

Know the installation site before designing the system. A site visit is absolutely required to determine component placement, wire runs, shading, terrain peculiarities and special requirements. Doing an accurate Solar Pathfinder analysis will reveal daily and seasonal shading problems, and will more accurately predict your annual solar energy output.

Install the system carefully. Make each connection as if it has to last 30 years—it does, and make sure all subsystems are similarly designed. Solar electric modules with a 20-year guarantee mounted on a wooden frame won't last 20 years. Putting new solar electric modules on an old roof simply means that the entire solar electric array will have to be removed when it is time to replace the roof. System reliability is no higher than its weakest connection.

Plan periodic maintenance. Solar electric systems have an enviable record for unattended operations; many systems have no moving parts. However, no system works forever without some care. Solar electric modules may have to be cleaned annually in dirty locations (especially if they are installed horizontally). Batteries will have to be replaced every five to 10 years.

Last but not least – perform a careful economic analysis. Calculate the Return on Investment and Net Present Value of the system (how much all of your savings will be worth in today's dollars), and compare to various alternatives. Perform an accurate site survey using the proper instruments, and make sure your analysis includes realistic assumptions about energy price increases, interest rates, system maintenance, equipment costs, installation costs, and local shading. Calculate the life-cycle cost (LCC) to compare photovoltaics to other energy alternatives. The LCC should reflect the complete cost of owning, operating, and maintaining a system.

4.5 Installation

4.5.1 *Photovoltaic*

One of the most important issues in the design of PV arrays on buildings is the structural attachment of the array mounting system to the roof structure and structural members. The PV array may encounter several types of loading on the roof top. The design of the modules and the mounting system must withstand these forces and comply with applicable building codes and standards. Primary load types include dead loads and live loads. Dead loads are static and due to weight of the arrays and support structure. Dead loads are typically minimal, no more than 5-10 lbs/ft^2. However the loads are often transferred to the roof top through the mounting devices that concentrate the array dead loads onto small surface areas of the roof or individual load bearing members.

These conditions can significantly add to the loading conditions of a single truss, joist, rafter, decking or other roof component. Live loads can be large in magnitude, but are intermittent and attributed to wind, snow, etc., and maintenance personnel. Most PV modules are rated for static loading of 50-55 lbs/ft^2, or equivalent to the pressure of constant 110-120 mph winds acting normal to the module surface. The location of roof brackets or mounts may depend on the dimensions of the panels or sub-arrays and may not coincide with the locations of structural members. In these cases direct attachment to the roof decking is often used, but the strength and reliability of this approach is questionable. It is strongly recommended to attach mounts to the roof truss, rafter, purlin or joist rather that to the roof deck alone when high wind induced loads are anticipated.

The possible need for reproofing within the lifetime of PV arrays presents another variable to consider with the design of array mounting systems. For example common fiberglass shingles have expected lifetimes of less than twenty years, while the economics associated with a PV system are generally computed over a period in excess of twenty years. The costs associated with the removal and reinstallation of the array at least once during the life of the system is rarely considered in any payback calculations.

Weather sealing of array mounting attachments and roofing penetrations is a critical issue fro PV array installations on buildings. In addition to obvious problems associated with leaking roof penetrations, water entering through or around a roof penetration can weaken the roof substrate and compromise the structural integrity of the array attachment. The physical damage to the roof can occur long before the leak is visible or before cosmetic damage occurs.

Although accepted roofing industry practices are used in weather sealing many rooftop PV installations, many more use methods that may function initially but are likely to degrade over time.

4.5.2 *Battery Connections*

The connections from battery to battery and on to the charging and load circuits are critical. Before connecting your batteries together, be sure that the interconnects and battery terminals are clean. When making your series and parallel battery connections, be careful not to torque the connecting hardware too tight as the battery's lead posts can break easily. After all battery connections are made, go back to each battery terminal and apply anti-corrosion coating or grease to minimize corrosion build up. Torquing all bolts equally avoids variations in resistance. This variation in resistance is the main reason we prefer to minimize the number of parallel strings in the bank. Higher resistance values on one string of batteries result in less charge to that string and consequently shorter life. We also place the main negative and positive on opposing corners of the battery bank. The goal is to keep the variation of resistance from one parallel string to another to a minimum.

4.5.3 *Controllers*

Electronic controllers, converters, or inverters are often installed in the control center along with switches, fuses, and other BOS. Electronic components must be able to withstand expected temperature extremes in both operating and non-operating states. Any printed circuit boards in these units should be coated or sealed to protect the electronics from humidity and dust. Certified electrical service boxes should be used. Consult any electrical supply company to get advice about the type of box needed for a specific application.

High temperatures will shorten the life of electronic equipment. Try to mount the boxes in a shaded area and/or provide air circulation, particularly for inverters. Dust can be a problem in a well-vented enclosure. Some boxes have filters at the air access points. Filters require regular cleaning. Screen the inlets of the electrical boxes to prevent spiders, wasps, and other insects from setting up residence. Finding wasps in the electrical box may not affect performance, but it will certainly make maintenance more exciting.

4.5.4 *Wiring*

Check exposed array wiring for rating and sunlight resistant insulation.
Check from the ground to see that all wiring is neat and well supported to stay in place.
Check that strain relief/cable clamps are properly installed on all cables and cords by pulling on cables to verify [NEC 300-4, 400-10]. Make sure that all grounded conductors are white and equipment grounding conductors are green or bare [NEC 200-6(a), Ex 5].

Perform insulation test on system wiring. Use a test voltage of 500 V for all wiring 600 V and below. Check that all field wiring are tagged at both ends with permanent wire markers.

4.6 Operational Safety

4.6.1 *PV System*

All installers must be able to identify electrical and non-electrical hazards associated with PV installations, and implement preventative and remedial measures to ensure personnel safety.
Keep the following in mind:

- Identify and implement appropriate codes and standards concerning installation, operation and maintenance of PV systems and equipment
- Identify and implement appropriate codes and standards concerning worker and public safety
- Identify personal safety hazards associated with PV installations, and implement preventative and remedial measures
- Identify environmental hazards associated with PV installations, and implement preventative and remedial measures

4.6.2 *Batteries*

Most types of batteries contain toxic materials that may pose serious health and safety problems. The National Electric Code (NEC), battery companies, and PV system designers recommend that lead-acid and wet cell batteries, which give off explosive hydrogen gas when recharging, be located in a well-ventilated space isolated from the other electrical components of the system and away from living spaces.

When a battery is charging, hydrogen and oxygen are being liberated. These gases will burn—explosively! Keep matches, cigarettes, fire and sparks of all kinds away from a charging battery.
Allow enough space for easy access during maintenance, repair, and replacement.

Always wear protective goggles and gloves—and old clothes—when maintaining your batteries as the sulfuric acid can seriously damage your eyes and eat holes in your clothes. When maintaining your batteries, it's not a bad idea to cover all the batteries with canvas or an old blanket, save for the battery you're servicing.

Always exercise extreme caution around batteries. Keep children, pets, and people who lack common sense away from them.

4.6.3 *Grounding*

A good ground will provide a well-defined, low-resistance path from the stand-alone PV system to earth ground. This path is expected to carry fault current if system malfunctions occur so the ground wire must be as large as the largest conductor in the system. Two types of grounding are needed in PV systems--system ground and equipment ground. For the system ground, one of the current carrying conductors, usually the negative, is grounded **at a single point**. This establishes the maximum voltage with respect to ground and also serves to discharge surge currents induced by lightning. Any exposed metal that might be touched by personnel should be grounded. This includes equipment boxes and array frames. This will limit the risk of electrical shock should a ground fault occur.

A low-resistance earth ground requires good contact between the ground rod and earth. Subterranean water lowers the resistively of the contact. If the system is in an area with rocky soil, a good ground may be difficult to achieve. Consult a local electrician for suggestions.

A PV array can attract lightning, especially if located at a high elevation relative to the surrounding terrain. In particular, water pumping systems may draw lightning because of the excellent ground path provided by the well casing. Current surges can be caused by a direct lightning hit or by electromagnetic coupling of energy into the PV system's conductors. There is little that can be done to protect the PV system equipment from a direct lightning strike. Surges caused by near strikes occur more frequently and the severity of possible damage depends on the distance from the strike to the array. Commercially available surge protection devices (movistors and silicon oxide varistors (MOVs and SOVs) are reasonably priced and their use is recommended. They are normally installed in the array output and at the dc input to any electronic device. If an inverter is used, surge protection devices should be installed at the AC output as well as the DC input. Installing the wiring in grounded, buried metallic conduit will decrease susceptibility to lightning.

4.7 Validation, Operation & Maintenance

The performance of PV modules and arrays are generally rated according to their maximum DC power output (watts) under Standard Test Conditions (STC). Standard Test Conditions are defined by a module (cell) operating temperature of 25° C (77 F), and incident solar irradiance level of 1000 W/m2 and under Air Mass 1.5 spectral distribution. Since these conditions are not always typical of how PV modules and arrays operate in the field, actual performance is usually 85 to 90 percent of the STC rating.

A very useful reference for validation testing of your installed system can be found at: http://cetc-varennes.nrcan.gc.ca/fichier.php/codectec/Fr/1998-15-51/1998-15-51e.pdf

Today's photovoltaic modules are extremely safe and reliable products, with minimal failure rates and projected service lifetimes of 20 to 30 years. Most major manufacturers offer warranties of twenty or more years for maintaining a high percentage of initial rated power output. When selecting PV modules, look for the product listing (UL), qualification testing and warranty information in the module manufacturer's specifications. Your system might not require all this but the list contains basics information that you need to have the answers to install, maintain, and operate a viable system.

Appendix II list most of the Codes and Standards for Photovoltaic Systems and Equipment.

The majority of problems in stand-alone PV systems tend to fall into three areas: 1) poor design or selection of inferior or inappropriate components by the system designer; 2) poor installation or inexperienced system installers; and, 3) improper use, or lack of maintenance, of the PV system by the user.

4.7.1 *Battery Care*

Batteries are the "heart" of stand-alone PV systems. While the rest of the system will require little maintenance, batteries require regular monitoring and maintenance. (See Appendix V for more information on Batteries and their maintenance).

CHAPTER 5

WIND ENERGY

5.1 Principles: Wind Turbines

5.1.1 *Basic Knowledge for Aerodynamics*

Air moving relative to an object will create a force on the object called *aerodynamic force***.** Generally aerodynamic force consists of two parts:

- The speed of airflow on the surface of an object will change when the airflow is flowing around it. The pressure of airflow follows the change in speed. Since the pressure of airflow is different at every spot on an object, there is a resultant force on that object.
- Friction results from viscosity of airflow on the sides of an object from air flowing around it.

The resultant force, composing all forces on the surface, is aerodynamic force.
The blade is one of most important components of a wind turbine. Its plane shape and geometric profile shape relate well with the aerodynamic characteristics of wind turbines. The aerodynamic characteristics of an airfoil (the cross section profile of the wind generator blade) especially influence the wind energy available for wind turbines.

5.2 Site Analysis - Wind Turbine

In all work choosing an installation site, the first tasks are to determine prevailing wind direction, consider favorable terrain, and take relevant measures. By this means, we can find the most logical installation site for wind turbines and avoid blindly choosing a site that will not perform as expected

The site is key when considering wind energy. The most important factor is energy output, but economy, technology, environment, transportation, living conditions, and location must be considered. Topography causes varying wind conditions even in the same area. A principle for siting from a meteorological point of view is presented as follows:

5.2.1 *Principles in siting wind turbines*

<u>*Rich wind area*</u>

A wind survey must be conducted to determine the area where the annual wind speed is highest. The distance between the measuring points should be about 100 km. A macro selection could be worked out according to a wind atlas.

A more detailed survey should be conducted in promising areas based on the wind atlas. The distance between the measuring points should be about 10 km. According to the measurements in such a scale, the area with good wind regime could be marked.
To fix the sit for wind turbine installation, especially in a complex topography, a very detailed measurement and evaluation must be undertaken. The distance between the measuring points shall be about 100 m. Then the exact location for installation can be decided.

<u>*Stable main wind direction*</u>

In addition to a high wind speed, a stable wind direction is very important to harness wind energy. In accordance with the meteorological measurement the wind direction is described in 16 positions. The frequency of wind direction is recorded by meteorological stations, then a wind rose is worked out.

The main wind direction means the most frequent wind direction. It is better to add wind speed distribution curve over the wind rose, it becomes a three-dimensional curve to clearly display the wind pattern, showing the prevailing wind direction. The three-dimensional curve would be helpful to the siting.

<u>*Small daily and seasonally fluctuation*</u>

Stability of wind speed shall be considered, especially when energy storage and standby power are needed. In such a case the smaller the daily and seasonally fluctuation is the better the site.
Stability of wind speed shall be considered, especially when energy storage and standby power are needed. In such a case the smaller the daily and seasonally fluctuation is the better the site.

Small turbulence

Wind turbulence may seriously damage wind turbines and reduce their output. It causes the rotor to vibrate, which shortens its life. The installation should avoid rough ground and close obstacles. For small turbines if possible the hub height should be 6–7 m higher than obstacles and the distance to the obstacle 5-10 times the height of the obstacle.

Avoid areas with disastrous weather

Disastrous weather includes strong storms (typhoons, hailstorms, and cyclones), thunder and lightning, ice storm, sandstorm, heavy snow, and salty fog. If a wind turbine is installed in such a region, it must be protected.

5.3 Equipment, Wind Turbines

5.3.1 *Main Types and Structures of Wind Turbines*

A wind turbine generator system (WTGS) includes a wind turbine, which transforms wind energy into mechanical energy, and a generator, which transforms the mechanical energy into electrical energy. There are many designs for wind turbines. The main component that transforms the wind energy into mechanical energy is the rotor, so wind turbines are classified by the structure of the rotor and its location in airflow. The two main types of wind turbine are horizontal axis and vertical axis.

Horizontal Axis Wind Turbine

The rotor of a horizontal axis wind turbine revolves around a horizontal axis. The revolving plane is perpendicular to the wind direction when the wind turbine is working (see Figure 5-3). The blades of the wind rotor

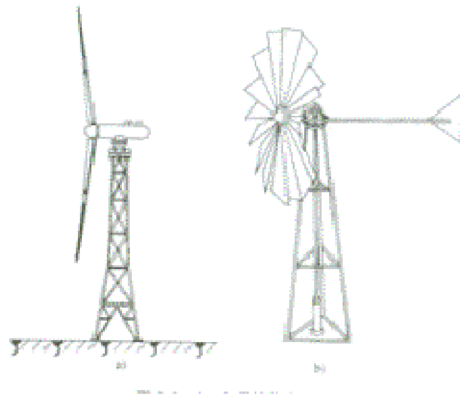

Figure 5-3 Horizontal axis wind turbine.
a) High-speed wind turbine   b) Low-speed wind turbine

The horizontal axis wind turbine can be separated into upwind and downwind designs according to whether the rotor is upwind or downwind of the tower. The upwind turbine must have an orientation mechanism to keep the rotor facing the wind. The downwind turbine faces the wind direction automatically, so it does not need an orientation mechanism. However, for a downwind turbine the tower interferes with the airflow passing by the blades because the airflow passes the tower before the rotor. This is called influence by the tower shadow, and will reduce the performance of a downwind turbine compared to an upwind turbine.

are arranged radially in a plane perpendicular to the revolving axis. There is a φ angle (installation angle) between the blades and the revolving plane of the wind rotor. The number of blades determines the function of the wind turbine. In general, a wind turbine for generating electrical power has 1–4 blades (most have 2–3 blades), and a wind turbine for water pumping has 12–24 blades. A multi-bladed wind turbine is called a low-speed WECS (wind energy conversion system). It develops a high rotor power coefficient at low speed and high torque. Its starting torque is large, and starting wind speed is low, so it usually used for water pumping. A wind turbine with a few blades is called a high-speed WECS. It develops a high rotor power coefficient at high speed, but has a high starting wind speed and low starting torque. Because it has few blades and need not withstand high torques, it is lighter than a low-speed rotor at same power output, so it is generally used for power generation.

Vertical Axis Wind Turbine

The rotor of a vertical axis wind turbine revolves about a vertical axis (see Figure 5-4). Its main characteristic is that it can receive any direction of wind so it doesn't need an orientation mechanism. For this reason, the structural design is simpler. Another benefit of this is that the gearbox and generator can be installed on the ground. This can greatly simplify maintenance work compared to the horizontal axis wind turbine high off the ground.

The vertical axis wind turbine has two main types:

The S type rotor operates on aerodynamic drag and is made of two semi-columniform blades with a staggered axis. Its strong point is its large starting torque, but it develops a strong side thrust that requires a strong structure and bearings, so it is generally not used for a large-scale WECS, which is restricted by yawing and safe limit stress. The rotor power coefficient of S type WECS is lower than that of a high-speed vertical axis WECS or horizontal axis WECS and its output power is very low with the same rotor size, weight, and cost, so it cannot generate power competitively. The Darrieus type WECS is the other major type of vertical axis wind turbine. It operates on aerodynamic lift, using airfoil blades. It was snubbed until the petroleum crisis

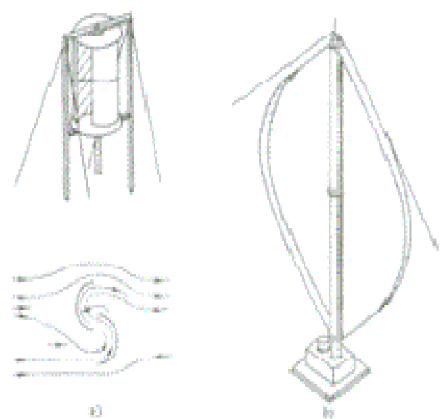

Figure 5-4 Vertical axis wind turbine.
a) S type wind rotor   b) Darrieus type wind turbine

of the 1970s, then the National Research Council of Canada and Sandia National Laboratories began researching this turbine. Now it is the horizontal axis WECS's chief competitor.

In summary, two kinds of WECS generate electrical power: high-speed horizontal axis WECS and Darrieus type vertical axis WECS. Most turbines installed are the high-speed horizontal axis WECS. Some new conceptual wind energy conversion mechanisms are being proposed, but they are still not mature designs.

5.3.2 *Components and Structure of a Wind Turbine*

There are several designs of wind turbines, but their working principles and structures are all similar. A horizontal axis wind turbine, for example, has a rotor, gearbox, generator, chassis, tower, regulating mechanism, orientation mechanism, and braking mechanism.

Wind rotor

The most obvious part of a wind turbine is the rotor. The rotor is made up of 2–3 blades connected to a hub. Its function is to transform wind energy into mechanical energy.

The blades of a small-scale wind turbine are made of high-quality wood laminated together, then painted with protective lacquer. The blades are connected to the metal hubs by screws or bolts. Some blades are made of fiberglass or compound materials for better performance. The blades of a large-scale wind turbine are made of several lengthwise battens. The back of the airfoil is primed with light foam then wrapped with fiberglass to become an integrated structure.

For cheaper construction some small-scale wind turbine blades are made of a thick fiberglass airfoil or of metal. A layer of sheet iron or aluminum is added to an iron or aluminum pipe and it is assembled with round-head rivets. Future small-scale wind turbine blades will probably change from wood to fiberglass or high-strength compound materials as are already used for large- and medium-scale wind turbines.

The hub connects the base of the blades to the main axis of the rotor. All power from blades is transferred to the drive system through the hub, then transferred to the gearbox or generator. The hub can also contain a mechanism for controlling blade pitch. For variable pitch blade designs making sure the hub is strong enough is more complicated. For turbines, which use a stall regulated speed control, fixed pitch blades can be used (the blades are solidly fixed into the hub) and the structural design is simplified, reducing cost and increasing life expectancy.

Regulating Mechanism or Speed Limiting Mechanism

In many cases, the wind rotor requires a regulating mechanism or speed limiting mechanism to maintain a fixed turning speed or prevent over speeding (turning too fast in strong winds). When the wind speed is very high, such a mechanism will limit power and reduce the power to blades. A regulating mechanism or speed limiting mechanism operates by turning the wind rotor out of the wind, using aerodynamic resistance, or adjusting the blade pitch angle.

(1) Protection for out of wind side and over speed control:

To simplify the structure, the blades of a small-scale wind turbine are fixed at the hub. To avoid destroying the blades by over-speeding, the rotor tilts so the wind is parallel instead of perpendicular to the plane of the rotor when the wind speed becomes too high.
The key of this mechanism is to install the turbine chassis with an offset between the rotor axis and the yaw axis. The tail of the turbine is installed with a hinge that can allow the tail to fold perpendicular to the plane of the rotor. When operating under low wind speeds, a spring keeps the tail of the turbine parallel to the rotor axis and the tail keeps the rotor plane pointed perpendicular to the wind direction. When the wind speed becomes too high, the thrust on the rotor becomes greater than the strength of the spring, and the turbine folds to the side, relative to the tail. The tail remains pointed parallel to the wind direction, keeping the plane of the rotor parallel to the wind direction. The rotor can either fold to the side (horizontal yawing) or up (vertical yawing).

(2) Braking with aerodynamic resistance:

Aerodynamic resistance can also be used as a braking mechanism. A flap on the blade (called a blade tip brake) is linked to the blade's leading edge by a spring. Under low wind speeds the spring is strong enough to keep the blade tip brake against the blade where it does not affect air flow. If the rotor speed is high enough, the centrifugal force will overcome the spring's force, and the blade tip brake will open, reducing the rotor speed by increasing the air resistance of the rotor. When the wind speed and rotor speed decrease, the spring will return the blade tip brake to the closed position.

(3) Regulating Mechanism by Adjusting the Pitch of Blade (RMAPB):

RMAPB is widely used to control the speed of the rotors and reduce the pressure on rotors and on the components of the driving chain. Also, it helps wind turbines with adjustable pitch to run well in high winds while generating power. For small- and medium-sized wind turbines, a centrifugal force regulating mechanism, which controls centrifugal force on blades or loads fixed on the wind rotors, is commonly used. When turning speed of rotors increases, centrifugal force on the blades follows the increase and the spring is compressed to change pitch angle. This causes the wind force on blades to decrease and rotational speed to decrease. It reaches a balance position when the centrifugal force equals the strain of the spring. Many devices are based on this principle.

5.3.3 *Device of following the wind*

Downwind turbine rotors can aim at the wind direction automatically so they do not require a control to follow the wind direction (to reduce structure flutter, an orientation mechanism is generally used in large downwind turbines).

Upwind turbines need devices to follow changing wind direction. Several devices are in common use:

(1) Tail Vane

A tail vane is used mostly in a small wind turbine. Its benefit is that it can aim the tubine to the wind direction automatically without special controls. For satisfactory effect, it must have a certain relation between tail vane area (A') and rotor swept area (A). Because their structures are heavy, tail vanes are seldom used in medium and large wind turbines.

(2) Side Rotor

This design uses a small rotor on the side of the nacelle. Its turning axis is perpendicular with the axis of master rotor. If the master rotor does not aim at the wind direction, the side rotor will be blown to produce departure force, which will aim the master rotor at the wind direction by adjusting the worm mechanism.

(3) Wind Direction Tracing System Driven by Electric Motor (WDTSDEM)

A WDTSDEM is generally used in a large-sized wind turbine. The whole yawing moment system consists of electric motor, regulating mechanism, yawing adjusting system, rolling cable protection devices, etc. A sensor or small wind vane determines the wind direction and uses an electric drive motor to adjust the orientation of the rotor to match.

5.3.4 *Transmission Mechanism*

A transmission mechanism commonly consists of low-speed shafts, high-speed shafts, gear boxes, shaft couplings, brakes, etc. Not all wind turbines include all components. Some hubs for wind turbines are connected with gear boxes directly without low-speed shafts. Some others (especially small turbines) have no gear boxes and are connected with electric generators directly.

5.3.5 *Tower*

A tower supports the weight of the turbine and withstands wind pressure on itself and the turbine. It also supports varying loads when the turbine is running. Their rigidity relates to the flutter of wind turbines. Although tower stiffness has little effect on small sized wind turbines, its effect on large sized wind turbines can be important.

There are two types of towers for horizontal axis wind turbines: tubular and lattice. Tubular towers may be simple wood poles or large-scale steel or concrete poles. Small towers can be strengthened by guy wires to increase their stiffness. Generally the drag of a tubular tower is low. Turbulent flow produced by tubular towers is lower than that produced by lattice towers, which is beneficial for downwind turbines. Lattice towers are generally applied to medium and small turbines. The benefits of lattice towers are low price and easy transportation.

5.3.6 *Generator*

A generator converts mechanical energy into electrical energy for a wind turbine generator system (WTGS). Induction generators, also called asynchronous generators, are generally used in medium- and large-sized WTGSs. Synchronous generators are used in grid-connected WTGSs. AC permanent magnet generators and brushless generators are mostly applied to small power stand-alone WTGS. The reliability and efficiency of generators strongly influence the overall performance of WTGSs.

5.4 Project Model: Wind Energy

A wind turbine generator system (WTGS) consists of three units: wind turbine, power generator, and controller. The wind turbine converts wind energy to mechanical energy, the power generator and controller convert mechanical energy into electricity. The specification and efficiency of energy transformation are related to the power generator and controller, and the operation method and structure of energy transformation are related to them. The wind turbine, power generator, and controller should have high efficiency, good specification, and be able to adapt to transform wind energy.

5.4.1 *Rough estimate of wind power*

The most common and reliable method of estimating potential wind power is to use local wind speed data. Thus, it is necessary to know which weather element is needed in wind power calculation, and how to choose factors most economically. The following definitions are very useful.

Wind power formula

The kinetic energy of atmospheric movement is translated into other kinds of energy to use wind energy. To calculate wind energy is to calculate the kinetic energy of airstreams.

Wind power (W) is defined as wind energy flowing through an area in a unit time span:

$$W = 1/2\, \rho \upsilon^3 F \qquad (5.1)$$

In the formula: W = unit is $kg{\cdot}m^2s^{-3}$
ρ= density of air
υ= wind speed
F = the area wind is flowing through

Formula (5.1) is the most common wind power formula in wind power engineering. Wind energy is at a direct ratio to area, air density, and cube of wind speed. Thus, the most important factor in wind power calculation is wind speed. Whether the wind speed is exact is crucial to the evaluation of wind power.

Average wind power density and valid wind power density

To evaluate wind power or potential wind power, wind power density is the most convenient and valuable quantity. Wind power density is the wind energy through a unit area vertically in a unit time span. Wind power density formula could be gained by dividing formula (5.1) with area F:

$$\omega = 1/2\, \rho \upsilon^3 \quad (W/m^2) \qquad (5.2)$$

Due to its randomness, wind speed must be observed in long run for average value:

$$\overline{\omega} = 1/T\int_0 1/2\,\rho\upsilon^3\,d\,t \qquad (5.3)$$

In the equation, $\overline{\omega}$ is wind power density of the time span

For ideal efficiency, the wind turbine should be designed based on wind speed, called *design wind speed*. The least wind speed in which wind turbine could begin to work is called *startup wind speed*. When wind speed reaches a value, regulating the mechanism would fix the speed of the rotor and stabilize the output of the wind turbine. This wind speed is called *rated wind speed*. When wind speed increases to a high value, the wind turbine is vulnerable to damage and must be shut down. This wind speed is called *shutdown wind speed*. Startup wind speed and shutdown wind speed must be calculated when the potential wind power is evaluated with wind speed. Wind speed between startup wind speed and shutdown wind speed is commonly called *effective wind speed*. Wind power in this range is called *effective wind power*.

Theoretically, the only data needed to determine the wind power density of a location are wind speed and air density.

Calculate potential wind power with weather data

Many people evaluate the wind power resource of a location with average wind speed. Although convenient, this method is greatly limited. Wind power calculated could have a great difference when the average wind speed is the same but wind speed distribution is different. Thus, it could be a reference only when evaluating wind power resource when average yearly and average monthly wind speed data are available.

Weather data are necessary to calculate potential wind power of a community.
Wind power density of a year, a season or a month and utility hours of a year could be estimated in two ways.

- Calculate wind power directly from observed data.
- Calculate potential wind power indirectly through average and estimated statistical distribution of wind speed.

Both methods have advantages and disadvantages. The first calculates wind power more accurately and results in greater reliability. But data must be calculated from many observation stations if the region is large. The task is time consuming and requires many years of data collection. With the latter method, the problem of calculating wind power is based on estimating of several statistical parameters. When parameters are decided, the wind power character is decided. Reducing the problem to that of calculating parameters brings great convenience to designs and layouts in wind power use. But because wind is random, there is no ideal model that depicts the statistical character of wind.. Thus the calculation always has some error to the value. In most circumstances, this error is small enough to be allowable.

Because wind speed varies from year to year, data from a short period cannot reflect the complete characterization of the wind power resource. Only observation data of an enough long periods could reflect well. Commonly, 7–10 years of observation data are needed for adequate accuracy. Because hourly wind speed data are needed, obtaining these data can be labor intensive.

5.4.2 *Stand-alone wind turbine generator system (WTGS)*

There are several types of Wind Turbine Generator Systems (WTGS)s, two of which are: grid connected and stand-alone. These guidelines will concentrate on stand-alone WTGS. The stand-alone horizontal axis type WTGS (small type) is commonly used in rural village systems. Electricity provided by a stand-alone WTGS is not stable because natural wind is random. Certain measures are necessary to meet the system balance in accordance with load demand.

5.4.3 *Stand-alone operation with battery bank*

This operation model has a simple structure, consists of a wind turbine, gear case, AC generator, rectifier, battery bank, and inverter. The variable frequency AC from the wind turbine generator is rectified and flows to the DC load and provides additional energy to the battery bank. The current is transformed from DC to AC through the inverter to meet load demand. The wind turbine generator is operating with variable speed under rated wind speed, with limited speed above rated wind speed. (See chapter 4 for more information on batteries).

5.4.4 *Stand-alone operation with load adjustment*

The load adjustment method can provide a solution for the stand-alone operation of a 20-kW (or higher) WTGS. The key problem of stand-alone operation is power matching between output from the wind turbine and input to the load. To obtain as much wind energy as possible and run the wind turbine safely, a different load is necessary under a different wind speed. The wind turbine drives the synchronous generator, and output voltage can be controlled by exciting the generator. The voltage value is maintained at a constant when the rotation speed of the wind turbine reaches minimum. The output frequency of the synchronous generator can show the rotation speed of wind turbines, and the direction of the load switch.

Figure 5-5 Windmill installed at Nakor, Kenya.
EWB-Valparaiso University

5.4.5 *Direct mechanical wind mills*

Wind powered water pumping systems fall under three categories. Direct mechanical coupling, wind-electric, and wind-compressed air. Each has different properties. The most common type in the past has been direct mechanical, however this has been replaced with wind-electric now.

Direct mechanical connection to jack pump, or helical rotor pump. This would also include rope pumps driven by windmills. In Africa many of these pumps, using helical rotor pumps, were installed in the 80's. In America, the jack pump was the more used option. These performed poorly in low winds compared to helical rotor pumps, due to the cyclic load imposed by the pump jack, unless a flywheel or counterbalance is used to smooth the load. (See Appendix VI for more information on pumps).

5.5 Installation: Wind Turbines

There are three types of tower installations; use of a crane, tilt-up gin-pole, and a tower-mounted gin-pole. Different techniques will be used for these systems and care should be taken in making this selection. The following text describes the installation using the tilt-up approach as it is the most important. Crane installation of the tower is quite straightforward, using a tower mounted gin-pole is quite difficult and should not be attempted without specific training. This said, tilt-up tower installation should only be attempted with some level of training.

NEVER INSTALL A WIND TURBINE WITHOUT PROPER TRAINING OR INSTRUCTION. The forces involved in raising and lowering even small wind turbines are very large. Inadequate attention to proper rigging and procedures has led to destruction of the equipment, serious injury, and death.

Always follow the manufacturer's recommended procedures for installing and lowering their specific wind turbine. In general, all wind turbine tower installations should be performed by experienced work crews. It is very important from the viewpoint of safety and the wind turbine warranty that the installation is carried out without mistakes and in strict compliance with manufacturer specifications. Generally refer to the installation manual provided with the wind turbine for specific safety warnings and instruction.

Figure 5-6 Windmill tower installed at Loupwana Kalayso, Kenya. EWB-Valparaiso University

windmill that was installed at Loupwana Kalayso

5.5.1 *Wind Turbine Towers*

<u>*Tower Types*</u>

There are different types of wind turbine towers, and each has its own particular requirements in terms of siting and special equipment.

In most cases wind turbines should be purchased with a specific tower or a specific tower design. Whenever wind turbine towers are not purchased from the wind turbine manufacturer or a dealer authorized by the manufacturer, the owner of the system is taking a risk. To minimize this risk a set of tower specifications should be developed and enforced. The turbine manufacturer should be involved in their preparation. A qualified engineer or a wind turbine manufacturer representative should inspect the tower before it is installed.
Some issues that should be addressed in the specifications are:

- Static and dynamic loads that occur during installation, maintenance, and normal operation
- Methods and supports for climbing the tower
- Fatigue life
- Installation method
- Accumulation of water or ice in or on structure
- Electrical resistance from top to bottom of tower
- Corrosion protection

Guyed towers are most commonly used with small wind turbines of 40 kW or less. They can either be lattice or tubular in construction. Pole towers have the advantage they are lighter in weight and can usually be made with local materials, such as heavy-duty water pipe, but cannot be climbed to service the turbines. Lattice towers are generally more costly, but allow turbine service and inspection without requiring that the turbines be taken down.

Guyed towers can be erected in one of two ways. The first is to attach successive tower sections starting at the base of the tower. This operation will require either a crane or a gin-pole. Use of a crane may be limited by poor site accessibility and cost. A gin-pole is basically a pole or boom attached to the top of the tower and used to raise tower sections above a previously installed section. Gin poles can be relatively simple with only a tower attachment device at its base and a pulley at the top. Low weight and high strength are very important attributes of the gin pole. Only experienced installers should attempt to use a gin pole. This type of installation can be performed by two people—one on the ground and one on the tower. A gin-pole may be used to add sections to a guyed lattice tower. This can only be done using lattice type towers.

5.5.2 *Tower Safety*

Not enough can be said about tower safety. Working on and around towers can be dangerous. This applies to people on the ground as well as those climbing on the tower. Familiarity with all the warnings in the wind turbine manufacturer's installation manual is essential. As a rule, all wind turbines mounted higher than about 6 meters from the ground should only be installed by experienced personnel.

5.5.3 *Foundations and Anchoring*

Foundations for the tower base and guy wire anchor rods will depend on many factors, and focus on the size of the wind turbine being considered and the classification of soil that the turbine will be placed on. As discussed previously, small wind turbines (>1 kW) can be placed on small towers with simple or no foundations; slightly larger turbines (>40 kW) require more substantial foundations but are likely supported by guy wires. Even larger turbines require large foundations and free standing towers. The foundations themselves also vary with soil type, water level, freeze depth, and weather variations. The turbine or tower manufacture should be required to provide a foundation specification that should include exact foundation requirements for the different soil conditions expected for your installation. Be sure to obtain this information from these parties.

5.5.4 *Guy Wires*

Guy wires are critical in turbine installation. Most tower failures are the result of guy wire failures. Three things are vital as they are likely the primary element keeping a wind turbine from falling over:

- Corrosion
- Proper guy wire fastening
- Proper guy wire tensioning.

<u>Corrosion:</u>

Corrosion of guy wires is a problem, especially in saline environments. Installations in these areas should have guy wires coated with anti-corrosion sealant. Guy wire hardware should likewise have an anti-corrosion layer, either in production or applied after installation. However, the sealant cannot have lubrication properties as they may cause turnbuckles to self-loosen if applied to the threads.

<u>General Fastening:</u>

Proper connection of the guy wires is critical to a safe installation. All connections should have three wire rope malleable clips (cable bolts) on each guy wire end. Proper installation should also include thimbles around the loop unless the anchor rod eye is designed with a large enough radius to disregard them. Most large installations will also use turnbuckles to allow easy adjustment of the guy wires. To install the guy wires, thread the guy wire end through the anchor rod eye using a thimble, double back and slide through the first wire rope malleable clip. The guy wires are wrapped around the anchor eye. Place the wire rope clips on the wire so that the forged, grooved part cradles the wire coming from the tower (the tension side) and the U-bolt part clamps down on the end-most section of the wire. The first malleable clip should be snug up to the thimble of the anchor eye, the remaining two should be spaced about 15 cm apart.

When lowering or raising a tilt-up guyed tower, the first cable bolt should be snug, although it may be necessary to adjust them during the tilt-up procedure. Let the other two clips remain loose until the tower has been erected and leveled.

<u>*Guy Wire Tension/Slack*</u>

A guy wire will have about 23 kg of tension when the tower is properly erected. This amount of tension is a comfortable but hearty pull on the wire for an average crew member. The uppermost guy wire will have 300–600 cm of droop with 23 kg of tension. Letting out just 15 cm of the top guy wire will add approximately 600 cm of droop to the wire and will cause the tower to move over several centimeters at the attachment point. Guy wires should be checked after about two to three weeks and readjusted if necessary.

5.6 Operational Safety

5.6.1 *General Safety*

The following recommendations should be carefully observed as part of any tower raising and lowering, and during the tower siting process. In particular, the safety of the crew members must be placed ahead of all other considerations. Some of the following warnings or cautions have been highlighted in the appropriate section of the manual.

Things that you **should do**:

1. Carefully read and understand the manual provided by the manufacturer of the wind turbine.
2. Determine the soil type at your site and install the correct anchoring.
3. Place tower anchors according to the anchor manufacturer's recommendations.
4. Properly ground the towers electrically.
5. Thoroughly understand the tower erection procedure before beginning the installation.
6. Only use a tractor or truck to erect the tower while exercising extreme caution.

Things that you **should not do:**

1. Install turbine if the wind is above 5 m/s.
2. Install turbine if there is any chance of lightning or windstorms.
3. Climb the tower until after all guy wires are in place.

4. Climb the tower without a protective work harness.
5. Erect the tower within 2 times the tower height of electric power lines.
6. Erect the tower within 2 times the tower height of buildings or roads.
7. Permit unnecessary persons on the tower site while the tower is being raised or lowered.
8. Cut corners or attempt to do the job without enough time.

5.6.2 *Cautions and Warnings*

At several points in the manual items of special interest or significant impact are highlighted by one of the following notices.
Warning: Hazards or unsafe practices that could cause personal injury or death.
Caution: Hazards or unsafe practices that could cause product damage.
Note: Significant points of interest

5.7 Validation, Operation & Maintenance

5.7.1 *Performance evaluation of an off-grid wind turbine generator*

It is important to evaluate the performance of a wind turbine generator when choosing a wind turbine energy system. We will introduce some parameters on how to choose a wind turbine generator.

<u>*Cut-in and cut-out wind speed*</u>

As the rotor speed of a generator is very low, output energy is limited. When the wind speed is up to cut-in wind speed, the wind turbine can generate electricity normally. The higher the wind speed, the greater the output power. As the speed reaches cut-out wind speed, output power is higher than the rated power limit, so the wind turbine generator stops generating. Presently, cut-out wind speed parameter in an off-grid wind turbine generator is not necessary. Only when output power exceeds the rated value, is it reduced by limited speed.
Today the speed section between cut-in and cut-out is called *operating wind speed*. In fact, operating wind speed is effective wind speed. The larger the section, the more the wind energy is used. In short, cut-in wind speed should be as low as possible, cut-out wind speed should be as high as possible,

<u>*Rated wind speed and rated output power*</u>

Rated wind speed is defined as the lowest wind speed when the output power of a wind turbine reaches its rated value. It is a key parameter of a wind turbine generator. The rated output power is defined as the power under rated wind speed.

In general, the generator with lower rated wind speed is better than one with high wind speed. The lower the rated wind speed of wind turbine is, the more efficiently the wind energy is used.

Maximum output power and survival wind speed

Maximum output power is defined as maximum power output when the rated wind speed is reached. This parameter indicates the safety coefficient of the wind turbine generator. Survival wind speed is the maximum speed that ensures wind turbine generator safety. High survival wind speed indicates that the wind turbines have good safety performance.

Rotor power coefficient and efficiency of a WTGS

The higher the rotor power coefficient, the more the wind energy is absorbed by the rotor and the better the aerodynamics performance.

Rotor power coefficient indicates only the rotor efficiency. The parameter of efficiency of WTGS shows the performance of energy transformed from wind to electricity. The efficiency of a WTGS includes mechanical, electricity, and other losses. The efficiency of a WTGS is much lower than the rotor power coefficient. Like other mechanical devices, the efficiency of a WTGS should be as high as possible.

Speed regulation and brake unit

Safety is the most important fact in evaluating the quality of a WTGS. For an off-grid WTGS, safety performance is closely related to speed regulation and brake unit.

1. Speed regulation unit

   The safe operation of an off-grid WTGS under high wind speed depends on the speed limit function of the regulation unit. Speed can be regulated through yawing, variable pitch, and aerodynamic stall. Different types of speed regulation have different technical performances.

2. Brake unit

   An off-grid WTGS must shut down immediately when the wind speed exceeds survival wind speed, or in case of emergency. This is accomplished by the brake unit. Small WTGSs have many types of brake unit: manual brake unit, dynamic brake unit and servo brake unit; atmospheric and hydraulic pressure brake unit, electromagnetic brake unit and combination brake unit. Different types of brake units have different technical performances.

Adapt to harsh environments

The climate in rural areas varies from one area to another, so adapting to different environments is important to evaluating a WTGS. Wind, salt fog, ice, heat, thunderstorms and rain increase the maintenance demand for a WTGS.

Easy to install and maintain

A wind hybrid system is usually installed in remote areas. The living and transportation are very inconvenient. It is very important to simplify installation and maintenance.

Figure 5-7
Training on Windmill pumping
Nakor, Kenya.
EWB-Valparaiso University

5.7.2 *Principles requirements for Operation & Maintenance*

A wind turbine generator system runs under extreme conditions such as sun, rain, windblown sand, lightning, hail storms, frost, and heat. Regular maintenance is very important. The principles and fundamental requirements are listed below:

1. Maintenance manuals and training must be provided to the community on the basic principles of operation and maintenance of the Wind Turbine System.
2. The maintenance and troubleshooting of a wind turbine generator system must be performed by a specially trained person who is familiar with the manufacturer's specifications. This person must be familiar with the fundamental theories, capabilities, and peculiarities of the system and must understand its maintenance and troubleshooting techniques. Also, the person must have safety education and training.
3. The rules of maintenance, checking, and troubleshooting established by the designer, installer, and manufacturer must be followed. A violation may shorten the system's lifetime, increase operating costs, or lead to damage or injury.
4. The steps in the user's handbook should be followed in order. Any abnormal phenomenon should be noted and reported to the designer, installer, or facility provider if the problem cannot be solved.
5. An integrated handbook and maintenance data, maintenance equipment, and other necessary components and materials must be kept at the wind power station.

5.7.3 *Maintenance and troubleshooting of wind turbine generator system*

Rules

1. To prevent breakdowns, regular maintenance and troubleshooting must be conducted according to the standards in the handbook.
2. A plan that includes tasks, staff, schedule, tools, meters, components, materials, expenditures, etc. should be established.
3. A quality assurance check should be performed after each maintenance project is completed.
4. Maintenance and troubleshooting should be performed when wind speeds are less than 7m/s.
5. The handbook or technical standard provides the interval between maintenance and troubleshooting activities.
6. Security measures should be taken before any maintenance or troubleshooting is performed.
7. All maintenance and troubleshooting information, including system status, components and accessories, flaws, and possible hidden problems must be carefully documented.

5.7.4 *Regular patrol and examination*

Most functions of the wind turbine generator system–startup, parking, and operation—are automatic and need no manual intervention. Systems should stop when the wind speed is too high (some kinds of wind turbines do not need to be stopped). Some kinds of wind turbines automatically park when the wind speed is too high. Others need to be furled out of the wind manually, or have a brake applied manually.

The main responsibility of the maintenance person is to monitor the operation of the wind power system and take charge of routine maintenance and troubleshooting. The intervals between patrols and examinations are determined by the handbook or the technical standard. During patrols and examinations, the maintenance person should:

1. Observe the system operating status and ensure the turbine is running smoothly and that there are no abnormal sounds when the system is started up, is operating, or is parked.
2. Ensure the turbine is securely fastened to the ground, especially if the earth has been damaged or loosened by weather or heavy equipment.
3. Ensure the yawing, speed control, and brake systems are in good working order in different wind speeds.
4. Check for leaks in the hydraulic system and ensure the operating components and axle are well lubricated.
5. Ensure the turbine is in good working order in different wind speeds and intervals. Analyze and compare output power and generation, and determine the reasons for any abnormality.
6. Check for scorching or unusual odors with the electrical components and parts in the control box while the turbine is operating, especially under windy conditions. Ensure the temperature of the controller and circuit breaker is normal.
7. Ensure the connections in the control box are tightened.
8. Ensure the electrical meters displays on the control box are normal.
9. Check outdoor cables and trolley wires to ensure there are no short or open circuits.
10. Document all problems carefully.

5.7.5 *Regular maintenance*

General demand

Regular maintenance and troubleshooting of a stand-alone wind turbine generator system according to the operations manual is important to system security, operating efficiency, and working life.

Tasks may be categorized as routine maintenance, regular maintenance, and overhaul. A new system requires an initial 30-day examination period. If everything is in order, it should be observed continually for 180 days. Thereafter, maintenance intervals are 6 months, 1 year, or 2 years, depending on the manufacturer. The system should also be examined carefully following a severe weather event. Many parts will show evidence of wear after several years, so the system must be overhauled to replace them.

CHAPTER 6

MICRO HYDROPOWER

6.1 Basic Principles

6.1.1 *Description*

All hydropower depends on water falling. The conversion of hydropower into usable mechanical energy (such as in a turning shaft) or the conversion to electric power (by a generator or alternator) is considered in this chapter. Micro hydropower (generally below 100kW of electrical capacity) can provide an important source of renewable energy, providing power in hilly or mountainous areas that have sufficient rainfall. Small streams may be able to provide sufficient power for one or two houses, and a large stream or small river can often provide power for a village. Hydropower can be a reliable and steady source of power, compared with solar or wind, because water flows all day. For this reason, hydroelectric power systems can operate without batteries, however smaller systems may include batteries because of load control issues and to provide the ability to meet peak energy demand higher than the continuous energy available in the stream. Seasonal variability in stream flow is a concern. A stand-alone hydropower system may be designed to rely on solar, wind, or generator power during the dry season, or during drought years.

The development and implementation of a micro hydropower project should be considered for sites that meet rainfall, streamflow, and vertical drop criteria. Small projects (perhaps under 30 kW) could be handled by typical EWB chapters if adequate technical resources are available. Projects larger that this often require considerable expertise, funding, and coordination and should only be entered into when known resources can be dedicated to the project, from both the community and from EWB.

6.1.2 *Site Considerations*

Micro hydropower, while much smaller in scale than large utility scale hydropower plants, can involve a significant amount of civil engineering compared to other renewable energy sources. Hydraulic structures, including small dams, diversion weirs, pipelines, and canals, can represent over fifty percent of the project cost. These should be carefully designed and may be labor intensive or require the use of heavy equipment to install. If local labor is available, the cost of the installation can be reduced. Local fabrication of some turbines, and much of the piping, is possible if metal workers and welders are available.

Unlike large hydroelectric systems, micro hydroelectric systems do not often involve large dams and water storage. Micro systems typically use very small dams, weirs, and canals to divert portions of the available stream for "run of river" designs – they only make power when water is available. Perhaps most common is the diversion weir, requiring only a small pond or no pond, to direct water from the river or stream into a pipeline (penstock) or power canal, which provides water to the turbine. The turbine turns the working shaft for the mill or process, or turns an electric generator that can produce AC or DC power. After flowing through the turbine, the water is returned to the river. There are also designs in which the turbine itself it submerged in the river, with no piping or earthworks.

6.1.3 *Project Development*

To develop a hydro project, several social and technical aspects need to be verified and confirmed in order to ensure the project economically and socially worthwhile. While keeping environmental impacts in mind, the following evaluations should be completed:

- Community evaluation of possible uses for the power (mechanical or electrical), including hours of use, types of use, and distribution of the power.
- Topography and geologic setting should be understood, usually requiring a site survey and inspection by geologist if structures are being designed.
- Water resource evaluation, including rainfall and runoff surveys over the course of a year or more. These can be precise or general, but should be trustworthy.
- Site selection and basic system layout. Careful evaluation of where the powerhouse should be located, how to route the water to the powerhouse, and precautions against storms and flooding conditions.
- Evaluation of possible turbines, generators, and their control, including voltage levels, who will operate the plant, and how to obtain spare parts.
- Environmental impact assessment and mitigation measures.
- A complete economic evaluation and financing scheme.
- Institutional framework and administrative authorizations. Water use permits, building permits, and local authorization is critical.

6.2 Site Analysis

6.2.1 *Measuring flow rate and hydraulic head*

The most important site consideration for determining whether a micro hydropower system is appropriate are issues relating to the available water to be used, including water rights, continuity of the water, the reliable water flow rates, and the available head, or vertical drop between inlet and generating plant. The power available is the product of the water flow rate and the head the water falls. Sites with large head are preferred since a smaller volume of water is needed to generate the equivalent amount of power, allowing use of smaller piping and equipment and reducing cost. Conversely, sites with a large volume of water and small head are also useable.

For sites on shallowly sloping rivers a dam may be necessary to capture this vertical head. Otherwise, a very long (and large) pipeline would be needed. On steep sites a dam is usually not used, as more head can be more cheaply obtained with a relatively shorter pipeline, or with a power canal followed by a very short pipeline.

Seasonal variability is an important consideration. If the variability is high, the turbine must able to run efficiently with different flow rates, or it must be designed for the lowest possible flow.

The vegetation and rockiness of a site can affect the construction. If the site is in northern climates that may freeze, the pipelines must be underground. The ease of this must be taken into account. Very steep rocky terrain can complicate construction of a power canal, and vegetation and other debris can clog the canal.

Dams provide water storage and can increase head for low head (shallowly sloping) sites. For these sites, a small dam can provide more head and reduce the need for installing a very long pipeline. A dam does not usually give significant head increase for high head (steep) sites. For micro-hydro installations a weir and power canal is usually used instead of a dam even at low head sites. Specific guidelines for flow rate and head measurements are noted below.

6.2.2 *Location of powerhouse*

The powerhouse contains the turbine, the mechanical shaft or power generating equipment, and may contain control panels, batteries and a power inverter. The powerhouse is at the lowest point on the system and ideally should be near the point of use of power. The powerhouse should be elevated or sited away from the river to prevent damage from floods or seasonal high water, without sacrificing too much head.

6.2.3 *Coexisting with other water uses*

There are usually many uses of water in a stream. Installation of a hydropower system must carefully consider these other uses, including ecology of the area, fishing, irrigation, household and recreational uses. Hydropower does not remove water permanently from a stream, but it will temporarily channel water through a penstock around an area of irrigation or fish habitat. Partial flow diversion is typically required, leaving some flow for the natural streambed habitat. The construction of dams and intake structures can also cause large temporary disturbances to the stream. In some cases several small run of river hydro facilities may be more compatible with other uses than a single larger facility.

6.3 System Design

he following paragraphs describe general design considerations. To provide a successful project, the design team should be adept in hydro system designs, should consult with experienced designers, and should make full use of available design resources. A few of the available resources are noted in the reference section. A thorough design effort will result in a project that provides reliable power for 30 to 50 years.

6.3.1 *Site Development*

Efficient and cost effective development of the site will be needed to direct the water to the turbine while increasing, maintaining, or only slightly lowering the available head of the water. The hydraulic features and improvements are often the largest portion of the total cost, and various options must be evaluated. Figure 6-5 shows layout options for a typical micro hydro installation. [use Figure 1 from ITDG Tech Brief]

6.3.2 *Converting Water to Watts*

To know the power potential of water in a river or stream it is necessary to know the flow in the river and the available head. The flow of the river is the amount of water (in m^3 or liters) which passes in a certain amount of time a cross section of the river. Flows are normally given in cubic meters per second (m^3/s) or in liters per second (l/s). Flow rates should be recorded over the course of at least one year, preferably by the local community. The stream flow rates can be estimated with an in-stream flow rate device, typically a handheld turbine velocity meter if the stream area can be estimated. Temporary installation of a flume or weir with known dimensions could be used and flow determined by measuring the depth.

Head is the vertical difference in level (in meters) the water falls down. This should be estimated by either a site survey or, if generally not possible due to terrain, use of a high quality GPS unit to estimate the altitude difference. The elevation of the inlet should be compared to elevation of the centerline of the proposed turbine location, subtracting any head that the turbine will discharge into (if submerged).

The theoretical power (P) available from a given head of water is in exact proportion to the head H and the flow rate Q. If P is measured in kilowatts, Q in m^3/s and H in meters, the gross (theoretical) power of the flow of water is:

$$P\ (\mathrm{kW}) = Q \times H \text{ x } g \text{ (gravity, } 9.8\ \mathrm{m/s^2})$$

This available power will be converted by the hydro-turbine into mechanical power on the turbine shaft. All turbines have an efficiency lower than 1, so the generated power will be a fraction of the available gross power.

Example: A turbine generator set operating at a head of 10 meters with flow of 0.3 cubic meters per second with efficiency of 50% will deliver approximately, (0.3 x 10 x 9.8 x 0.5) = 18 kW of electricity.

6.3.3 *Dams and Diversion Weirs*

This is the most common method of obtaining head for utility scale hydroelectric installations but should be minimal for run of the river plants. Possible benefits of a small dam include increasing available head and providing some amount of water storage, which can allow a turbine to meet peak daily power demands greater than the average stream flow is capable of providing. Disadvantages include more design needed, high construction cost, and disruption to the natural stream flow and surrounding lands. For micro hydro installations, the peak load is usually met with other power sources or batteries, so water storage is not necessary. The head obtained from a dam is generally no higher than the height of the dam. If the slope of the river is only 1%, it may be easier to construct a small dam than to invest in many meters of penstock or a long power canal. If the site is steep, a much greater head could be obtained even with a relatively short power canal or a relatively short penstock. The water leaving the dam can be routed directly into a penstock, or to a power canal at the edge of the dam. Dams typically require overflow devices and diversion structures to provide the stream with some water if the stream is to be kept as a viable habitat.

A diversion weir is a structure built into or across the flow of stream, and therefore is not considered a dam. The weir does not appreciably increase the height of the river behind it or store large quantities of water. It is used only to direct water into a power canal or penstock intake, or deepen the stream water sufficiently to be able to install an intake to a power canal or penstock. The diversion weir should have adjustable height controls, or intake valving to regulate the amount of water diverted into the turbine.

6.3.4 *Power Canals*

The power canal is a relatively level open channel canal used to transport water a distance horizontally across a slope without loosing a great deal of head. At the end of the power canal the water enters a closed pipeline (penstock) descending the slope, where the vertical head is developed. A power canal can be used on a shallowly sloping site as a cost effective alternative to a very long penstock or a dam. The benefits are that a power canal will usually have less friction loss and cost less than a long penstock, although this will depend on how difficult it is to construct the power canal. The amount of earthworks will almost always be less than that required to build a dam. Sometimes a small lake, called a forebay, is included at the lower end of the power canal, before the penstock intake, in order to absorb flow surges from the turbine.

6.3.5 *Intake Structure*

The intake structure should provide protection for people, livestock, and native animals against entrance into the penstock. The suction on the penstock can be considerable and therefore a large area, low velocity entrance into the penstock is needed. If the intake is submerged at a dam, the entrance must be partitioned off from swimming or fishing. If the intake is on a diversion weir, it should have large accessible screens, possibly with finer screens, to keep out animals and all types of trash that may clog the turbine nozzles.

If the intake is located on a power canal, the canal should be provided with solid grating against intrusion.

Care must be taken at the water intake to avoid collecting debris and silt and sending it down to the turbine. Trash racks that can be easily cleaned are needed. They should protect against rocks and boulders even during storm or flood events, as well as against vegetation, and any manmade debris from entering the penstock. For large turbines this is done with a grate, often with a stop-log, which is a floating log to stop floating debris from entering the area of the intake. For small turbines similar schemes can be used. Sometimes a self cleaning grate that is oriented at an angle toward downstream will allow water through the intake while debris continues downstream.

6.3.6 *Penstock*

The penstock is a pipe which conveys the water to be used for power directly to the turbine from the water intake. For very small installations this can be made of PVC or HDPE pipe. For larger installations the penstock should be made of iron pipe or reinforced concrete. The diameter of the penstock is important and must be matched to the expected flow rates. Pipes of small diameter will induce a higher friction loss, leaving less power available in the water for the turbine. Small pipes may be buried or simply laid on the ground and secured at various points. Larger pipes experience great forces induced by the weight of the water and by flowing water. Pipeline design is critical, requiring supports and anchors that are fully engineered.

6.3.7 *Surge/control issues*

When water flow in the penstock is suddenly turned off, the pressure may alternately surge to twice the normal operating pressure, then drop to zero, due to the momentum of the water. If the system is not designed for this, the penstock may burst. Large scale hydro facilities incorporate a surge tank which can absorb the force of the water without large pressure changes. If the water flow into the penstock is suddenly stopped, the penstock may experience a vacuum, which will collapse a steel pipe like it was an aluminum can. Both surge and vacuum control is needed for the penstock design.

6.3.8 *Pumps as Turbines*

The selection of the mechanical equipment can be relatively simple or complex, depending on the amount of generation being installed. For small systems with very limited budgets, pumps can be used as turbines to convert the water energy into shaft power. The efficiency of these is less, somewhere in the 65 to 75% range. The shaft power can then be used by mechanical belts, pulleys, or any variety of mechanical power conversion equipment needed by the community.

If the flow and head are substantial, and if it is determined to be economically feasible, a turbine should be purchased to match the expected design values. The selection of the turbine is easy for smaller projects, but requires thorough evaluation for larger projects. An introduction to turbines is presented in Appendix V. Turbine manufacturers and suppliers should be contacted to discuss design options, and technical references should be used for turbine selection. Expert advice is recommended.

Drive systems to connect the turbine to the generator can be of many types, including direct drive (continuous shaft), V belts or pulleys, sprocket pulleys, or through gear boxes to increase the speed of the generator shaft. Gearboxes should be used with caution and are best if engineered into the turbine/generator system. The drive options should be evaluated for their initial cost and their ease of maintenance.

6.3.9 *Motors as Generators*

Similar to turbine selection, the selection of the generation equipment runs the range from simple to complex. For small systems, induction motors can be used as generators, with some loss of efficiency. Generators are synchronous (for larger AC, three phase power) or asynchronous (induction), and have many specific options to be selected by load type and power level. The selection should be carefully matched to the turbine power and expert advice is recommended because they represent a significant investment in the system.
If the generator is DC, the power could be used directly if the loads are set up for DC voltage. If not, the DC is converted to AC. Electrical conversion equipment to convert DC to AC current, and/or phase conversion may be needed. The electrical power can then be used to power the local grid, feed batteries, or tie directly to specific loads like lights or electric machinery.

Generators require special control considerations and protection from both the turbine supplying the input power and protection from the electrical system using the power. As perhaps the most expensive part of a rural electrical system, the protection should be coordinated to remove the generator from the mechanical and electrical system when electrical parameters such as frequency, voltage or current load are out of acceptable ranges. In small villages, there is often limited control of who connects to the power grid. Proper circuit protection should be enforced and at least fusing or circuit breakers should be provided at each load tap.

6.3.10 *Control Equipment*

Generator controls include all typical electrical parameters and the added element of speed (frequency of power, hertz). Gross control of water flow is needed for the turbine long term water flow rates, and fine control is needed for speed control of the turbine as the water impinges on the turbine blades.

- Flow control at the water intake structure (dam, weir, canal, pipeline) should be controlled to match the allocated water use from the stream.
- Flow control at the turbine is used to increase/decrease turbine speed due to loads on the generator. Generator frequency control is critical for small, stand alone systems. As the electrical loads increase, the generator works harder to produce

the current needed and will start to slow down. More water is needed to provide the additional mechanical energy to the shaft and generator to maintain output frequency.

Generator voltage control is provided by a voltage regulator and/or converter, or by the excitation controls for synchronous generators. Controls for under/over frequency, voltage, or current should be provided to disconnect the generator if the parameters are out of range for specific periods of time, with either automatic or manual reset after tripping. Electronic load controllers are now available that can provide excellent generator control, protection, and monitoring functions.

6.3.11 *Load Factor*

As part of the economic evaluation of the project, the expected generation from the plant and the electrical load profile over typical 24 hour periods should be evaluated. If the load can be made more even over a 24 hour period, the hydroelectric power generation, which runs continuously with the stream flow, is more efficient. The load factor is defined as:

Load Factor = (amount of power used) / (amount of power that is available)

For hydropower generation, which is without fuel costs, the plant is more efficient the higher the percentage of time the power is used. Thus the plant becomes more cost effective the higher the load factor. It is important to ensure a high plant load factor if the project is to be cost effective. This should be taken into account during the planning stage. Creative methods of using the excess power may be needed if the water supply cannot be controlled to severely reduce the turbine shaft power. Otherwise a ballast load, typically resistive load banks, are used to divert the power to maintain generator control.

6.4 Installation

6.4.1 *Construction and Installation*

Before starting the construction and installation phase, ensure that you have finalized every detail, including the final cost of the system, water license, land-use approval and other local permits as necessary.

For small hydropower systems, get the community involved. Construction and installation of a micro hydropower system requires civil works, mechanical and electrical skills and experience working with heavy objects. Ensure you have professional help in these skills to construct the intake and headrace canal; install and align the penstock, turbine and generator; build the powerhouse; and put up the transmission line.

The time of the year to construct the system can influence the pace and quality of work. Schedule the project around the severe weather patterns in the area, preferably doing the construction at the driest time of the year. Include contingency plans in case of unexpected wet weather.

Ensure that all equipment and materials will be delivered on time, and be aware that the cost of labor could be more than the cost of the materials and equipment. Performing some of the unskilled manual labor with the community will reduce labor costs substantially and provide valuable experience in every aspect of the construction. This will also aid in the maintenance training and understanding of the system. It is actually during the construction that training of the local community can really be given.

6.5 Validation, Operation & Maintenance

6.5.1 *Testing*

The important final stage in installing a micro hydropower system involves performance tests. The purpose is to check the performance of each component to ensure that it functions as specified. The validation test should measure overall performance to verify that it functions according to the design specification and parameters.

The following items should be tested, and retested if there was a problem:

- The amount of water flowing from the intake
- Penstock pressure tests
- Penstock head losses
- The turbine performance at rated and over speed
- Voltage and frequency protection trip circuits
- Response time of the electronic load controller to load changes
- The overload and over speed protection circuit of the generator
- Total electrical power generation at design flow
- Automatic safety features under abnormal conditions, such as short-circuit and emergency shutdowns.

All components must be fully tested. To ensure that safety protection devices are set correctly, the tests may need to be repeated several times.

6.5.2 *Operation and Maintenance*

Operation and maintenance of micro hydropower systems generally takes little time. It may be necessary, in extreme cases, to check the system daily to make sure that the intake is not becoming clogged and that the system is in good working order. Weekly or monthly inspection is much more common. Depending on the design of the system, you may need to adjust the intake valve, nozzle or guide vane occasionally to match the water flow into the turbine with the amount of power you are using or to conserve the amount of water you have in the stream, especially in the dry season. More extensive maintenance, such as greasing the machinery and bearings, tightening of belts and checking the water level in the batteries for battery-based systems should be done every month.

It may also be necessary to clean out silt, weeds and so forth in the civil works and to repair any leaks or deterioration. This is usually done about twice a year or as often as needed. The manufacturer of the mechanical equipment should provide detailed information on maintenance procedures and when they should be carried out. It is good practice and cost-effective to practice preventive maintenance rather than wait for the system to fail. A well-maintained micro-hydropower system can provide an uninterrupted power supply for many years.

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APPENDIX I: CODES AND STANDARDS FOR PHOTOVOLTAIC SYSTEMS AND EQUIPMENT

Standards and Conformity Assessment Organizations
American National Standards Institute (ANSI)
National Standards Systems Network (NSSN)
National Institute for Standards and Technology (NIST)
Institute of Electrical and Electronics Engineers (IEEE)
National Electrical Safety Code (NESC)
IEEE Standards Coordinating Committee 21 (SCC21)
IEEE Standards Coordinating Committee 29 (SCC29)
International Electrotechnical Commission (IEC)
International Organization for Standardization (ISO)

Fire, Electrical and Safety Codes
National Fire Protection Association (NFPA)
National Electrical Code (NEC)
Occupational Safety and Health Administration (OSHA)

Underwriters and Product Listing Organizations
Underwriters Laboratory (UL)
ETL Semko (ETL Semko)
Factory Mutual Research (FM Global)
Canadian Standards Association (CSA)

Equipment and Materials Standards
American Society for Testing and Materials (ASTM)
National Electrical Contractors Association (NECA)
National Electrical Installation Standards (NEIS)
National Electrical Manufacturers Association (NEMA)
Battery Council International (BCI)
Illuminating Engineering Society of North America (IESNA)
American Society of Mechanical Engineers (ASME)
American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE)

Building and Structural Codes
American Society of Civil Engineers (ASCE)
ASCE's Structural Engineering Institute (SEI)
International Code Council (ICC)
Building Officials and Code Administrators International Inc. (BOCA)
International Conference of Building Officials (ICBO)
Southern Building Code Congress International Inc. (SBCCI)
The International Association of Electrical Inspectors (IAEI)
International Association of Plumbing and Mechanical Officials (IAPMO)

Accreditation and Certification Organizations
American Association for Laboratory Accreditation (A2LA)
PowerMark Corporation (PMC)
Global Approval Program for Photovoltaics (PV GAP)
Institute for Sustainable Power (ISP)
International Accreditation Forum, Inc. (IAF)

APPENDIX II: ELECTRIC LOAD ESTIMATION WORKSHEET

First, list the various electric loads that are desired or required. If possible and practical, obtain the quantity and electrical specifications, including alternating current or direct current voltage, amperage, and wattage of each load. Then list the average hours of use per day and the number of days used per week that are expected. In some cases these figures may have to be calculated or estimated. Be sure to allow for major seasonal variations of insulation or use.

1. Electric Load Estimation

Loads	Qty	x	Volts	x	Amps	=	Watts		x	Use hrs/day	x	Use days/wk	□	7 days	=	watt hours	
							AC	DC								AC	DC
		x		x		=			x		x		□	7	=		
		x		x		=			x		x		□	7	=		
		x		x		=			x		x		□	7	=		
		x		x		=			x		x		□	7	=		
		x		x		=			x		x		□	7	=		
		x		x		=			x		x		□	7	=		
		x		x		=			x		x		□	7	=		
		x		x		=			x		x		□	7	=		
		x		x		=			x		x		□	7	=		
		x		x		=			x		x		□	7	=		
		x		x		=			x		x		□	7	=		
AC Total Connected Watts										AC Average Daily Load							
DC Total Connected Watts										DC Average Daily Load							

Table 2-1: The Electric Load Estimation worksheet

First, calculate every kind of load's power and add them up.

$P = \Sigma Pi \times Ni$

In the formula:

P: peak power (kW, it usually determines capacity of system's inverter)

Pi: rate power of every kind of load (KW)

Ni: number of this kind of load (number of load with completely same peak power)

i = 1`n number of different kinds of loads

$Pa = \Sigma Pi \times Ni \times Ci$

In the formula:

Pa: peak power after being adjusted (KW, according to time pertinence of load's use , peak power adjusted)

Pi: rate power of every kind of load (kW)

Ni: number of this kind of load (number of load with completely same peak power)

i = 1`n number of different kinds of loads

Ci: time pertinence of different loads' use.

Estimation and calculation of consumed power of system

$L = \Sigma Pi \times Ni \times Hi$

L: everyday largest power consumption consumed by loads

Pi: rate power of every kind of load (kW)

Ni: number of this kind of load (number of load with completely same peak power)

Hi: average time of use of every kind of load in each day i = 1`n

APPENDIX III: PV CALCULATION WORKSHEETS

Worksheet #1 **CALCULATE THE LOADS (for each month or season as required)**

Load Description	QTY		Load Current (Amps)		Load Voltage (Volts)		DC Load Power (Watts)		AC Load Power (watts)		Daily Use (hrs/day)		Weekly Use (days/weeks)			Power Conversion Efficiency (decimal)		Nominal System Voltage (volts)		Amp-Hour Load (AH/day)
DC	1	x		x		=				x		x		÷ 7	÷		÷		=	
DC		x		x		=				x		x		÷ 7	÷		÷		=	
DC		x		x		=				x		x		÷ 7	÷		÷		=	
DC		x		x		=				x		x		÷ 7	÷		÷		=	
DC		x		x		=				x		x		÷ 7	÷		÷		=	
DC		x		x		=				x		x		÷ 7	÷		÷		=	
DC		x		x		=				x		x		÷ 7	÷		÷		=	
AC		x		x				=		x		x		÷ 7	÷		÷		=	
AC		x		x				=		x		x		÷ 7	÷		÷		=	
AC		x		x				=		x		x		÷ 7	÷		÷		=	
AC		x		x				=		x		x		÷ 7	÷		÷		=	
AC		x		x				=		x		x		÷ 7	÷		÷		=	
AC		x		x				=		x		x		÷ 7	÷		÷		=	
AC		x		x				=		x		x		÷ 7	÷		÷		=	
Total Load Power (Watts)				DC				AC						Total Amp-Hour Load (AH/day)						

Total DC Load Power (Watts)		Total AC Load Power (Watts)		Nominal System Voltage (volts)		Peak Current Draw (Amps)
	+		+		=	

Total Amp-Hour Load (AH/day)		Wire Efficiency Factor (decimal)		Battery Efficiency Factor (decimal)		Corrected Amp-Hour Load (AH/day)
	÷		÷		=	

Worksheet #2 **DESIGN CURRENT AND ARRAY TILT**

System Location		Latitude		Longitude	
Insolation Location		Latitude		Longitude	

	Tilt at Latitude -15˚					Tilt at Latitude					Tilt at Latitude 15˚				
MONTH	Corrected Load (AH/day)		Peak Sun (hrs/day)		Design Current (Amps)	Corrected Load (AH/day)		Peak Sun (hrs/day)		Design Current (Amps)	Corrected Load (AH/day)		Peak Sun (hrs/day)		Design Current (Amps)
J		÷		=			÷		=			÷		=	
F		÷		=			÷		=			÷		=	
M		÷		=			÷		=			÷		=	
A		÷		=			÷		=			÷		=	
M		÷		=			÷		=			÷		=	
J		÷		=			÷		=			÷		=	
J		÷		=			÷		=			÷		=	
A		÷		=			÷		=			÷		=	
S		÷		=			÷		=			÷		=	
O		÷		=			÷		=			÷		=	
N		÷		=			÷		=			÷		=	
D		÷		=			÷		=			÷		=	

Select the largest design current and corresponding peak sun from each latitude and enter below

Latitude -15˚		Latitude		Latitude 15˚	
Peak Sun (hrs/day)	Design Current (Amps)	Peak Sun (hrs/day)	Design Current (Amps)	Peak Sun (hrs/day)	Design Current (Amps)

Select the smallest design current and corresponding peak sun

Peak Sun (hrs/day)	Design Current (Amps)
Tilt Angle =	

NOTE: DO NOT MIX TRACKING AND FIXED ARRAY ON THE SAME SHEET

Worksheet #3 CALCULATE SYSTEM BATTERY SIZE

Corrected Load (AH/day)		Storage Days		Maximum Depth of Discharge (decimal)		Derate for Temperature (decimal)		Required Battery Capacity (AH)		Capacity of Selected Battery (AH)		Batteries in Parallel
	x		÷		÷		=		÷		=	

Nominal System Voltage (volts)		Nominal Battery Voltage (volts)		Batteries in Series		Batteries in Parallel		Total Batteries
	÷		=		x		=	

NOTE: **ROUND UP CAPACITY OF SELECTED BATTERY FOR CRITICAL DESIGN**

Batteries in Parallel		Capacity of Selected Battery (AH)		System Battery Capacity (AH)		Maximum Depth of Discharge (decimal)		Useable Battery Capacity (AH)
	x		=		x		=	

Battery Information	
Make	
Model	
Type	
Nominal Voltage (volts)	
Rated Capacity (AH)	

NOTE: **IF THE NUMBER OF STORAGE DAYS ARE GREATER THAN 10 YOU MAY ELECT TO USE THE OPTIONAL ARRAY SIZING WITH SEASONAL DERATE**

Worksheet #3SD

ARRAY SIZING WITH SEASONAL DERATE

System Battery Capacity (AH)		Seasonal Depth of Discharge (decimal)		Seasonal Discharge (AH)		Peak Sun (Hrs/Day)		Seaonal Low Sun Days		Seasonal Derate (amps)
	x		=		÷		÷		=	

NOTE: THE VALUE ENTERED FOR SEASONAL LOW SUN DAYS SHOULD NOT BE LESS THAN 30 OR GREATER THAN 60.

Design Current (amps)		Seasonal Derate (amps)		Optional Design Current (amps)
	-		=	←

ENTER THIS VALUE INTO WS #4 - ARRAY SIZE DESIGN CURRENT

Worksheet #4 **CALCULATE SYSTEM ARRAY SIZE**

Design Current (Amps)		Module Derate Factor (decimal)		Derated Design Current (Amps)		Rated Module Current (Amps)		Modules in Parallel						
	÷		=		÷		=							
		Nominal Battery Voltage		Batteries in Series		Voltage required to Charge Batteries (volts)		Highest Temperature Moduel Voltage (volts)		Modules in Series		Modules in Parallel		Total Modules
1.2	x		x		=		÷		=		x		=	

Modules in Parallel	Rated Module Current (Amps)		Rated Array Current (Amps)
x		=	
	Module Short Circuit Current (Amps)		Array Short Circuit Current (Amps)
x		=	
Modules in Series	Rated Module Voltage (volts)		Rated Array Voltage (volts)
x		=	
	Open Circuit Module Voltage (volts)		Array Open Circuit Voltage (volts)
x		=	

PV MODULE INFORMATION

Make/Model				Nominal Volts	
Length		Width		Thickness	
Weight			Bypass Diode	y	n
Voltage (volts)	At STC	Open Circuit	At Highest Expected Temperature		
Current (amps)	At STC	Open Circuit			

APPENDIX IV: DESIGN REVIEW AND APPROVAL CHECKLIST

DESIGN REVIEW AND APPROVAL CHECKLIST

GENERAL INFORMATION

System design name: ____________________

Model number: ____________________

1. SYSTEM DESIGN DOCUMENTATION

Check boxes for items below that are complete and acceptable.

- ☐ 1.01 Electrical drawings
- ☐ 1.02 Mechanical drawings
- ☐ 1.03 Site description and component locations (as applicable)
- ☐ 1.04 System specifications
- ☐ 1.05 Parts list
- ☐ 1.06 Source list
- ☐ 1.07 Installation and checkout procedures
- ☐ 1.08 Owners manual
- ☐ 1.09 Maintenance and troubleshooting instructions
- ☐ 1.10 System warranty
- ☐ 1.11 Component warranties

2. ELECTRICAL DESIGN

Check boxes for items below that are clearly defined and acceptable.

- ☐ 2.01 DC wiring type
- ☐ 2.02 DC wiring size
- ☐ 2.03 Acceptable DC voltage losses
- ☐ 2.04 AC wiring type
- ☐ 2.05 AC wiring size
- ☐ 2.06 Wiring terminations
- ☐ 2.07 Overcurrent protection

- [ ] 2.08 Disconnect locations and hardware
- [ ] 2.09 Grounding of conductors
- [ ] 2.10 Grounding of metal non-conductors
- [ ] 2.11 Bypass diodes
- [ ] 2.12 Blocking diodes
- [ ] 2.13 Surge and lightning protection
- [ ] 2.14 Instrumentation
- [ ] 2.15 Junction box: locations and ratings

3. MECHANICAL DESIGN

Check boxes for items below that are acceptable.

- [ ] 3.01 Array mounting design
- [ ] 3.02 Mechanical strength and compatibility with local code requirements
- [ ] 3.03 Environmentally compatible materials
- [ ] 3.04 Mounting hardware compatibility
- [ ] 3.05 Weather sealing materials and approach
- [ ] 3.06 Accessibility for array maintenance
- [ ] 3.07 Safety
- [ ] 3.08 Aesthetics

4. MODULES / ARRAYS

Check boxes for items below that meet referenced standards and are acceptable.

- [ ] 4.01 IEEE Standard 1262
- [ ] 4.02 UL Standard 1703
- [ ] 4.03 Panel, sub-array, array wiring
- [ ] 4.04 Array DC voltage
- [ ] 4.05 Bypass diode locations and sizes
- [ ] 4.06 Module performance at STC: Isc, Voc, Imp, Vmp, Pmax
- [ ] 4.07 Module performance at SOC: Isc, Voc, Imp, Vmp, Pmax

- [ ] 4.08 Predicted array output at STC: Isc, Voc, Imp, Vmp, Pmax
- [ ] 4.09 Predicted array output at SOC: Isc, Voc, Imp, Vmp, Pmax

5. INVERTER

Check boxes for items below that meet referenced standards and are acceptable.

- [ ] 5.01 UL Standard 1741
- [ ] 5.02 Location, weather-proofing
- [ ] 5.03 DC input voltage
- [ ] 5.04 Inverter power rating and operating range

APPENDIX V: BATTERIES

Battery Types

Different chemicals can be combined to make batteries, with differing discharge/recharge characteristics. Some types are low cost but provide low power. Others can store huge power but will cost a lot - a huge price. The cost depends on the battery capacity (amp-hours), the climatic conditions in which it will operate, how frequently it will receive maintenance, and the types of chemicals it uses to store and release electricity.

Lead-acid batteries generally offer the best balance of capacity per dollar, although many require maintenance. This type is the most common battery used in stand-alone power systems. “Sintered plate" NiCd batteries suffer from the well known memory effect, in which the useful capacity of the battery appears to drop after it has been discharged over many cycles or if it is discharged at low rates. Sintered plate NiCd batteries are not therefore attractive for use in PV systems. “Pocket plate" NiCd batteries can be used in PV systems, because they have additives in their plates to prolong their life and to minimize the memory effect. In addition, they are highly resistant to extremes of temperature, and can safely be taken down to less than 10% state of charge. Their main disadvantage is their high cost compared with lead acid batteries.

The biggest problem with all batteries is their disposal at the end of their useful life. Proper recycling is required to prevent a local garbage mess and negative impacts to the environment. A good recycling program can prevent this problem. Recycling of lead batteries costs much less energy than the production of lead. Negative environmental impacts can result from improper disposal of lead-acid batteries. While careful recycling of lead-acid batteries is the best way to prevent this, current recycling practices vary substantially by country. As the use of PV systems becomes more widespread, it is important to develop well-managed battery recycling programs. Hopefully battery technology will improve with respect to environmental soundness. In the interim, these guidelines will focus on lead-acid batteries.

Lead Acid Batteries – How they work

The lead-acid battery cell consists of positive and negative lead plates of different composition suspended in a sulfuric acid solution called electrolyte, Figure 4. When cells discharge, sulfur molecules from the electrolyte bond with the lead plates and releases electrons. When the cell recharges, excess electrons go back to the electrolyte. A battery develops voltage from this chemical reaction. Electricity is the flow of electrons.

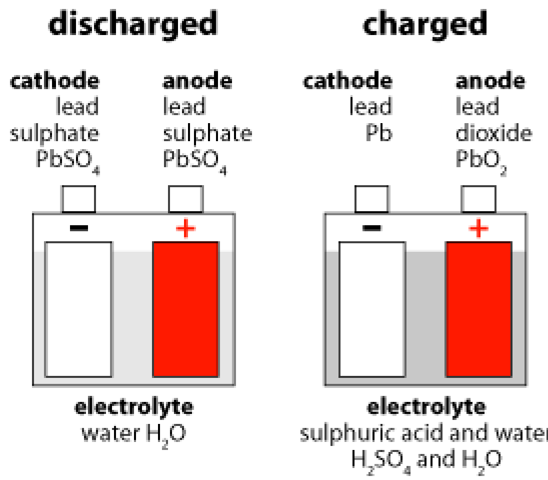


Figure 4-4. Typical lead-acid battery

In a typical lead-acid battery, the voltage is approximately 2 volts per cell regardless of cell size. Electricity flows from the battery as soon as there is a circuit between the positive and negative terminals. This happens when any load (appliance) that needs electricity is connected to the battery.

Good care and caution should be used at all times when handling a battery. Improper battery use can result in explosion. Read all documentation included with your battery in its entirety.

Battery Bank Sizing

Ideally, a battery bank should be sized to be able to store power for 5 days of autonomy during cloudy weather. If the battery bank is smaller than 3 day capacity, it is going to cycle deeply on a regular basis and the battery will have a shorter life. System size, individual needs and expectations will determine the best battery size for your system. A correctly sized battery bank is vital to the proper functioning of your system. Compromising on the battery bank can lead to poor performance and dissatisfaction with the entire system. Do not skimp here.

Deep Cycle vs. Shallow Cycle Batteries

In battery lingo, a cycle on your battery bank occurs when you discharge your battery and then charge it back up to the same level. A lead acid battery is designed to absorb and give up electricity by a reversible electrochemical reaction.

How deep a battery is discharged is termed depth of discharge (DOD) while the state of charge (SOC) is 100% minus the DOD. This means that a 25% DOD equals a 75% SOC. A shallow cycle occurs when the top 20% or less of the battery's energy is discharged and then recharged. Automotive starting, lighting and ignition batteries (SLI) are of the shallow cycle type and are not recommended for use in a photovoltaic system. The lead plates inside an SLI battery are thin with a large overall surface area. This design can produce a high amount of current in a very short time (which is ideal for starting engines), but cannot be discharged very deeply without damaging them and/or shortening their life span considerably.

Deep cycle batteries on the other hand can be repeatedly discharged to 80% DOD and recharged without damaging them (although repeated deep cycling will shorten the battery's life as compared to the same number of shallow cycles). Deep cycle batteries have thicker lead plates which have less overall surface area as compared to an SLI battery. Because of the lessened availability of surface area for chemical reaction, deep cycle batteries produce less current than a shallow cycle battery but can produce that amount of current for a much longer period of time.

The depth of cycling has a good deal to do with determining a battery's useful life. Even batteries designed for deep cycling are "used up" faster as the depth of discharge is increased. It is common practice for a system to be designed with deep cycle batteries even though the daily or average discharging amounts to a relatively shallow depth of discharge. To get the longest life out of your battery bank, purchase deep cycle batteries and shallow cycle them.

Lead-Acid Battery Types

(1). Starting Batteries - Shallow cycle automotive battery not suitable for Photovoltaic Systems. Automotive batteries are shallow-cycle batteries and should not be used in PV systems because they are designed to discharge only about 20% of their capacity. If drawn much below 20% capacity more than a few dozen times, the battery will be damaged and will no longer be able to take a charge.

(2). RV or Marine "Deep-Cycle" - 12 volt batteries usually 80 and 160-amp hour capacity. A compromise between shallow and true deep cycle batteries. Life expectancy is about 2 to 3 years.

(3). Lead-Calcium Batteries -Occasionally these shallow-cycle batteries recycled from the telephone company are used in remote power systems. At 400 pounds per 2 volt cell and cycle limited to 15% - 20%, these batteries are not recommended.

(4). Sealed Batteries - These are liquid-tight batteries that can operate in any position without leaking acid. Because of the seal construction, you cannot check cell conditions with a hydrometer. Vents prevent pressure build-up in case of gassing. Recommended only for situations where hydrogen gassing during charging cannot be tolerated, or the battery is going to be moved a great deal, or to be fit in tight spaces. Requires lower voltage charge controls.

a). Absorbed Glass Mat Sealed Lead Acid (AGM)**:**
AGM batteries are seeing more and more use in solar electric systems as their price comes down and as more systems are getting installed that need to be maintenance free. This makes them ideally suited for use in grid-tied solar systems with battery back-up. Because they are completely sealed they can't be spilled, do not need periodic watering, and emit no corrosive fumes, the electrolyte will not stratify and no equalization charging is required. AGM's are also well suited to systems that get infrequent use as they typically have less than a 2% self discharge rate during transport and storage. They can also be transported easily and safely by air. Last, but not least, they can be mounted on their side or end and are extremely vibration resistant. AGM's come in most popular battery sizes and are even available in large 2 volt cells for the ultimate in low maintenance large system storage.

When first introduced, because of their high cost, AGM's were mostly used in commercial installations where maintenance was impossible or more expensive than the price of the batteries. Now that the cost is coming down they are seeing use in all types of solar systems as some of today's owners think the advantages outweigh the price difference and maintenance requirements of flooded lead acid batteries.

b) Gelled Electrolyte Sealed Lead Acid:
Gelled lead acid batteries actually predated the AGM type but are losing market share to the AGM's. They have many of the same advantages over flooded lead acid batteries including ease of transportation, as the AGM type, except the gelled electrolyte in these batteries is highly viscous and recombination of the gases generated while charging, occurs at a much slower rate. This means that they typically have to be charged slower than either flooded lead acid or AGM batteries. In a solar electric system you have a fixed amount of sun hours every day and need to store every solar watt you can before the sun goes down. If charged at too high a rate, gas pockets form on the plates and force the gelled electrolyte away from the plates, decreasing the capacity until the gas finds its way to the top of the battery and is recombined with the electrolyte. For use in a grid-tie with back up system or any system where discharge rates are less than severe, gel batteries could be a good choice.

Most AGM batteries (absorbed glass mat) have a life expectancy of 2-5 years, and 5-10 years for higher quality Gel cell batteries. Most sealed batteries are AGM.

(5). True Deep-Cycle Batteries - True deep-cycle batteries are specifically designed for energy storage and deep-cycle service. They tend to have larger and thicker plates as shown in the image above. Ideal for renewable energy systems, deep-cycle batteries withstand having a majority of their capacity used before being recharged and survive hundreds and even thousands of 80% cycles. It is recommended to use 50% as the normal maximum discharge and leave 30% for emergencies. Do not use the bottom 20%, the less deeply you cycle your battery, they longer it will last. Available in many sizes and types.

Batteries and Climate

The speed of the charging and discharging chemical reactions occurring inside a lead-acid battery is governed by temperature and charge/discharge current. The colder the temperature the slower the reactions and conversely the warmer the temperature the faster the reactions. Hence a cold battery will deliver less amperage in any given time frame as compared to a warm battery. Most of us have experienced this effect when trying to start our cars on a cold morning; the engine just doesn't turn over as quickly if at all. Warm that same battery up and you will see a major improvement. (See the bar graph of temperature effects below). The optimum temperature for a lead-acid battery is around 77°F, but 60-80°F is acceptable. For this reason we like to see batteries placed indoors or in a heated and ventilated space to maintain them between 60° to 80°F. If you do install them in an unheated space, battery capacity must be increased to compensate for this derating. On the other extreme, high temperatures (110°F+) can drastically shorten the life of the battery and should be avoided as well.

Battery Efficiency

Batteries aren't 100% efficient. Energy is never consumed or produced, it merely changes form. The efficiency of conversion is never 100% and in the case of new batteries averages around 90%. This means that if you want to discharge 100 watt-hours of energy from a battery you must charge it with approximately 110 watt-hours of energy.

Due to impurities in the chemicals used for battery construction, batteries will lose power to local action, an internal reaction which occurs whether you are using the battery or not. This slow discharging is termed self-discharge and rates vary greatly among battery types and increases along with temperature. The rate also increases with the age of a battery, so much so that an old battery may require significant amount of charging just to stay even. Even new batteries may lose 1 to 2% of charge per day. Lead calcium grid batteries have the lowest self-discharge rates, but are not designed for deep cycling applications.

Determining battery state of charge

Battery state of charge is determined by reading the static (i.e., not charging or discharging) battery voltage or the specific gravity of the electrolyte. The density or specific gravity of the sulfuric acid (H2SO4) electrolyte of a lead-acid battery varies with the state of charge and temperature. The density is lower when the battery is discharged and higher as the cells are charged, (see the table below). This is because the electrolyte is part of the chemical reaction; it changes as the chemical reaction takes place. Specific gravity is read with a hydrometer, which will tell the exact state of charge. A hydrometer cannot be used with sealed or gel-cell batteries.
Voltage meters are used to approximate battery state of charge. They are relatively inexpensive and easy to use. The main problem with relying on voltage reading alone is the

high degree of battery voltage variation through the working day. Battery voltage reacts highly to charging and discharging. In a PV system we are usually charging or discharging and many times are doing both at the same time. As a battery is charged the indicated voltage increases and as discharging occurs, the indicated voltage decreases.

These variations may seem hard to track, but in reality they are not. A good accurate digital meter with a tenth of a volt accuracy can be used with success. The pushing and pulling of voltage, once accounted for by experience, can also help indicate the amount of charging or discharging that is taking place. By comparing voltage readings to hydrometer readings, shutting off various charging sources or loads and watching the resulting voltage changes, the system owner can learn to use indicated voltage readings with good results.

Battery Life

The life of a battery and its energy delivery capability are highly dependent on the manner in which it is operated. Many deep discharges (above 70-80%) reduce the life of lead-acid batteries. High rates of discharge reduce the energy delivery potential of lead-acid batteries. Batteries also have shelf life limitations.

Poor charging practices are responsible for the short battery life more that any other cause. A number of methods exist for charging batteries used in stationary utility applications. Optimum life and energy output from batteries, but not efficiency, are best achieved when depth of discharge (low, e,g, 40%) and time for recharge are predetermined and repetitive, a condition not always achievable in PV applications. Modified constant-potential charging is common for deep cycling batteries and preferred for PV batteries designed for optimum life.

Used Batteries

Like most things, you get what you pay for. Used lead acid batteries, especially large two volt telephone type cells can be found for sale at some very attractive prices. While used solar modules and inverters are usually an acceptable risk, used batteries are not. Should you consider them? It is difficult to know how an older battery has been used and cared for. Our recommendation on used batteries is to inspect them carefully in person, get as much information as you can on them (manufacturer, age, amp-hour capacity and type of system they were used in) and have them load tested. Without load testing used batteries you are really guessing as to their remaining life. If you are considering telephone cells, realize that they are normally shallow cycle lead calcium grid construction, and should not be used in a system designed for deep cycling.

Battery Care

Batteries are the "heart" of stand-alone PV systems. While the rest of the system will require little maintenance, batteries require regular monitoring and maintenance. Battery maintenance is the single largest responsibility of the system owner. It is said that "few batteries die - most are killed" by neglect and poor maintenance.

Below is some very basic information on battery care and always check with the manufacturer .to ascertain their system specific maintenance requirements. Make certain the maintenance person knows what batteries are in the system, and the battery O&M requirements. Batteries are too expensive and hazardous to take their care and maintenance lightly.

1) The battery cabling connections should be kept clean and tight at all times, and inspected at least annually. A slight acid mist is formed as the electrolyte bubbles upon charging. This mist is highly corrosive, especially to the metallic connectors on the tops of the batteries. Inspect for corrosion and carefully clean these periodically as needed with baking soda and water. Be sure not to get any baking soda into the battery electrolyte as it will have a neutralizing effect. Corrosion buildup can create a good deal of electrical resistance, which can contribute to shortened battery life and the waste of power. Anti-corrosion chemicals can be used to keep them clean and fit; petroleum jelly works well.

2) All new batteries should be fully charged prior to use.

3) New batteries need to be gently cycled several times before reaching full capacity (20 to 50 cycles, depending on what kind of batteries you have). Like a new car, do not work them too hard during this "breaking-in" period.

4) Use only distilled water to replenish batteries. As batteries are charged they create bubbles of gas, produced when the chemical reaction cannot keep up with the energy input. Some gassing is necessary in flooded cell batteries. The amount and duration of gassing varies from one battery to another. Gassing mixes the electrolyte and compensates for the tendency of the electrolyte to stratify with the more dense acid on the bottom. Gassing is the product of splitting water molecules into hydrogen and oxygen. This consumes water and creates the need for its periodic replacement.

5) Add distilled water AFTER charging; the plates should be covered by approximately 1/8" of acid. Check levels after charging. The acid level should be 1/4" below the bottom of the fill well in the cell cover. Be sure to keep the battery's electrolyte level at the marked full level and never let the plates become exposed to the air. Do not over-fill the batteries or fill when the batteries are discharged. Over-watering dilutes the acid excessively and electrolyte will be expelled when charging.

6) Batteries should never be discharged below *80% of their rated capacity. Shallow cycling of your deep cycle batteries will promote battery longevity (*some batteries can be regularly taken to an even greater depth of discharge without damaging the plates).

7) The maintenance requirements of older batteries change. This means longer charging times, and probably higher finishing amperage. Older batteries will need more water, and their capacity will decline.

8) Batteries basically like the same temperatures that we do; extreme temperatures can negatively affect battery performance and charging. Cold reduces capacity and retards charging. High temperatures increase water usage, gassing, and can result in extremely unsafe conditions. Avoid charging at temperatures above 120°F or higher! And be careful above 100°F. The ideal temperatures for batteries are 55-80°F. In below freezing temps it will take more power to charge your batteries, as cold batteries have a greater self-discharge rate. Liquid lead-acid cells should be protected from freezing. At high temps gassing is excessive and you may have to add more distilled water to maintain your cells.

9) All deep cycle batteries (excepting gel cells or certain glass mat technologies) should be equalized on a regular basis. This is a "controlled overcharging" which removes sulfates off of the plates and mixes it back with the electrolyte. It helps keep individual cells in balance. A battery bank should be equalized at least every three months; certain electronic regulators automatically equalize your batteries every two to four weeks. Some manufacturers feel that heavily used batteries should be equalized once a week to once a month. Equalizing produces gassing--which consumes water; add distilled water as needed after equalizing.
Equalization charging voltages vary widely, as do duration times, so the batteries should be monitored closely during this process. Check periodically during the EQ process. You don't have to check every cell each time, but watch any that show a high variation from the rest of the cells. Keep checking the specific gravity of the electrolyte until you receive three readings of 30 minutes apart which indicate no further increase of specific gravity values. Keep a record of individual cell voltages and specific gravity before and after equalizing. Equalization will take your voltage to 15 volts or higher (30 volts on a 24 volt system) so make sure any DC loads are disconnected before you begin.

Do not equalize sealed or gel-type batteries! Their upper voltage range is around 13.8 to 13.9V. Higher charging rates will shorten their life span significantly--or just kill them quick.

10) Where multiple batteries are in series, parallel, or series/parallel, do not mix batteries differing in age, size or usage level. Your best batteries will operate only at the capacity of your poorest or oldest cells. When purchasing batteries, plan on their longevity, and upgrade as needed at the end of their expected life span. If you add new batteries to old, expect them to perform at the capacity of your poorest or oldest cells.

11) Use a hydrometer—a tool to test the specific gravity of each cell in your battery—to give you an indication of the quality of each cell and true charge level. A good time to do this is after equalization; a written record is handy, to compare results with previous equalizations and to keep an eye on any cells that may be a problem in the future. A weak battery can cause premature failure of companion batteries--or simply pull the efficiency of your entire system down. If you don't check and maintain your batteries, you will never

know what problem cells you may have. Don't call your service person about a problem without a basic check of battery condition.

12) Match your voltage charger to the size of your battery bank; you will not be happy with the performance of an undersized charger, and an oversized charger can cause excessive heat and gassing—and even a deadly explosion or other problems.

13) Bring your lead acid batteries up to full charge as soon as you can; using them in a partially discharged condition will compromise their longevity and reduce their capacity. If you are using you batteries hard in a home power system, they should be brought up to a full state of charge at least once to twice a week

14) Inactivity can kill a lead acid battery. If seasonal usage is mandated, try the following:

A. Completely charge the battery before storing.

B. Remove all electrical connections from the battery.

C. Store the battery in as cool a place as possible—but not below 32°F. The colder the temperatures, the more the rate of self-discharge.

D. When not in use, boost with a charge every two months or so; or, buy a small (10 watt or less) solar module (per battery) to "trickle charge" your battery.

APPENDIX VI: WATER PUMPING DESIGN

Pumps

A solar-powered water system is one of the easiest solar power systems to install, since you will not need a battery or battery charging equipment. When the sun is shining, the system is pumping, when the sun is not shining, the system is off—simple.

By adding a storage tank and increasing the size of the pumping system, excess pumped water can be stored, which can continue to supply water during the night or when it's cloudy and the pump is off. Low voltage DC pumps designed to operate on solar power are not designed like 220-volt AC water pumps. A DC water pump is designed to pump using the absolute minimum of electrical power. Unfortunately, this also usually means a very low flow rate, so having a storage tank or open trough is essential.

Although the flow rate can be less than one gallon per minute (GPM) for the smaller pump sizes, this small flow will be fairly constant throughout the solar day (9 AM to 3 PM for most locations). This low flow rate can still provide over 350 gallons of water per day from all but the deepest well applications.

Most applications should have the modules and pump controller mounted on a raised pole to avoid potential damage from animals. A pole mount also allows easier adjustment of module tilt and east-west orientation during initial setup to achieve the best overall year-round performance. For most applications the tilt will be equal to your latitude.

Pumping basics

Any well or pressure pump is designed to provide a given flow of water (GPM) for a given pressure or lift (head). Pumping "head" is measured in feet, and represents the total lift the pump can raise water from a low point to a high point. When measuring the distance a submerged pump must raise water, you do not start with how far down the pump is in the well. You start by measuring from the above ground surface down to the lowest level the well water will be during pumping.

Well Example:
The project is to fill an open water tank (no pressure) that is on the top of a small hill. It is estimated that the water level in this tank will be 3 feet high above ground level, but the hill top is 50-feet higher than where the well is going to be drilled. The well will be 100 feet deep and the pump will be positioned 80 feet down. The water level is only 30 feet below the surface, but will probably drop considerably when the pumping starts unless it is a very fast refilling well. It will also be necessary to estimate how much "draw-down" the well will have during pumping (the well driller may be able to provide this information). Assuming a fast recharging well, add another 20 feet for this estimated draw-down.

Therefore for this example, the pump would need to have a minimum lift of (30 feet + 20 feet to lowest water level) + 50 feet elevation of the tank + 3 feet tank water depth = 103 feet total pumping head. To convert feet head to pounds per square inch (PSI) pressure, divide by 2.31 which equals 45 PSI (103/2.31). In a situation in which the tank is closed and pressurized, the desired tank water pressure must be added to this pump's head pressure.

Lake Example:
Instead of a deep well, the project might necessitate pumping from a lake or pond at a lower level up to a storage tank. The pump lift estimating procedures used in the above deep well example also apply. However, measurement is from the lake's surface level, regardless of how deep the pump will be below the surface.

When using a large body of water as a water source the pump should be suspended off the bottom using an underwater support or surface floats to avoid plugging the pump intake with mud from the bottom.

Solar module sizing

Always consult with the DC pump distributor to confirm the size of solar array that the project team has calculated for your specific application. For high pumping heads (feet of lift) or high flow rates, consider buying a higher voltage DC pump instead of a smaller 12-volt DC pump. This will require using two or more nominal 12-volt solar modules to provide the higher voltage.

To get you started with solar array sizing, it is rare that any solar-pumping application can get by with less than a 75-watt solar module, and larger applications will require two modules for acceptable pump performance. A 48-volt DC pump will require a minimum of four nominal 12-volt solar modules (4x12).

Pump Controller

A solar powered pumping system should include a pump controller. Although it is possible to connect the pump leads directly to the output terminals of the solar module, a controller provides much better pump performance and start/stop control. It will also avoid trying to operate the pump in a stalled condition when solar output is too low.

Each residential-size solar module will produce a fairly constant 17-volts output at almost any level of sunlight. However, the current output (amps) will be directly proportional to sun intensity. The pump will have a minimum current draw when stalled and no pumping is taking place. As the voltage is increased, pump rotation and water pumping is increased as long as enough current is available. During less than ideal solar periods, the current output of the solar module(s) can be below the amp draw required for the pump to begin pumping. A solar pump controller will convert any excess voltage of the solar array to more output current.


Figure 4- 9. Kyocera solar pump controller (cover removed)

The resulting lower voltage will not provide the normal flow output from the slower turning pump, but it will allow reduced flow during those hours the pump will normally be "stalled." In addition to matching the voltage and current load of the pump with the charging current and voltage output of the solar module, a solar-pump controller also includes wiring terminals for normally open (n.o.) and normally closed (n.c.) switch contacts. This makes it easy to add a high and low level float switch to the storage tank, or a low-limit float switch for the well or pond providing the water source.

Water Demand

The average person needs a minimum of five litres (1.3 gallons) of water per day to survive in a moderate climate at an average activity level, according to UN figures. The minimum amount of water needed for drinking and cooking, bathing and sanitation is 50 litres (13 gallons).

The average person in the United States uses between 250 to 300 litres of water (65-78 gallons) per day for drinking, cooking bathing, and watering their yard. The average person in the Netherlands uses only 104 litres (27 gallons) per day.

Piping head loss

In addition to the elevation head (feet) your pump must lift the water from a low pond or drilled well up to a storage tank, it also must overcome the resistance to flow of the pipe. For small-flow DC pumping applications, if you oversize the piping to reduce friction loss, you could increase sediment problems at these low flow data rates. Table 2 provides piping resistance to flow in terms of head (feet). This makes it easy to calculate total pump size, by adding this pipe friction head loss to the lift head estimate.

A typical residential size 1/2-HP deep well pump can pump over six GPM, which produces a much higher velocity. For these larger flow AC pumps, larger pipe sizing is used to keep flow resistance low on long piping runs. However, for a low-flow solar pump for applications requiring less than 100 feet of piping, a 1/2-inch PVC pipe size will probably work just fine. For runs over 100 feet, consider using 3/4-inch PVC piping. If it is necessary to pump water over 300 feet, a 1-inch pipe size will lower the high pressure drop of the smaller pipe, but this may result in problems with sediment settling in the bottom of the pipe due to the low flow rates involved.

TABLE 2: PVC piping head loss (feet) for each 100 feet of pipe

FLOW GPM	½-INCH	¾-INCH	1-INCH
0.5	0.27	X	X
1.0	0.99	X	X
1.5	2.09	X	X
2.0	3.56	0.90	X
2.5	5.38	1.37	X
3.0	X	1.92	X
4.0	X	3.26	1.01
5.0	X	4.93	1.52
6.0	X	X	2.13
8.0	X	X	3.64

Note: "X" not recommended due to low velocity or high pressure drop.

As an example, calculate the piping pressure loss for a 2-gallon per minute flow through 250 feet of pipe. If 1/2-inch PVC pipe is used, the loss would be 8.9 feet head (3.56 x 250/100). If the pipe size is increased to 3/4-inch PVC, the loss would be 2.3 feet head (0.90 x 250/100). At this low flow rate either pipe size will work, unless the pump cannot handle the additional pressure loss of the smaller pipe. As flow rates increase, a larger pipe may be unavoidable on longer pipe runs.

Pump selection

Table 3 provides a size comparison of several popular models of smaller DC pumps, and the relationship of pump flow (GPM) to pump head (feet). Notice how the same pump will have a substantially reduced flow rate as this head pressure is increased. This is only a very limited list of pump models and brands available, consult specific manufacturers for more specific sizing information.

TABLE 3: DC pump flow vs. head

PUMP MODEL	DC Volts	25 ft. head	100 ft. head	200 ft. head
ShurFlo #9300	12	0.98 GPM	0.86 GPM	X
	24	1.9 GPM	1.72 GPM	X
SolarJack SCS	30	6.5 GPM	X	X
	60	X	5.1 GPM	X
	75	X	X	3.0 GPM
Dankoff #5218	48	2.7 GPM	2.1 GPM	1.8 GPM
Dankoff #5226	48	3.6 GPM	3.2 GPM	2.7 GPM

Note: Some DC pumps are designed to operate at several different voltages, producing higher flow as you add more solar modules.

The manufacturers listed in Table 3 offer many other pump models having many different combinations of DC voltage, flow rate, and head or lift. Selecting the right pump for your specific application can reduce the size and cost of the solar array that will be required to provide the power.

Buying a low cost pump with poor efficiency will require a much more expensive solar array.

Direct mechanical wind mills

Wind powered water pumping systems fall under three categories. Direct mechanical coupling, wind-electric, and wind-compressed air. Each has different properties. The most common type in the past has been direct mechanical, however this has been replaced with wind-electric now.

Direct mechanical connection to jack pump, or helical rotor pump. This would also include rope pumps driven by windmills. In Africa many of these pumps, using helical rotor pumps, were installed in the 80's. In America, the jack pump was the more used option. These performed poorly in low winds compared to helical rotor pumps, due to the cyclic load imposed by the pump jack, unless a flywheel or counterbalance is used to smooth the load.

Wind-compressed air pumps

Another method of transferring the mechanical wind power to moving water is to operate an air compressor on the top of the tower. The compressed air can be sent via a hose for long distances to the pump. There are three types of pumps which can be used with this. Because these pumps introduce water into the supply line, it must be sloped uniformly upward until is surfaces to an open storage reservoir, where the air can escape.

Airlift Pump

In this pump the compressed air is injected into the bottom of a riser pipe. The bubbles of air reduce the density of the liquid in the pipe, and it rises. The location where the air is injected must be some depth below the surface of the water in the well – usually 60% of the total lift will be below the water surface level.

Geyser Pump

The geyser pumps operates similarly to the airlift pumps, but with modifications for improved performance under varying airflow. Instead of continuously injecting air bubbles into the water, air flows into an accumulator chamber, which then releases a large bubble. This solved the problem of small amount of air, but not enough to lift the water, under low air flow conditions, which may be encountered when the compressor is driven by a variable speed source, such as a windmill.

APPENDIX VII: HYDRO TURBINES

Types of Turbines

The turbine is the machinery, which the water runs through to convert its mechanical energy to kinetic energy. The runner is the actual turning part of the turbine. The turbine converts the energy in falling water into shaft power. There are several types of turbines as discussed below.

Impulse turbines

For an impulse design turbine, the water pressure is converted to kinetic energy by a nozzle, which reduces the area of flow and increases the water flow velocity. This high speed jet of water is directed to strike the turbine buckets or blades, which turns the turbine by absorbing the kinetic energy of the jet.

The casing around the runner serves only as a splashguard and is not under pressure. Under certain designs the casing may actually be under suction if a draft tube is used to increase the effective head. Because the casing is not under pressure the shaft seals between the runner and the generator do not have to be high quality. The working parts of the turbine are easily accessible, and the turbine tends to be tolerant of dirt in the water supply, as long as clogging of the nozzles is prevented.

The impulse turbine must have free discharge, meaning that the runner cannot be submerged in the water. If the runner becomes submerged, it will stop.

There are three types of Impulse turbines in wide use for micro-hydro installations. All may achieve over 90% peak efficiency.

Pelton turbines

Pelton turbines have bucket-shaped runners as shown in Figure 1. The water enters on the same plane as the plane of runner rotation and is diverted to both sides. A single jet can only be about 1/3rd the width of the runner, to prevent exiting water from interfering with incoming water, but up to four jets can be used on one runner. Another alternative to increase power output without increasing bucket size (which increases runner diameter and decreases runner speed) is to use two or more runners on the same shaft, with separate nozzles for each. Efficiency of this type of runner can be good over a wide range of flow rates by adjusting the number of nozzles operating at any particular time. This turbine is particularly good at resisting dirty water, and has been used in one case to extract energy from sewage coming from a town to a treatment plant below it.

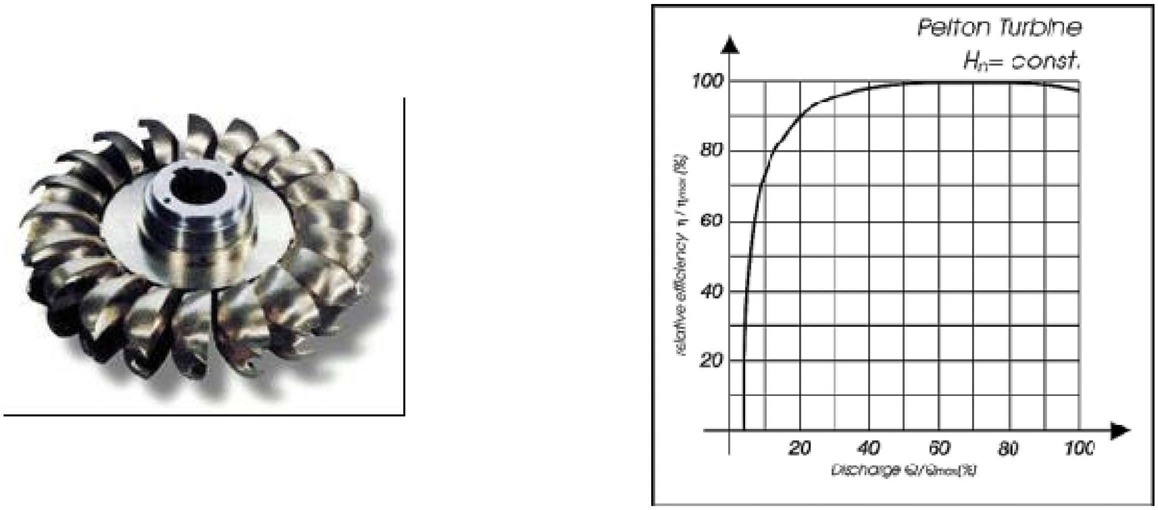


Figure 1: The Pelton Turbine

Turgo turbines

Turgo turbines are similar to a Pelton turbine except that water enters from one side of the runner, and is directed out the other side, as shown in Figure 2. This allows a larger jet size for a given runner diameter and can therefore can obtain more power from a smaller runner than with a pelton runner. This can also translate to higher speed for a given head and flowrate than is achievable with a pelton runner. The drawback of the turgo runner is that it produces an axial force on the runner, which means that bearings must be more robust.

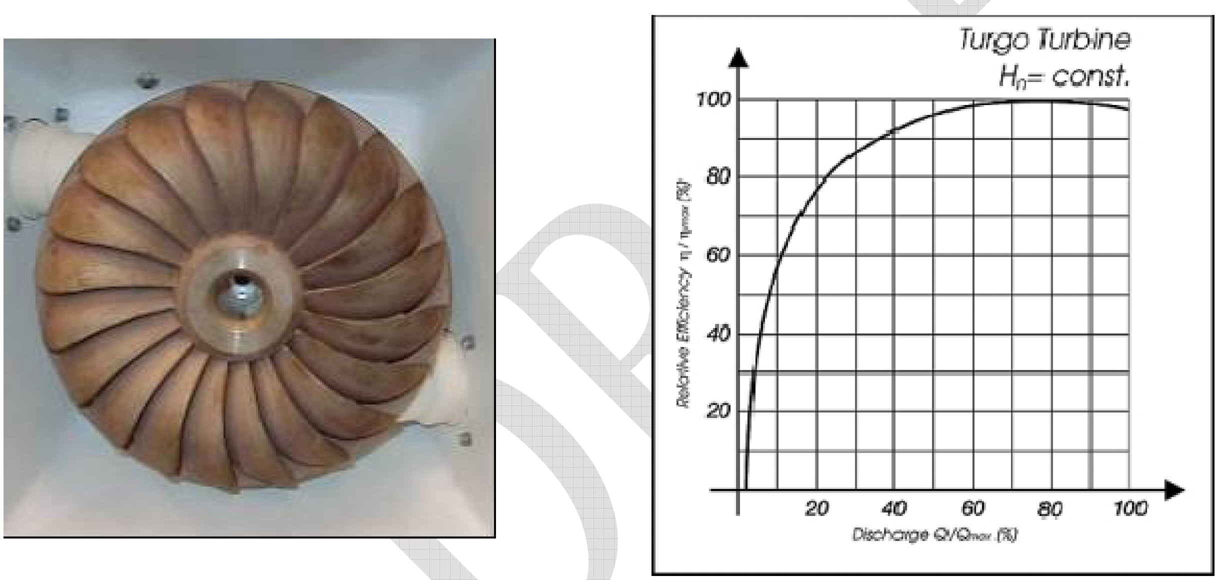


Figure 2: The Turgo Turbine

Crossflow Turbine

The Crossflow turbine's design is shown in Figure 3. An advantage of this runner is that it can be made as wide as needed for a given flow rate and power output, without affecting diameter, and hence rotational speed. It uses a rectangular jet instead of the circular jet of the Pelton and Turgo runners. If the jet is very close to the runner it can have a reaction component as well as impulse component. A Crossflow turbine can also operate efficiently over a wide range of design flows by changing the active width of nozzle. This type is popular for local fabrication since is does not require complicated metal shaping. Sometimes a draft tube is used to increase the head by creating a suction on the housing. This is only useful at a low head site, as the theoretical maximum suction created could only be 32 feet, and the actual value will be much less. This requires sealing the housing well to prevent air leaks, as well as providing a vent in case the water level in the draft tube becomes to deep, to prevent submergence of the runner.

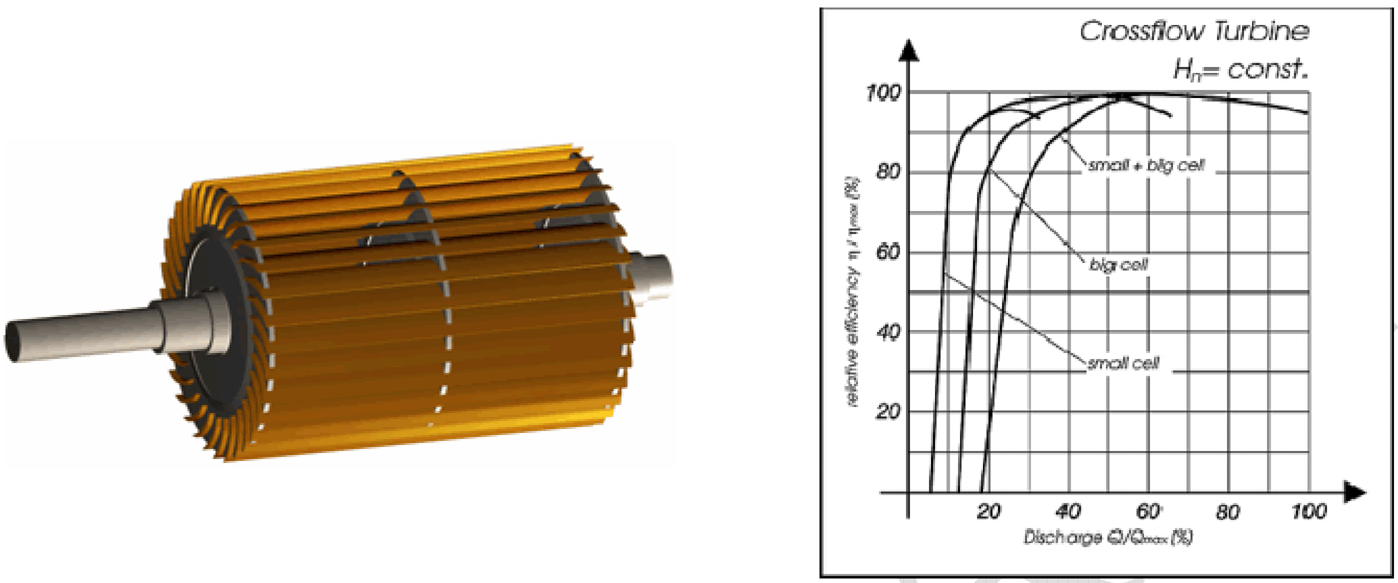


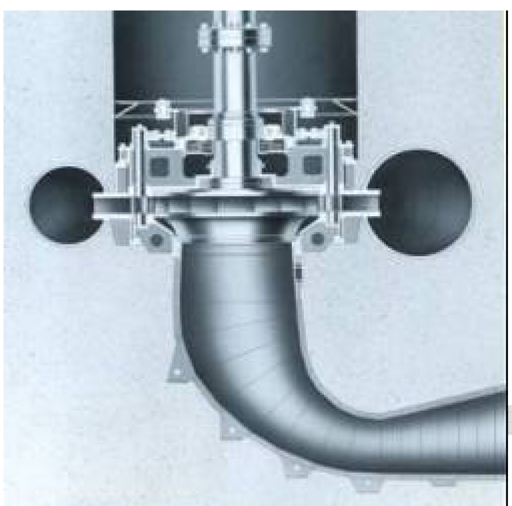
Figure 3: The Cross-flow Turbine

Reaction turbines

In a reaction turbine water pressure exerts force directly on runner as it flows through and the angular and linear momentum of the water is transferred to the turbine. The runner is completely submerged. Advantages of this design over an impulse turbine are higher rotational speed for a given diameter runner. For micro hydro systems a high enough speed can often be obtained with an impulse turbine, however for the much larger utility scale hydroelectric plants a reaction turbine is usually needed. Another benefit is that the available head can be increased with a draft tube below the runner more easily than for impulse turbines, making development of low head sites more practical. Drawbacks are that the casing of the runner must withstand water pressure, as it is filled with water. They are also more susceptible to runaway speed from load loss, whereas impulse turbines will self limit to around twice their design speed by stalling at high speeds due to the attack angle of the water to the bucket being too high. For a fully submerged runner this does not happen as rapidly and under no load the turbine may reach xxx times the design speed. Peak efficiency may be up to 90%. See Table 1 for a summary of turbine types.

Francis Turbine

Francis turbines are a popular type for large-scale hydro installations, however the difficulty and expense of manufacturing usually precludes their use for micro hydro facilities. While a typical Francis runner cannot function satisfactorily as a pump, a typical centrifugal pump will function as a Francis runner. Therefore small centrifugal pumps are sometimes adapted to use for micro hydro stations. The efficiency will not be as high as for a turbine runner designed for that purpose, however the cost is often much lower than having a small Francis runner custom fabricated. Efficiency tends to be best as the design flow rate and fall off relatively quickly at lower flow rates.



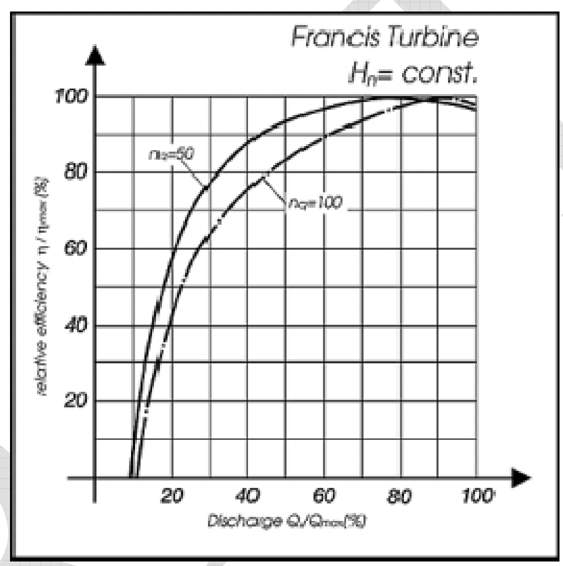


Figure 4: The Francis Turbine

Propeller turbines

Propeller turbines look like a ship propeller. They may have external guide vanes to direct the water into the propeller. They can generate relatively high speeds with low head. Various configurations are used with the axis of the turbine being vertical, horizontal, or angled. Because the flow of the water is along the axis, some method must be used for getting the power shaft outside the water flow. As with the Francis turbine, it looses efficiency at less than the design flow. A variation of the propeller turbine called the Kaplan turbine uses variable pitch blades in order to operate efficiently down to 30% of the design flow.

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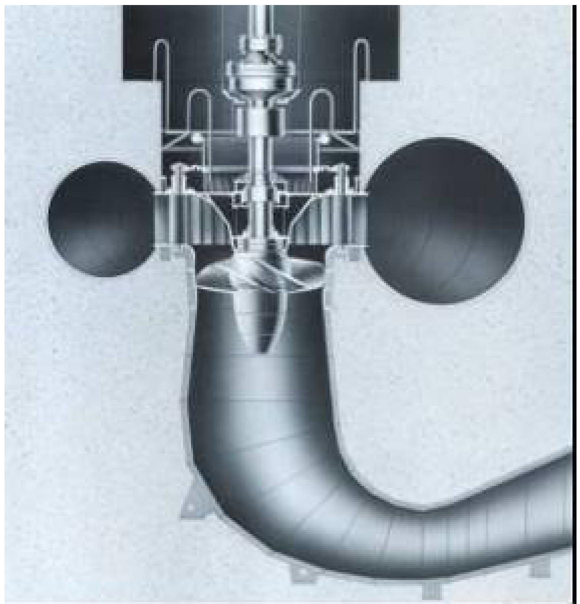

Figure 5: The Propeller Turbine

TURBINE RUNNER	HEAD PRESSURE		
	High	**Medium**	**Low**
Impulse	Pelton Turgo Multi-jet Pelton	Crossflow Turgo Multi-jet Pelton	Crosflow
Reaction		Francis	Propeller
		Pump-as Turbine	Kaplan

Table 1 – Classification of turbine types.
Source: Micro-hydro Design Manual, IT Publications, 1993

Speed control of turbines

The speed of turbines can be controlled several ways. The most common method for large hydroelectric installations is to use a governor, which adjusts the amount of water allowed into the turbine using a mechanical speed governing linkage with the turbine shaft. For small turbines this type of speed control is often too expensive. Instead, the turbine is always run at full power and an electronic controller adjusts a dump load to regulate the battery voltage. In some cases this is also done with systems without batteries, regulating the load to maintain a operational speed. Constant speed control is less important with DC turbines than AC turbines, as frequency of the power is not related to the rotational speed of the turbine. In some cases an impulse turbine operating a DC generator can be allowed to over-speed until it stalls, instead of regulating the speed. Pelton wheels can be fitted with sleeves that to not impede water flow at normal speed, but at higher speeds they obstruct the exiting water jet, causing the turbine to stall at only 1.5-2 times the rated operating speed.

Gearing for proper generator speed

For small turbines the runner is often directly coupled to the generator. Larger turbines may require gearing up to obtain the required speed. This may be done with flat, V, or timing belt drives, chain drives, or gearboxes. Flat or V belt drives are the most common, as they are the least expensive, and give a margin of safety because of the slight slip and stretch of the belts if one component were to suddenly stop. Timing belts and chain drives give slightly higher efficiency. Gearboxes are usually not used because of cost, however used automotive components could be used.