Converters

The regulator provides DC power at a specific voltage. Converters and inverters are used to adjust the voltage to match the requirements of your load.

DC/DC Converters

DC/DC converters transform a continuous voltage to another continuous voltage of a different value. There are two conversion methods which can be used to adapt the voltage from the batteries: ***linear conversion*** and ***switching conversion***.

Linear conversion lowers the voltage from the batteries by converting excess energy to heat. This method is very simple but is obviously inefficient. Switching conversion generally uses a magnetic component to temporarily store the energy and transform it to another voltage. The resulting voltage can be greater, less than, or the inverse (negative) of the input voltage.

The efficiency of a linear regulator decreases as the difference between the input voltage and the output voltage increases. For example, if we want to convert from 12 V to 6 V, the linear regulator will have an efficiency of only 50%. A standard switching regulator has an efficiency of at least 80%.

DC/AC Converter or Inverter

Inverters are used when your equipment requires AC power. Inverters chop and invert the DC current to generate a square wave that is later filtered to approximate a sine wave and eliminate undesired harmonics. Very few inverters actually supply a pure sine wave as output. Most models available on the market produce what is known as "modified sine wave", as their voltage output is not a pure sinusoid. When it comes to efficiency, modified sine wave inverters perform better than pure sinusoidal inverters.

Be aware that not all the equipment will accept a modified sine wave as voltage input. Most commonly, some laser printers will not work with a modified sine wave inverter. Motors will work, but they may consume more power than if they are fed with a pure sine wave. In addition, DC power supplies tend to warm up more, and audio amplifiers can emit a buzzing sound.

Aside from the type of waveform, some important features of inverters include:

- **Reliability in the presence of surges.** Inverters have two power ratings: one for continuous power, and a higher rating for peak power. They are capable of providing the peak power for a very short amount of time, as when starting a motor. The inverter should also be able to safely interrupt itself (with a circuit breaker or fuse) in the event of a short circuit, or if the requested power is too high.

- **Conversion efficiency.** Inverters are most efficient when providing 50% to 90% of their continuous power rating. You should select an inverter that most closely matches your load requirements. The manufacturer usually provides the performance of the inverter at 70% of its nominal power.
- **Battery charging.** Many inverters also incorporate the inverse function: the possibility of charging batteries in the presence of an alternative source of current (grid, generator, etc). This type of inverter is known as a charger/inverter.
- **Automatic fall-over.** Some inverters can switch automatically between different sources of power (grid, generator, solar) depending on what is available.

When using telecommunication equipment, it is best to avoid the use of DC/AC converters and feed them directly from a DC source. Most communications equipment can accept a wide range of input voltage.

Equipment or load

It should be obvious that as power requirements increase, the expense of the photovoltaic system also increases. It is therefore critical to match the size of the system as closely as possible to the expected load. When designing the system you must first make a realistic estimate of the maximum consumption. Once the installation is in place, the established maximum consumption must be respected in order to avoid frequent power failures.

Home Appliances

The use of photovoltaic solar energy is not recommended for heat-exchange applications (electrical heating, refrigerators, toasters, etc.) Whenever possible, energy should be used sparingly using low power appliances.

Here are some points to keep in mind when choosing appropriate equipment for use with a solar system:

- The photovoltaic solar energy is suitable for illumination. In this case, the use of halogen light bulbs or fluorescent lamps is mandatory. Although these lamps are more expensive, they have much better energy efficiency than incandescent light bulbs. LED lamps are also a good choice as they are very efficient and are fed with DC.
- It is possible to use photovoltaic power for appliances that require low and constant consumption (as in a typical case, the TV). Smaller televisions

use less power than larger televisions. Also consider that a black-and-white TV consumes about half the power of a color TV.

- Photovoltaic solar energy is not recommended for any application that transforms energy into heat (thermal energy). Use solar heating or butane as alternative.
- Conventional automatic washing machines will work, but you should avoid the use of any washing programs that include centrifuged water heating.
- If you must use a refrigerators, it should consume as little power as possible. There are specialized refrigerators that work in DC, although their consumption can be quite high (around 1000 Wh/day).

The estimation of total consumption is a fundamental step in sizing your solar system. Here is a table that gives you a general idea of the power consumption that you can expect from different appliances.

Equipment	Consumption (Watts)
Portable computer	30-50
Low power lamp	6-10
WRAP router (one radio)	4-10
VSAT modem	15-30
PC (without LCD)	20-30
PC (with LCD)	200-300
Network Switch (16 port)	6-8

Wireless telecommunications equipment

Saving power by choosing the right gear saves a lot of money and trouble. For example , a long distance link doesn't necessarily need a strong amplifier that draws a lot of power. A Wi-Fi card with good receiver sensitivity and a fresnel zone that is at least 60% clear will work better than an amplifier, and save power consumption as well. A well known saying of radio amateurs applies here, too: The best amplifier is a good antenna. Further measures to reduce power consumption include throttling the CPU speed, reducing transmit power to the minimum value that is necessary to provide a stable link, increasing the length of beacon intervals, and switching the system off during times it is not needed.

Most autonomous solar systems work at 12 or 24 volts. Preferably, a wireless device that runs on DC voltage should be used, operating at the 12 Volts that most lead acid batteries provide. Transforming the voltage provided by the battery to AC or using a voltage at the input of the access point different from the voltage of the battery will cause unnecessary energy loss. A router or access point that accepts 8-20 Volts DC is perfect.

Most cheap access points have a switched mode voltage regulator inside and will work through such a voltage range without modification or becoming hot (even if the device was shipped with a 5 or 12 Volt power supply).

WARNING: Operating your access point with a power supply other than the one provided by your manufacturer will certainly void any warranty, and may cause damage to your equipment. While the following technique will typically work as described, remember that should you attempt it, you do so at your own risk.

Open your access point and look near the DC input for two relatively big capacitors and an inductor (a ferrite toroid with copper wire wrapped around it). If they are present then the device has a switched mode input, and the maximum input voltage should be somewhat below the voltage printed on the capacitors. Usually the rating of these capacitors is 16 or 25 volts. Be aware that an unregulated power supply has a ripple and may feed a much higher voltage into your access point than the typical voltage printed on it may suggest. So, connecting an unregulated power supply with 24 Volts to a device with 25 Volt-capacitors is not a good idea. Of course, opening your device will void any existing warranty. Do not try to operate an access point at higher voltage if it doesn't have a switched mode regulator. It will get hot, malfunction, or burn.

Equipment based on traditional Intel x86 CPUs are power hungry in comparison with RISC-based architectures as ARM or MIPS. One of the boards with lowest power consumptions is the Soekris platform that uses an AMD ElanSC520 processor. Another alternative to AMD (ElanSC or Geode SC1100) is the use of equipment with MIPS processors. MIPS processors have a better performance than an AMD Geode at the price of consuming between 20-30% of more energy.

The popular Linksys WRT54G runs at any voltage between 5 and 20 volts DC and draws about 6 Watts, but it has an Ethernet switch onboard. Having a switch is of course nice and handy - but it draws extra power. Linksys also offers a Wi-Fi access point called WAP54G that draws only 3 Watts and can run OpenWRT and Freifunk firmware. The 4G Systems Accesscube draws about 6 Watts when equipped with a single WiFi interface. If 802.11b is sufficient, mini-PCI cards with the Orinoco chipset perform very well while drawing a minimum amount of power.

Equipment	Consumption (Watts)
Linksys WRT54G (BCM2050 radio)	6
Linksys WAP54G (BCM2050 radio)	3
Orinoco WavePoint II ROR (30mW radio)	15
Soekris net4511 (no radio)	1.8
PC Engines WRAP.1E-1 (no radio)	2.04
Mikrotik Routerboard 532 (no radio)	2.3
Inhand ELF3 (no radio)	1.53
Senao 250mW radio	3
Ubiquiti 400mW radio	6

The amount of power required by wireless equipment depends not only on the architecture but on the number of network interfaces, radios, type of memory/storage and traffic. As a general rule, a wireless board of low consumption consumes 2 to 3 W, and a 200 mW radio card consumes as much as 3 W. High power cards (such as the 400 mW Ubiquity) consume around 6 W. A repeating station with two radios can range between 8 and 10 W.

Although the standard IEEE 802.11 incorporates a power saving mode (PS) mechanism, its benefit is not as good as you might hope. The main mechanism for energy saving is to allow stations to periodically put their wireless cards to "sleep" by means of a timing circuit. When the wireless card wakes up it verifies if a beacon exists, indicating pending traffic. The energy saving therefore only takes place in the client side, as the access point always needs to remain awake to send beacons and store traffic for the clients. Power saving mode may be incompatible between implementations from different manufacturers, which can cause unstable wireless connections. It is nearly always best to leave power saving mode disabled on all equipment, as the difficulties created will likely outweigh the meager amount of saved power.

Selecting the voltage

Most low power stand-alone systems use 12 V battery power as that is the most common operational voltage in sealed lead-acid batteries. When designing a wireless communication system you need to take into consideration the most efficient voltage of operation of your equipment. While the input voltage can accept a wide range of values, you need to ensure that the overall power consumption of the system is minimal.

Wiring

An important component of the installation is the wiring, as proper wiring will ensure efficient energy transfer. Some good practices that you should consider include:

- Use a screw to fasten the cable to the battery terminal. Loose connections will waste power.
- Spread Vaseline or mineral jelly on the battery terminals. Corroded connection have an increased resistance, resulting in loss.
- For low currents (<10 A) consider the use of Faston or Anderson powerpole connectors. For bigger currents, use metallic ring lugs.

Wire size is normally given in American Wire Gauge (AWG). During your calculations you will need to convert between AWG and mm^2 to estimate cable resistance. For example, an AWG #6 cable has a diameter of 4.11 mm and can handle up to 55 A. A conversion chart, including an estimate of resistance and current carrying capacity, is available in **Appendix D**. Keep in mind that the current carrying capacity can also vary depending on the type of insulation and application. When in doubt, consult the manufacturer for more information.

Orientation of the panels

Most of the energy coming from the sun arrives in straight line. The solar module will capture more energy if it is “facing” the sun, perpendicular to the straight line between the position of the installation and the sun. Of course, the sun's position is constantly changing relative to the earth, so we need to find an optimal position for our panels. The orientation of the panels is determined by two angles, the ***azimuth* a** and the ***inclination*** or ***elevation* ß**. The azimuth is the angle that measures the deviation with respect to the south in the northern hemisphere, and with respect to the north in the southern hemisphere. The inclination is the angle formed by the surface of the module and the horizontal plane.

Azimuth

You should have the module turned towards the terrestrial equator (facing south in the northern hemisphere, and north in the southern) so that during the day the panel catches the greatest possible amount of radiation (a = 0).

It is very important that no part of the panels are ever under shade!. Study the elements that surround the panel array (trees, buildings, walls, other panels, etc.) to be sure that they will not cast a shadow on the panels at any time of the day or year. It is acceptable to turn the panels ±20º towards the east or the west if needed (a = ±20º).

Inclination

Once you have fixed the azimuth, the parameter that is key in our calculations is the inclination of the panel, which we will express as the angle beta (ß). The maximum height that the sun reaches every day will vary, with the maximum on the day of the summer solstice and the minimum on the winter solstice. Ideally, the panels should track this variation, but this is usually not possible for cost reasons.

In installations with telecommunications equipment it is normal to install the panels at a fixed inclination. In most telecommunications scenarios the energy demands of the system are constant throughout the year. Providing for sufficient power during the "worst month" will work well for the rest of the year.

The value of ß should maximize the ratio between the offer and the demand of energy.

- For installations with consistent (or nearly consistent) consumption throughout the year, it is preferable to optimize the installation to capture the maximum radiation during "the winter" months. You should use the absolute value of the latitude of the place (angle F) increased by 10° (ß = I F I + 10 °).
- For installations with less consumptions during winter, the value of the latitude of the place can be used as the solar panel inclination. This way the system is optimized for the months of spring and autumn (ß = I F I).
- For installations that are only used during summer, you should use the absolute value of the latitude of the place (angle F) decreased by 10° (ß = I F I - 10°).

The inclination of the panel should never be less than 15° to avoid the accumulation of dust and/or humidity on the panel. In areas where snow and ice occur, it is very important to protect the panels and to incline them an angle of 65° or greater.

If there is a considerable increase in consumption during the summer, you might consider arranging for two fixed inclinations, one position for the months of summer and another for the months of winter. This would require special support structures and a regular schedule for changing the position of the panels.

How to size your photovoltaic system

When choosing equipment to meet your power needs, you will need to determine the following, at a minimum:

- The number and type of solar panels required to capture enough solar energy to support your load.
- The minimum capacity of the battery. The battery will need to store enough energy to provide power at night and through days with little sun, and will determine your number of days of autonomy.
- The characteristics of all other components (the regulator, wiring, etc.) needed to support the amount of power generated and stored.

System sizing calculations are important, because unless the system components are balanced, energy (and ultimately, money) is wasted. For example, if we install more solar panels to produce more energy, the batteries should have enough capacity to store the additional energy produced. If the bank of batteries is too small and the load is not using the energy as it is generated, then energy must be thrown away. A regulator of a smaller amperage than needed, or one single cable that is too small, can be a cause of failure (or even fire) and render the installation unusable.

Never forget that the ability of the photovoltaic energy to produce and store electrical energy is limited. Accidentally leaving on a light bulb during the day can easily drain your reserves before nighttime, at which point no additional power will be available. The availability of "fuel" for photovoltaic systems (i.e. solar radiation) can be difficult to predict. In fact, it is never possible to be absolutely sure that a standalone system is going to be able to provide the necessary energy at any particular moment. Solar systems are designed for a certain consumption, and if the user exceeds the planned limits the provision of energy will fail.

The design method that we propose consists of considering the energy requirements, and based on them to calculate a system that works for the maximum amount of time so it is as reliable as possible. Of course, if more panels and batteries are installed, more energy will be able to be collected and stored. This increase of reliability will also have an increase in cost.

In some photovoltaic installations (such as the provision of energy for telecommunications equipment on a network backbone) the reliability factor is more important that the cost. In a client installation, low cost is likely going to be a the most important factor. Finding a balance between cost and reliability is not a easy task, but whatever your situation, you should be able to determine what it is expected from your design choices, and at what price.

The method we will use for sizing the system is known as the ***method of the worst month***. We simply calculate the dimensions of the standalone system so it will work in the month in which the demand for energy is greatest with respect to the available solar energy. It is the worst month of the year, as this month with have the largest ratio of demanded energy to available energy.

Using this method, ***reliability*** is taken into consideration by fixing the maximum number of days that the system can work without receiving solar radiation (that is, when all consumption is made solely at the expense of the energy stored in the battery.) This is known as the ***maximum number of days of autonomy*** (N), and can be thought of as the number of consecutive cloudy days when the panels do not collect any significant amount of energy.

When choosing N, it is necessary to know the climatology of the place, as well as the economic and social relevance of the installation. Will it be used to illuminate houses, a hospital, a factory, for a radio link, or for some other application? Remember that as N increases, so does the investment in equipment and maintenance. It is also important to evaluate all possible logistical costs of equipment replacement. It is not the same to change a discharged battery from an installation in the middle of a city versus one at the top a telecommunication tower that is several hours or days of walking distance.

Fixing the value of N it is not an easy task as there are many factors involved, and many of them cannot be evaluated easily. Your experience will play an important role in this part of the system sizing. One commonly used value for critical telecommunications equipment is N = 5, whereas for low cost client equipment it is possible to reduce the autonomy to N = 3.

In **Appendix E**, we have included several tables that will facilitate the collection of required data for sizing the system. The rest of this chapter will explain in detail what information you need to collect or estimate and how to use the method of the "worst month".

Data to collect

- **Latitude of the installation**. Remember to use a positive sign in the northern hemisphere and negative in the south.
- **Solar radiation data**. For the method of the "worst month" it is enough to know just twelve values, one for every month. The twelve numbers are the monthly average values of daily global irradiation on horizontal plane ($G_{dm}(0)$, in kWh/m^2 per day). The monthly value is the sum of the values of global irradiation for every day of the month, divided by the number of days of the month.

If you have the data in Joules (J), you can apply the following conversion:

$$1\ J = 2.78 \times 10^{-7}\ kWh$$

The irradiation data $G_{dm}(0)$ of many places of the world is gathered in tables and databases. You should check for this information from a weather station close to your implementation site, but do not be surprised if you cannot find the data in electronic format. It is a good idea to ask companies that install photovoltaic systems in the region, as their experience can be of great value.

Do not confuse "sun hours" with the number of "peak sun hours". The number of peak sun hours has nothing to do with the number of hours without clouds, but refers to the amount of daily irradiation. A day of 5 hours of sun without clouds does not necessary have those hours when the sun is at its zenith.

A peak sun hour is a normalized value of solar radiation of 1000 W/m^2 at 25 C. So when we refer to 5 peak sun hours, this implies a daily solar radiation of 5000 W/m^2.

Electrical characteristics of system components

The electrical characteristics of the components of your system should be provided by the manufacturer. It is advisable to make your our own measurements to check for any deviation from the nominal values. Unfortunately, deviation from promised values can be large and should be expected.

These are the minimum values that you need to gather before starting your system sizing:

Panels

You need to know the voltage V_{Pmax} and the current I_{Pmax} at the point of maximum power in standard conditions.

Batteries

Nominal capacity (for 100 hours discharge) C_{NBat}, operational voltage V_{NBat}, and either the maximum depth of discharge DoD_{max} or useful capacity C_{UBat}. You also need to know the type of battery that you plan to use, whether sealed lead-acid, gel, AGM, modified traction etc. The type of battery is important when deciding the cut-off points in the regulator.

Regulator

You need to know the nominal voltage V_{NReg}, and the maximum current that can operate I_{maxReg}.

DC/AC Converter/Inverter

If you are going to use a converter, you need to know the nominal voltage V_{NConv}, instantaneous power P_{IConv} and performance at 70% of maximum load H_{70}.

Equipment or load

It is necessary to know the nominal voltage V_{NC} and the nominal power of operation P_C for every piece of equipment powered by the system.

In order to know the total energy that our installation is going to consume, it is also very important to consider the average time each load will be used. Is it constant? Or will it be used daily, weekly, monthly or annually? Consider any changes in the usage that might impact the amount of energy needed (seasonal usage, training or school periods, etc.)

Other variables

Aside from the electrical characteristics of the components and load, it is necessary to decide on two more pieces of information before being able to size a photovoltaic system. These two decisions are the required number of days of autonomy and the operational voltage of the system.

N, number of days of autonomy

You need to decide on a value for N that will balance meteorological conditions with the type of installation and overall costs. It is impossible to give a concrete value of N that is valid for every installation, but the next table gives some recommended values. Take these values as a rough approximation, and consult with an experienced designer to reach a final decision.

Available Sunlight	Domestic Installation	Critical Installation
Very cloudy	5	10
Variable	4	8
Sunny	3	6

V_N, nominal voltage of the installation

The components of your system need to be chosen to operate at a nominal voltage V_N. This voltage is usually 12 or 24 Volts for small systems, and if the total power of consumption surpasses 3 kW, the voltage will be 48 V. The selection of V_N is not arbitrary, and depends on the availability of equipment.

- If the equipment allows it, try to fix the nominal voltage to 12 or 24 V. Many wireless communications boards accept a wide range of input voltage and can be used without a converter.
- If you need to power several types of equipment that work at different nominal voltages, calculate the voltage that minimizes the overall power consumption including the losses for power conversion in DC/DC and DC/AC converters.

Procedure of calculation

There are three main steps that need to be followed to calculate the proper size of a system:

1. **Calculate the available solar energy (the offer)**. Based on statistical data of solar radiation, and the orientation and the optimal inclination of the solar panels, we calculate the solar energy available. The estimation of solar energy available is done in monthly intervals, reducing the statistical data to 12 values. This estimation is a good compromise between precision and simplicity.
2. **Estimate the required electrical energy (the demand)**. Record the power consumption characteristics of the equipment chosen as well as estimated usage. Then calculate the electrical energy required on a monthly basis. You should consider the expected fluctuations of usage due to the variations between winter and summer, the rainy period / dry season, school / vacation periods, etc. The result will be 12 values of energy demand, one for each month of the year.

3. **Calculate the ideal system size (the result)**. With the data from the "worst month", when the relation between the solar demanded energy and the energy available is greatest, we calculate:
   - The current that the array of panels needs to provide, which will determine the minimum number of panels.
   - The necessary energy storage capacity to cover the minimum number of days of autonomy, which will determine the required number of batteries.
   - The required electrical characteristics of the regulator.
   - The length and the necessary sections of cables for the electrical connections.

Required current in the worst month

For each month you need to calculate the value of I_m, which is the maximum daily current that an array of panels operating at nominal voltage of V_N needs to provide, in a day with a irradiation of G_{dm} for month "m", for panels with an inclination of ß degrees..

The I_m(WORST MONTH) will be the largest value of I_m, and the system sizing is based on the data of that worth month. The calculations of G_{dm}(ß) for a certain place can be made based on G_{dm}(0) using computer software such as PVSYST (*http://www.pvsyst.com/*) or PVSOL (*http://www.solardesign.co.uk/*).

Due to losses in the regulator and batteries, and due to the fact that the panels do not always work at the point of maximum power, the required current I_{mMAX} is calculated as:

$$I_{mMAX} = 1.21\ I_m\ \text{(WORST MONTH)}$$

Once you have determined the worst month, the value of I_{mMAX}, and the total energy that you require E_{TOTAL}(WORST MONTH) you can proceed to the final calculations. E_{TOTAL} is the sum of all DC and AC loads, in Watts. To calculate E_{TOTAL} see **Appendix E**.

Number of panels

By combining solar panels in series and parallel, we can obtain the desired voltage and current. When panels are connected in series, the total voltage is equal to the sum of the individual voltages of each module, while the current remains unchanged. When connecting panels in parallel, the currents are summed together while the voltage remains unchanged. It is very important, to use panels of nearly identical characteristics when building an array.

You should try to acquire panels with V_{Pmax} a bit bigger than the nominal voltage of the system (12, 24 or 48 V). Remember that you need to provide a few volts more than the nominal voltage of the battery in order to charge it. If it is not possible to find a single panel that satisfies your requirements, you need to connect several panels in series to reach your desired voltage. The number of panels in series N_{ps} is equal to the nominal voltage of the system divided by the voltage of a single panel, rounded up to the nearest integer.

$$N_{ps} = V_N / V_{Pmax}$$

In order to calculate the number of panels in parallel (N_{pp}), you need to divide the I_{mMAX} by the current of a single panel at the point of maximum power I_{pmax}, rounded up to the nearest integer.

$$N_{pp} = I_{mMAX} / I_{Pmax}$$

The total number of panels is the result of multiplying the number of panels in series (to set the voltage) by the number of panels in parallel (to set the current).

$$N_{TOTAL} = N_{ps} \times N_{pp}$$

Capacity of the battery or accumulator

The battery determines the overall voltage of the system and needs to have enough capacity to provide energy to the load when there is not enough solar radiation.

To estimate the capacity of our battery, we first calculate the required energy capacity of our system (necessary capacity, C_{NEC}). The necessary capacity depends on the energy available during the "worst month" and the desired number of days of autonomy (N).

$$C_{NEC}\ (Ah) = E_{TOTAL}(WORST\ MONTH)(Wh) / V_N(V) \times N$$

The nominal capacity of the battery C_{NOM} needs to be bigger than the C_{NEC} as we cannot fully discharge a battery. To calculate the size of the battery we need to consider the maximum depth of discharge (DoD) that the battery allows:

$$C_{NOM}(Ah) = C_{NEC}(Ah) / DoD_{MAX}$$

In order to calculate the number of batteries in series (N_{bs}), we divide the nominal voltage of our installation (V_N) by the nominal voltage of a single battery (V_{NBat}):

$$N_{bs} = V_N \ / \ V_{NBat}$$

Regulator

One important warning: always use regulators in series, never in parallel. If your regulator does not support the current required by your system, you will need to buy a new regulator with a larger working current.

For security reasons, a regulator needs to be able to operate with a current I_{maxReg} at least 20% greater than the maximum intensity that is provided by the array of panels:

$$I_{maxReg} = 1.2 \ N_{pp} \ I_{PMax}$$

DC/AC Inverter

The total energy needed for the AC equipment is calculated including all the losses that are introduced by the DC/AC converter or inverter. When choosing an inverter, keep in mind that the performance of the inverter varies according to the amount of requested power. An inverter has better performance characteristics when operating close to its rated power. Using a 1500 Watt inverter to power a 25 Watt load is extremely inefficient. In order to avoid this wasted energy, it is important to consider not the peak power of all your equipment, but the peak power of the equipment that is expected to operate simultaneously.

Cables

Once you know the numbers of panels and batteries, and type of regulators and inverters that you want to use, it is necessary to calculate the length and the thickness of the cables needed to connect the components together.

The **length** depends on the location of your the installation. You should try to minimize the length of the cables between the regulator, panels, and batteries. Using short cables will minimize lost power and cable costs.

The **thickness** is chosen is based on the length of the cable and the maximum current it must carry. The goal is to minimize voltage drops. In order to calculate the thickness S of the cable it is necessary to know:

- The maximum current I_{MC} that is going to circulate in the cable. In the case of the panel-battery subsystem, it is I_{mMAX} calculated for every month. In the battery-load subsystem it depends on the way that the loads are connected.
- The voltage drop (V_a-V_b) that we consider acceptable in the cable. The voltage drop that results of adding all possible individual drops is expressed as a percent of the nominal voltage of the installation. Typical maximum values are:

Component	Voltage Drop (% of V_N)
Panel Array -> Battery	1%
Battery -> Converter	1%
Main Line	3%
Main Line (Illumination)	3%
Main Line (Equipment)	5%

Typical acceptable voltage drops in cables

The section of the cable is determined by Ohm's Law:

$$S(mm^2) = r(\Omega mm^2/m) L(m)\ I_{mMAX}(A) / \ (V_a-V_b)(V)$$

where S is the section, r is resistivity (intrinsic property of the material: for copper, 0.01286 $\Omega mm^2/m$), and L the length.

S is chosen taking into consideration the cables available in the market. You should choose the immediately superior section to the one that is obtained from the formula. For security reasons that are some minimum values, for the cable that connects panels and battery, this is a minimum of 6 mm^2. For the other sections, that minimum is 4 mm^2.

Cost of a solar installation

While solar energy itself is free, the equipment needed to turn it into useful electric energy is not. You not only need to buy equipment to transform the solar energy in electricity and store it for use, but you must also replace and maintain various components of the system. The problem of equipment replacement is often overlooked, and a solar system is implemented without a proper maintenance plan.

In order to calculate the real cost of your installation, we include an illustrative example. The first thing to do it is to calculate the initial investment costs.

Description	Number	Unit Cost	Subtotal
60W Solar panel (about $4 / W)	4	$300	$1,200
30A Regulator	1	$100	$100
Wiring (meters)	25	$1 / meter	$25
50 Ah Deep cycle batteries	6	$150	$900
		Total:	$2,225

The calculation of our investment cost is relatively easy once the system has been dimensioned. You just need to add the price for each piece equipment and the labor cost to install and wire the equipments together. For simplicity, we do not include the costs of transport and installation but you should not overlook them.

To figure out how much a system will really cost to operate we must estimate how long each part will last and how often you must replace it. In accounting terminology this is known as ***amortization***. Our new table will look like this:

Description	#	Unit Cost	Subtotal	Lifetime (Years)	Yearly Cost
60W Solar panel	4	$300	$1,200	20	$60
30A Regulator	1	$100	$100	5	$20
Wiring (meters)	25	$1 / meter	$25	10	$2.50
50 Ah Deep cycle batteries	6	$150	$900	5	$180
		Total:	$2,225	Annual Cost:	$262.50

As you see, once the first investment has been done, an annual cost of $262.50 is expected. The annual cost is an estimation of the required capital per year to replace the system components once they reach the end of their useful life.

8
Building an Outdoor Node

There are many practical considerations when installing electronic equipment outdoors. Obviously, it has to be protected from the rain, wind, sun, and other harsh elements. Power needs to be provided, and the antenna should be mounted at a sufficient height. Without proper grounding, nearby lightning strikes, fluctuating mains power, and even a light winds in the proper climate can annihilate your wireless links. This chapter will give you some idea of the practical problems you will be up against when installing wireless equipment outdoors.

Waterproof enclosures

Suitable waterproof enclosures come in many varieties. Metal or plastic may be used to create a watertight container for outdoor embedded equipment.

Of course, equipment needs power to work, and will likely need to connect to an antenna and Ethernet cable. Each time you pierce a watertight enclosure, you provide another potential place for water to seep in.

The National Electrical Manufacturers Association (NEMA) provides guidelines for protection of electrical equipment from rain, ice, dust, and other contaminants. An enclosure with a rating of ***NEMA 3*** or better is suitable for outdoor use in a fair climate. A ***NEMA 4X*** or ***NEMA 6*** provides excellent protection, even from hose driven water and ice. For fixtures that pierce the body of an enclosure (such as cable glands and bulkhead connectors), the International Electrotechnical Commission (IEC) assigns an ingress protection (IP) rating. An ingress protection rating of ***IP66*** or ***IP67*** will protect these holes from very strong jets of water. A good outdoor enclosure should also provide UV protection to prevent breakdown of the seal from exposure to the sun, as well as to protect the equipment inside.

Of course, finding NEMA or IEC rated enclosures may be a challenge in your local area. Often, locally available parts can be repurposed for use as enclosures. Rugged plastic or metal sprinkler boxes, electrical conduit housings, or even plastic food containers can be used in a pinch. When piercing an enclosure, use quality gaskets or o-rings along with a cable gland to seal the opening. UV stabilized silicone compound or other sealant can be used for temporary installations, but remember that cables flex in the wind, and glued joints will eventually weaken and allow moisture to seep in.

You can greatly extend the life of a plastic enclosure by providing some protection from the sun. Mounting the box in the shade, either beneath existing equipment, solar panel, or thin sheet of metal specifically for this purpose, will add to the life span of the box as well as the equipment contained inside.

Before putting any piece of electronics in a sealed box, be sure that it has minimal heat dissipation requirements. If your motherboard requires a fan or large heat sink, remember that there will be no airflow, and your electronics will likely bake to death on the tower. Only use electronic components that are designed to be used in an embedded environment.

Providing power

Obviously, DC power can be provided by simply poking a hole in your enclosure and running a wire. If your enclosure is large enough (say, an outdoor electrical box) you could even wire an AC outlet inside the box. But manufacturers are increasingly supporting a very handy feature that eliminates the need for an additional hole in the box: ***Power over Ethernet*** (***POE***).

The 802.3af standard defines a method for supplying power to devices using the unused pairs in a standard Ethernet cable. Nearly 13 Watts of power can be provided safely on a CAT5 cable without interfering with data transmissions on the same wire. Newer 802.3af compliant Ethernet switches (called ***end span injectors***) supply power directly to connected devices. End span switches can supply power on the same wires that are used for data (pairs 1-2 and 3-6) or on the unused wires (pairs 4-5 and 7-8). Other equipment, called ***mid span injectors,*** are inserted between Ethernet switches and the device to be powered. These injectors supply power on the unused pairs.

If your wireless router or CPE includes support for 802.3af, you could in theory simply connect it to an injector. Unfortunately, some manufacturers (notably Cisco) disagree on power polarity, and connecting mismatching gear can damage the injector and the equipment to be powered. Read the fine