7

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), NEMA 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 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 print and be sure that your injector and wireless equipment agree on which pins and polarity should be used for power.

If your wireless equipment doesn't support power over Ethernet, you can still use the unused pairs in a CAT5 cable to carry power. You can either use a ***passive POE injector***, or simply build one yourself. These devices manually connect DC power to the unused wires on one end of the cable, and connect the other end directly to a barrel connector inserted in the device's power receptacle. A pair of passive POE devices can typically be purchased for under $20.

To make your own, you will need to find out how much power the device requires to operate, and provide at least that much current and voltage, plus enough to account for loss in the Ethernet run. You don't want to supply too much power, as the resistance of the small cable can present a fire hazard. Here is an online calculator that will help you calculate the voltage drop for a given run of CAT5 : *http://www.gweep.net/~sfoskett/tech/poecalc.html*

Once you know the proper power and electrical polarity needed to power your wireless gear, crimp a CAT5 cable only using the data wires (pairs 1-2 and 3-6). Then simply connect the transformer to pairs 4-5 (usually blue / blue-white) and 7-8 (brown / brown-white) on one end, and a matching barrel connector on the other. For a complete guide to building your own POE injector from scratch, see this terrific guide from NYCwireless: *http://nycwireless.net/poe/*

Mounting considerations

In many cases, equipment can be located inside a building, provided there is a window with ordinary glass through which the beam can travel. Normal glass will introduce little attenuation, but tinted glass will introduce unacceptable attenuation. This greatly simplifies mounting, power, and weatherproofing problems, but is obviously only useful in populated areas.

When mounting antennas on towers, it is very important to use a stand off bracket, and not mount the antennas directly to the tower. These brackets help with many functions including antenna separation, antenna alignment and protection.

Stand off brackets need to be strong enough to support the weight of the antenna, and also hold it in place on windy days. Remember, antennas can act like small sails, and can put a lot of force on to their mounts in strong winds. When estimating wind resistance, the total surface of the antenna structure must be considered, as well as the distance from the centre of the antenna to the point of attachment to the building. Large antennas such as solid dishes or high gain sectorial panels can have considerable wind load. Using a slotted or mesh parabolic, rather than a solid dish, will help reduce the wind load without much affect on antenna gain. Be sure that the mounting brackets and supporting structure are solid, or your antennas will become misaligned over time (or worse, fall off the tower entirely!)

Mounting brackets must have enough clearance from the tower to allow for aiming, but not too much clearance that the antennas become too hard to reach if any service or maintenance is required.

Figure 7.1: An antenna with a standoff bracket being lifted onto a tower.

The pipe on the standoff bracket that the antenna will be mounted on needs to be round. This way the antenna can be pivoted on the pipe for aiming. Secondly, the pipe must also be vertical. If it is being mounted on a tapered tower, the standoff bracket will have to be designed to allow for this. This can be done using different lengths of steel, or by using combinations of threaded rod and steel plates.

As the equipment will be outside for all of its service life, it is important to be sure that the steel used is weatherproofed. Stainless steel often has too high a price tag for tower installations. Hot galvanizing is preferred, but may not be available in some areas. Painting all steel with a good rust paint will also work. If paint is chosen, it will be important to plan a yearly inspection of the mount and repaint when necessary.

Guyed towers

A climbable guyed tower is an excellent choice for many installations, but for very tall structures a self supporting tower might be required.

When installing guyed towers, a pulley attached to the top of a pole will facilitate the tower installation. The pole will be secured to the lower section already in place, while the two tower sections are attached with an articulated joint. A rope passing through the pulley will facilitate the raising of the next section. After the cantilever section becomes vertical, bolt it to the lower section of the pole. The pole (called a gin pole in the trade) can then be removed, and the operation may be repeated, if required. Tighten the guy wires carefully, ensuring that you use the same tension at all suitable anchoring points. Chose the points so that the angles, as seen from the center of the tower, are as evenly spaced as possible.

Figure 7.2: A climbable guyed tower.

Self-supporting towers

Self supporting towers are expensive but sometimes needed, particularly when greater elevation is a requirement. This can be as simple as a heavy pole sunk into a concrete piling, or as complicated as a professional radio tower.

Figure 7.3: A simple self-supporting tower.

An existing tower can sometimes be used for subscribers, although AM transmitting station antennas should be avoided because the whole structure is active. FM station antennas are acceptable, provided that at least a few of meters of separation is kept between the antennas. Be aware that while adjacent transmitting antennas may not interfere with your wireless connection, high powered FM may interfere with your wired Ethernet cable. Whenever using a heavily populated antenna tower, be very scrupulous about proper grounding and consider using shielded cable.

Figure 7.4: A much more complicated tower.

Rooftop assemblies

Non-penetrating roof mount antenna assemblies can be used on flat roofs. These consist of a tripod mounted to a metal or wooden base. The base is then weighed down with bricks, sandbags, water jugs, or just about anything heavy. Using such a rooftop “sled” eliminates the need to pierce the roof with mounting bolts, avoiding potential leaks.

Figure 7.5: This metal base can be weighed down with sandbags, rocks, or water bottles to make a stable platform without penetrating a roof.

Wall mount or metal strap assemblies can be used on existing structures such as chimneys or the sides of a buildings. If the antennas have to be mounted more than about 4 meters above the rooftop, a climbable tower may be a better solution to allow easier access to the equipment and to prevent antenna movement during high winds.

Dissimilar metals

To minimize electrolytic corrosion when two different metals are in moist contact, their electrolytic potential should be as close as possible. Use dielectric grease on the connection between two metals of different type to prevent any electrolysis effect.

Copper should never touch galvanized material directly without proper joint protection. Water shedding from the copper contains ions that will wash away the galvanized (zinc) tower covering. Stainless steel can be used as a buffer material, but you should be aware that stainless steel is not a very good conductor. If it is used as a buffer between copper and galvanized metals, the surface area of the contact should be large and the stainless steel should be thin. Joint compound should also be used to cover the connection so water can not bridge between the dissimilar metals.

Protecting microwave connectors

Moisture leakage in connectors is likely the most observed cause of radio link failure. Be sure to tighten connectors firmly, but never use a wrench or other tool to do so. Remember that metals expand and contract as temperature changes, and an over-tightened connector can break in extreme weather changes.

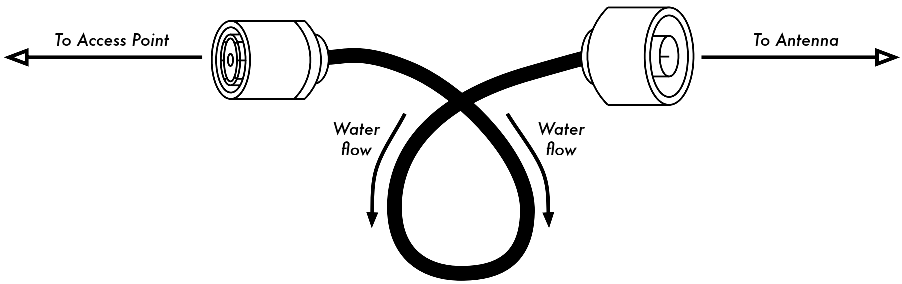

Figure 7.6: A drip loop forces rainwater away from your connectors.

Once tight, connectors should be protected by applying a layer of electrical tape, then a layer of sealing tape, and then another layer of electrical tape on top. The sealant protects the connector from water seepage, and the tape layer protects the sealant from ultraviolet (UV) damage. Cables should have an extra drip loop to prevent water from getting inside the transceiver.

Safety

Always use a harness securely attached to the tower when working at heights. If you have never worked on a tower, hire a professional to do it for you. Many countries require special training for people to be allowed to work on towers above a certain height.

Avoid working on towers during strong winds or storms. Always climb with a partner, and only when there is plenty of light. Tower work will likely take longer than you think it will. Remember that it is **extremely** hazardous to work in the dark. Give yourself plenty of time to complete the job long before the sun sets. If you run out of time, remember that the tower will be there in the morning, when you can start on the problem again after a good night's sleep.

Aligning antennas on a long distance link

The key to successfully aligning antennas on a very long distance link is communication. If you change too many variables at once (say, one team starts wiggling an antenna while the other tries to take a signal strength reading), then the process will take all day and will probably end with misaligned antennas.

You will have two teams of people. Ideally, each team should have at least two people: one to take signal readings and communicate with the remote end, the other to manipulate the antenna. Keep these points in mind while working on long distance links.

1. **Test all equipment ahead of time.** You don't want to fiddle with settings once you're in the field. Before separating the equipment, power everything on, connect every antenna and pigtail, and make sure you can establish a connection between the devices. You should be able to return to this known good state by simply powering on the device, without having to log in or change any settings. Now is a good time to agree on antenna polarity (see chapter two if you don't understand what polarity means).
2. **Bring backup communications gear.** While mobile phones are usually good enough for working in cities, mobile reception can be bad or nonexistent in rural areas. Bring a high powered FRS or GMRS radio, or if your teams have amateur radio licenses, use a ham rig. Working at a distance can be very frustrating if you are constantly asking the other team "can you hear me now?" Pick your communication channels and test your radios (including the batteries) before separating.
3. **Bring a camera.** Take some time to document the location of each site, including surrounding landmarks and obstructions. This can be very useful later to determine the feasibility of another link to the location without having to travel there in person. If this is your first trip to the site, log the GPS coordinates and elevation as well.
4. **Start by estimating the proper bearing and elevation.** To begin, both teams should use triangulation (using GPS coordinates or a map) to get a rough idea of the direction to point. Use a compass to roughly align the antenna to the desired bearing. Large landmarks are also useful for pointing. If you can use binoculars to see the other end, all the better. Once you have made your guess, take a signal strength reading. If you are close enough and have made a good guess, you may already have signal.

5. **If all else fails, build your own landmark.** Some kinds of terrain make it difficult to judge the location of the other end of a link. If you are building a link in an area with few landmarks, a self-made landmark such as a kite, balloon, flood light, flare, or even smoke signal might help. You don't necessarily need a GPS to get an idea of where to point your antenna.

6. **Test signal in both directions, but only one at a time.** Once both ends have made their best guess, the end with the lowest gain antenna should make fix their antenna into position. Using a good monitoring tool (such as Kismet, Netstumbler, or a good built-in wireless client), the team with the highest gain antenna should slowly sweep it horizontally while watching the signal meter. Once the best position is found, try altering the elevation of the antenna. After the best possible position is found, lock the antenna firmly into place and signal the other team to begin slowly sweeping around. Repeat this process a couple of times until the best possible position for both antennas is found.

7. **Don't touch the antenna when taking a reading.** Your body will affect the radiation pattern of the antenna. Do not touch the antenna, and don't stand in the path of the shot, when taking signal strength readings. The same goes for the team on the other side of the link, too.

8. **Don't be afraid to push past the best received signal.** As we saw in chapter four, radiation patterns incorporate many smaller sidelobes of sensitivity, in addition to a much larger main lobe. If your received signal is mysteriously small, you may have found a sidelobe. Continue sweeping slowly beyond that lobe to see if you can find the main lobe.

9. **The antenna angle may look completely wrong.** The main lobe of an antenna often radiates slightly to one side or the other of the visual dead center of the antenna. Don't worry about how the antenna looks; you are concerned with finding the best possible position to achieve the greatest possible received signal.

10. **Double-check polarization.** It can be frustrating to attempt aligning a dish only to discover that the other team is using the opposite polarization. Again, this should be agreed upon before leaving home base, but if a link stays stubbornly weak, a double check doesn't hurt.

11. **If nothing works, check all components one at a time.** Are the devices on both ends of the link powered on? Are all pigtails and connectors properly connected, with no damaged or suspect parts? As outlined in chapter eight, proper troubleshooting technique will save you time and frustration. Work slowly and communicate your status well with the other team.

By working methodically and communicating well, you can complete the job of aligning high gain antennas in just a short while. If done properly, it should be fun!

Surge and lightning protection

Power is the greatest challenge for most installations in the developing world. Where there are electrical networks, they are often poorly controlled, fluctuate dramatically and are susceptible to lightning. Proper surge protection is critical to not only protect your wireless equipment, but all of the equipment connected to it.

Fuses and circuit breakers

Fuses are critical, but very often neglected. In rural areas, and even in many urban areas of developing countries, fuses are difficult to find. Despite the added cost, it is always prudent to use circuit breakers instead. These may need to be imported, but shouldn't be overlooked. Too often, replaceable fuses are removed and pocket change is used instead. In a recent case, all of the electronic equipment at at rural radio station was destroyed when a lightning strike went through the circuit, without circuit breaker or even a fuse to protect it.

How to ground

Proper grounding doesn’t have to be a complicated job. When grounding, you are trying to accomplish two things: provide a short-circuit for a lightning strike, and provide a circuit for excess energy to be dissipated.

The first step is to protect equipment from a direct or near direct lightning hit, while the second provides a path to dissipate excess energy that would otherwise cause a build-up of static electricity. Static can cause significant degradation to signal quality, particularly on sensitive receivers (VSATs for example). Providing the short-circuit is simple. The installer simply needs to make the shortest path from the highest conductive surface (a lightning rod) to the ground. When a strike hits the rod, the energy will travel the shortest path and thus by-pass the equipment. This ground should be able to handle high-voltage (i.e. you need thick gauge wire, like 8 gauge braided copper).

To ground the equipment, mount a lightning rod above the equipment on a tower or other structure. Then use a thick gauge conductive wire to connect the rod to something that itself is well grounded. Underground copper pipes can be very well grounded (depending on their depth, the moisture, salinity, amount of metal and organic content of the soil). In many sites in West Africa, pipes aren’t yet in the ground, and previous grounding equipment is often inadequate due to ill-conductive soil (typical of seasonally arid, tropical soils). There are three easy ways to measure the efficiency of your ground:

1. The least accurate is to simply plug a good quality UPS or power strip into the circuit that has a ground detect indicator (a LED light). This LED is lit by energy that is being diffused to the ground circuit. An effective ground will dissipate small amounts of energy to the ground. Some people actually use this to pirate a bit of free light, as this energy does not turn an electrical counter!
2. Take a light socket and a low-wattage bulb (30 Watts), connect one wire to the ground wire and the second to the positive current. If the ground is working, the bulb should shine slightly.
3. The more sophisticated way is to simply measure the impedance between the positive circuit and the ground.

If your ground is not efficient you will need to bury a grounding stake deeper (where the soil is more moist, has more organic matter and metals) or you need to make the ground more conductive. A common approach where there is little soil is to dig a hole that is 1 meter in diameter and 2 meters deep. Drop in a highly conductive piece of metal that has some mass to it. This is sometimes called a ***plomb***, which literally means lead but can be any heavy piece of metal weighing 500 kg or more, such as an iron anvil or steel wheel. Then fill the hole with charcoal and mix in salt, then top with soil. Soak the area, and the charcoal and salt will diffuse around the hole and make a conductive area surrounding your plomb, improving the efficiency of the ground.

If radio cable is being used, it too can be used to ground the tower, though a more resilient design is to separate the ground for the tower from the cable. To ground the cable, simply peel back a bit of cable at the point closest to the ground before it goes into the building, then attach a ground cable from that point, either by soldering or using a very conductive connector. This then needs to be waterproofed.

Power stabilizers & regulators

There are many brands of power stabilizers, but most are either digital or electromechanical. The latter are much cheaper and more common. Electromechanical stabilizers take power at 220V, 240V, or 110V and use that energy to turn a motor, which always produces the desired voltage (normally 220V). This is normally effective, but these units offer little protection from lightning or other heavy surges. They often burn out after just one strike. Once burnt, they can actually be fused at a certain (usually wrong) output voltage.

Digital regulators regulate the energy using resistors and other solid state components. They are more expensive, but are much less susceptible to being burnt.

Whenever possible, use a digital regulator. They are worth the added cost, and will offer better protection for the rest of your equipment. Be sure to inspect all components of your power system (including the stabilizer) after lightning activity.

Solar and wind power

The applications described in this chapter use DC voltage. DC - Direct Current - has a polarity. Confusing the polarity will very likely immediately and irreversibly damage your equipment! I'll assume that you can handle a digital multimeter (DMM) to check out polarity. The DC voltages that are used in the described applications are not harmful when you touch conductors - but big lead-acid batteries can provide very high currents. A cable that creates a short between the terminals will immediately start to glow and burn its insulation. To prevent fire, there must be a fuse near the positive terminal of the battery at all times. That way the fuse will burn out before the cables do.

Lead acid batteries contain sulfuric acid that can cause severe burns. They release hydrogen when they are charged or have a short between terminals - even when they are the sealed acid type. Proper venting is necessary to prevent explosions, especially if the batteries are of the flooded cell acid type. It’s a good idea to protect your eyes with safety glasses when handling these batteries. I once met a battery “expert” that blew off three batteries during his career. Lead is toxic - make sure you dispose of worn out batteries properly. This may be difficult in countries that don't have any recycling infrastructure.

Off-the-grid power

There are many situations where you want to install a wireless node in an area where the grid providing mains power is unstable or just not existing. This could be a remote wireless relay, or a developing country where the grid fails often.

An autonomous power system consists basically of a battery which stores electric energy that is produced by a wind, solar and/or gasoline generator. Furthermore, electronic circuitry that controls the charging/discharging process is necessary.

It is important to choose a device that draws a minimum of energy when designing an system for operation on solar energy or wind power. Every watt that is wasted on the consumer side causes high costs at the side of the power source. More power consumption means that larger solar panels and bulkier batteries will be necessary to provide sufficient energy. 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 (toroid with copper wire wrapped around it). If they are present, 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.

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.

Another important strategy for saving power is keeping DC power cables short and using a good quality, thick cable. This will keep voltage loss at a minimum.

Calculating and measuring power consumption

The design of an autonomous system always begins with the calculation of how much power is consumed. The easiest way to measure your device is a laboratory power supply that features a voltage and ampere meter. The nominal voltage provided by a lead acid battery typically varies between 11 Volts (empty) and about 14.5 Volt (charging, voltage at charging limit). You can tune the voltage at the laboratory power supply and see how much current the device draws at different voltages. If a laboratory power supply is not available, measurement can be performed by using the supply shipped with the device. Interrupt one cable that goes to the DC input of your device and insert an ***ampere-meter*** (or ***ammeter***). Note that a ammeter will burn itself or your power supply if applied between the positive and negative terminal because it behaves like a simple cable between the probes - thus creating a short. Many ammeters have an unfused input, so exercise caution as they can be easily damaged.

The amount of power consumed can be calculated with this formula:

```
P = U * I
```

P being Power in Watts, U being voltage in Volts, I being current in Ampere. For example:

```
6 Watts = 12 Volts * 0.5 Ampere
```

The result is the rating of the device. If the device of the example is operating for an hour it will simply consume 6 Watt-hours (Wh), respectively 0.5 Ampere-hours (Ah). Thus the device will draw 144 Wh or 12 Ah a day.

To simplify things, I will use the nominal voltage rating of batteries for calculations and not take into account that the voltage provided by the battery varies depending on its state of charge. Batteries are rated at their capacity in Ah - so it is easier to calculate using Ah instead of Wh. A battery from a big truck has typically 170 Ah - thus a 100% charged truck battery would power the device for about 340 hours during a 100% discharging cycle.

Discharging characteristics - Rule of thumb

A 12 Volt lead-acid battery that delivers energy to a consumer provides a voltage depending on it's state of charge. When the battery is 100% charged it has a output voltage of 12.8 Volts which is quickly dropping to 12.6 Volts under load. Given that the battery has to provide constant current the output voltage is now linear, dropping from 12.6 Volt to 11.6 Volts over a long period. Beneath 11.6 Volt the output voltage is dropping down quickly over time. Since the battery provides approximately 95% of it's power within this linear voltage drop, the charging state could be estimated by measuring the voltage under load. The assumption is that the battery is 100% full at 12.6 Volts and has 0% charge at 11.6 Volts. So, when measuring a battery that is currently discharged, the status can be estimated with a digital multimeter. For example a reading of 12.5 Volts corresponds 90% charge, 12.3 Volts corresponds 70% charge, etc.

Lead acid batteries degrade quickly when charging cycles go down to 0% charge. A battery from a truck will lose 50% of it's design capacity within 50 - 150 cycles if it is fully charged and discharged during each cycle. At 0% charge the battery still has 11 Volt at the terminals under load. Never discharge a 12 Volt lead acid battery beneath this value. It will forfeit a huge amount of storage capacity. Discharging to 0 Volt will utterly ruin it. To avoid this, a low voltage disconnect circuit (LVD) should be used to build a battery powered system. In cycle use it is not advisable to discharge a simple truck battery beneath 70%. Not going beneath 80% will significantly increase it's durability. Thus a 170 Ah truck battery has only a usable capacity of 34 to 51 Ah!

A battery from a car or truck should stay beyond 12.3 Volts in the system. In rare cases it may be allowed to drop down beneath this value - an unexpected long period of bad weather for example. This is tolerable if the battery is fully charged after such an incident. Charging to 100% charge takes quite a while because the charging process slows down when approaching the charging end even if there is plenty of energy from the power source. A weak power source may seldom achieve a full charge and thus wear out batteries quickly. It is recommended to charge aggressively to keep cost of ownership low. A wind/solar charging regulator or automatic battery charger (with advanced charge characteristic) will help save money. Best is IUIa-characteristic, IU characteristic is second choice.

Starter batteries are the cheapest batteries available, but they may not be the best option. There are special solar batteries on the market which are designed for use in solar systems. They allow deeper recharging cycles (down to 50% charge, depending on type) and have a low self-discharge current. The same applies to most sealed lead acid batteries. Sealed lead acid batteries are more expensive but safer to handle.

Truck or car batteries that carry the label ***maintenance-free*** should have neglectable low self-discharge current. However, maintenance-free batteries still need maintenance. The level of the electrolyte fluid must be checked frequently, especially in hot climate. If there is loss of electrolyte, distilled water has to be used to fill up the fluid. Neglecting this will ruin the battery.

Charging your batteries too much will destroy them too! The charging current in a battery buffered system must be regulated. Excessive and unlimited charging will destroy the battery. If the voltage in the battery is too high, the water component of the sulfuric acid will be cracked up by electrolysis, causing an atmosphere which contains a concentrated amount of oxygen. Oxygen is very corrosive and will destroy internal connectors.

Designing a battery buffered system

Things are less complicated if there is an unstable mains grid available that does its job every now and then. In that case, all that is needed is a decent automatic charger that is capable of fully charging a battery of sufficient size. A switched mode charger with a wide range voltage input and sophisticated charging characteristics is desirable. This will help protect against the grid, which may provide varying voltages. Cheap chargers that feature a simple transformer may never charge your battery at all if the voltage of the grid is too low. A simple charger designed for 230 Volts AC will provide little to no charging current when operated at 200 Volts or lower. No matter how long it operates, it will never achieve a full charge. On the other hand, it will burn out if the voltage is a little higher than expected - or it will simply ruin the batteries after a while. An AC voltage stabilizer that prevents your charger from burning out due excessive high voltage may be a really good idea in many situations.

A battery buffered system looks like this:

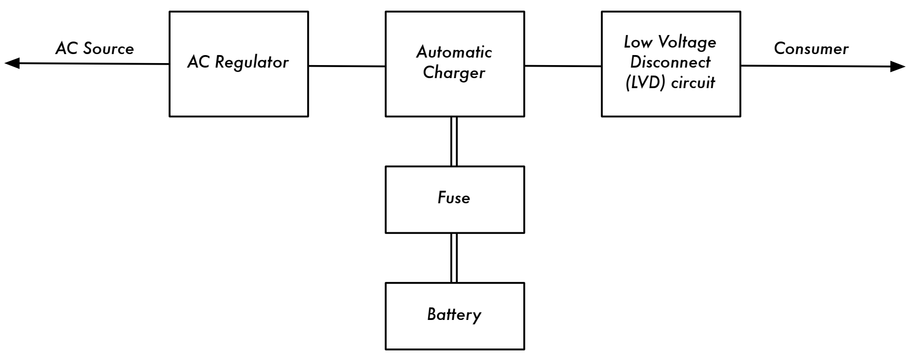

Figure 7.7: The complete battery buffered system.

Suppose our device draws 7 Watts at 12 Volts. We need the service 24 hours a day - so the device will draw:

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168 Wh = 24h * 7 W
```

At 12 Volt the current in ampere would be:

```
14 Ah = 168 Wh / 12 Volt
```

Now, lets assume that occasionally we get a situation where the grid fails for one week.

```
98 Ah = 14 Ah/day * 7 days
1176 Wh = 98 Ah * 12 Volt
```

If we allow our battery to get discharged from 100% to 30% charge, thus consuming 70% of the capacity, we need a storage capacity of:

```
140 Ah = 98 ah / 0.7
```

A truck battery is available with this size.

Usually power comes back for 5 hours a day, thus the system will run 19 hours on battery.

```
133 Wh = 19h * 7 Watt
```

Charging and discharging a battery is never 100% efficient. There will always be energy loss in the battery, so we have to charge with more energy than we get. Charging/discharging efficiency usually is about 75%.

```
177.4 Wh = 133 Wh / 0.75
```

We want to charge aggressively and achieve a full charge within 5 hours.

Considering charging efficiency:

```
166 Wh = 148 Wh / 0.75
```

Converting to Ah:

```
14.8 Ah = 177.4 Wh / 12 Volt
```

Considering charging time:

```
2.96 A = 14.8 Ah / 5h
```

While we are charging the access point/router still draws power. 7 Watts equals 0.6 Ampere at 12 Volts:

```
3.56 A = 2.96 A + 0.6 A
```

We should consider that the charging process slows down near the end of the charge period. It would be better to have a higher initial charging current than calculated to achieve a 100% charge. A charging time of 5 hours is quite short, so a IUIa-charger with 8 Amperes or more is a good investment.

Even a cheap truck battery should last for 5 years, given that the electrolyte is checked frequently. Don't forget to use a low voltage disconnect circuit. It is not a mistake to oversize such a system to some degree. No matter how well designed the system is, the battery component will wear out and need replacement. In general, it is more cost effective to oversize the power source rather than batteries.

Designing a solar or wind powered system

The amount of energy that you can harvest with a solar or wind powered system depends on the area where you are and the time of the year. Usually you'll find information about the energy of the sun radiation or wind speed from administrative bodies competent for weather. They collect such information over the years and can tell you what to expect for each time of the year. Simulation and calculation programs for solar systems are available, PVSOL being one commercial (and expensive) program. A demo version is available in several languages.

Calculating exactly how much energy a solar powered system will produce at a certain site is a lot of work. Involved in the calculation are factors like temperature, number of sun hours, intensity of radiation, reflections in the environment, alignment of the solar panels and so on. A simulation program and weather data are a good place to start, but remember that in the real world, something as simple as dirt on the solar panels can completely spoil the results of your theoretical calculation.

Estimating the amount of energy produced by a wind generator is hard if there are obstacles around the wind generator. The empiric approach would be to measure the actual wind speed at the site over a year - which is rather impractical.

This should be a practical guide. If a fancy computer program and detailed weather data is not available for your country, I would suggest building a pilot system. If the battery does not get sufficiently charged, it is time to increase the number or size of the solar panels. As mentioned before, keeping the power consumption at a minimum is really important to avoid unexpected high costs.

If the system needs to have 100% uptime, considerations will obviously start with the worst time of the year. You have to decide whether the system will need an oversized storage capacity or an oversized power source to provide power through calm periods. It may be much cheaper if someone manually charges the system with a generator running on gasoline in a time of a long dead calm.

Combining wind and solar energy makes the most sense in areas with seasons that provide wind energy when solar energy is weak. For example, in Germany the sun provides only 10% of the energy in winter time compared to summer. In spring and autumn there is not much solar power either, but it is quite windy. Huge batteries are necessary since it is possible that neither solar panels or a wind generator will provide much energy during wintertime.

Under such conditions, a system designed for 100% uptime needs a decent safety margin and a lot of storage capacity. Charging should be done aggressively to achieve full charge as often as possible during periods of good weather. In the long run, solar panels may need replacement every 25 years - while a battery in a system that lacks sufficient charging power may need replacement every year!

Circuit

An autonomous solar system consists of:

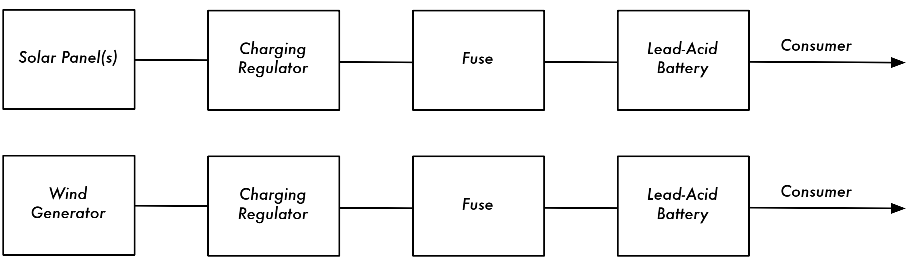

Figure 7.8: A solar powered or wind powered system.

Both systems are connected to the same battery if wind and solar power is combined.

Wind power

A wind generator is a clear option when an autonomous system is being designed for a wireless relay to be built on a hill or mountain. A concern for wind power is that the wind speed must be high enough at a site which may be surrounded by objects. The average wind speed over the year should be at least 3 - 4 meter per second, and the wind generator should be 6 meters higher than other objects within a distance of 100 meters. A location far away from the coast usually lacks sufficient wind energy to support a wind powered system.

Solar power

In most cases, a system using only solar panels is the best solution. It is usually pretty easy to find a location suitable for solar panels, and they contain no mechanical moving parts that need maintenance.

It is important for a solar system that the solar panels are mounted with the best alignment and angle to the sun. The best angle may vary over the year and is dependent on the location of the site. It is a good idea to take into account that dust, leaves or birds may defile a solar panel. The optimum mounting angle may be quite flat, causing dirt to settle on the solar panel, making frequent cleaning necessary.

Shade must not wander over the solar panel during the day, because solar panels consist of a number of solar cells that are connected in a daisy chain. A chain is as strong as its weakest element. If something covers one cell of a solar panel completely - a leaf for example - the entire solar panel will produce no power. Even the shade from a cable will significantly reduce the amount of energy produced by the solar system!

Charging regulators

Charging regulators for wind generators are different from regulators for solar panels. If the system features wind and solar energy two regulators are needed. Each regulator has to be connected to the terminals of the battery directly (via a fuse, of course!).

Influence of maximum power point tracking

Manufacturers of solar panels are optimistic when calculating the power rating of their panels. Thus, the power that is effectively produced by a panel is significantly lower than claimed on the data sheet. The power rating is only achieved at a certain voltage, at a panel temperature of 20 degrees Celsius and at a sun radiation of 1000 Watt per square meter. This is not realistic because a solar panel gets really hot at 1000 Watt radiation per square meter. High temperature reduces the effective power output of a panel. There is not much that can be done about it apart from keeping in mind that a panel never achieves the claimed power rating.

The influence of the panel output voltage is more important to consider in a autonomous system. If a simple charging regulator is used, the voltage in the panel drops down to the level of the battery voltage. A solar panel may have the best efficiency at 18 Volts - it may produce 1 Ampere at 300 Watt/m at 30 degrees Celsius. This point of best efficiency is called ***Maximum Power Point*** or ***MPP***.

Thus, our panel would produce:

```
18 Watt = 18 Volt * 1 Ampere
```

If this panel is connected to a battery at 12.3 Volt the current will be slightly higher than in the MPP, maybe 1.1 Ampere, but the panel voltage will drop down to the level of the battery:

```
13.5 Watt = 12.3 Volt * 1.1 Ampere
```

The efficiency in our example would be only 75% with a simple charging regulator. This problem could be addressed by using a solar regulator with maximum power point tracking. A well designed MPP-regulator achieves an efficiency of 90%. A system with a simple regulator may never achieve more than 70% of the power rating given by the manufacturer.

Increasing battery and solar panel capacity

If you want to combine two (or more) batteries to increase capacity, interconnect them parallel - that is, interconnect both positive terminals with a heavy gauge cable. There must be a fuse in the cable near every positive terminal. Interconnect the negative terminals without fuses. Interconnecting solar panels can be done accordingly without fuses.

Low voltage disconnect circuit

Consumers (your access point, wireless router, or other device) will be connected to the charging regulator. Most charging regulators come with a low voltage disconnect circuit. The low voltage disconnect circuit should never need to switch off, otherwise there is a serious design flaw or damage present. If it happens that there are two or more regulators in the system that have a Low Voltage Disconnect Circuit, then connect the consumers to one regulator only. Otherwise the regulators could be damaged.

Calculation

The calculation of a solar system is not much different than the battery buffered system (as detailed earlier). Obviously, the times when no energy is available for charging could be very long, and there is no fixed charging current that could be used for calculation.

A well designed system should be able to fully recharge an empty battery within a few days in good weather conditions while delivering power to the consumers.