Building a Single Bike Generator

SYSTEM DESIGN

Designing any off-grid system is a question of matching up your supply of energy with the amount of power you will need. A single bicycle generator's capacity for energy production is dependent on the power produced by the cyclist and the condition of the bicycle itself. There are many ways to put together a bike generator, from cheap to super expensive, from cheap to more complicated. All of them have pros and cons and so the choice is really up to you. The generator itself is not the whole story so we have to look at the bigger picture.

The areas we need to take into consideration when we are building our system are:

- Assessing our loads and the potential for reducing these where possible
- Storing power with a battery
- AC or DC or both
- System control
- Distribution of power
- Safety precautions as electricity can be dangerous
- Deciding upon your budget and thinking about a system that you can afford

In this workshop we'll follow the above sections in more detail with some examples of different generator setups at the end. Below is a simple diagram to help guide you through the process:

INITIAL ASSESMENT
- Existing Situation
- What you need to and want to power
- Resources available to you
- Your budget

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LOAD ASSESMENT
- Appliances
- How we're going to use them
- Priorities
- Load reduction

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SYSTEM DESIGN
- Stationary/portable
- Distribution
- Regulation
- AC/DC
- Storage
- Monitoring
- Safety

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SYSTEM

SYSTEM PARTS

Here is a complete list of the components we use to build a single bicycle generator. You may not necessarily need all of the items listed below (depending on your budget or requirements) but it's good to get an idea of all the bits and pieces that can go into the system.

- Bicycle (ideally with slick tyres)
- Bicycle training stand
- DC permanent magnet motor
- Plate or wood for mounting motor
- Skateboard wheel or roller
- Multimeter
- Cable & connectors (30 amp Anderson connectors or mains 3 way connectors)
- Screws, nuts and bolts
- Regulator
- Inverter
- Capacitor
- Heat sink
- 12V connectors x 4
- 12V sockets
- Fuses & fuse holders
- RCD
- Earthing system
- Battery
- System housing e.g. wood box
- Tools e.g.
- Crimp tool
- Soldering iron & solder
- Terminal blocks
- Electrical tape
- Electrical screwdriver
- Spanner
- Needle nose pliers
- Wire cutters and strippers
- Allen keys
- Plug in power meter
- Diode or Bridge Rectifier
- Battery Charger
- Dump Loads

Assessing our loads and the potential for reducing these where possible

Load usually refers to the equipment that we need and wish to power with our bicycle generator. A good first step would be to find out just how much power i.e. its power rating (our load) the different appliances require to do their job. Most appliances have stickers on the bottom of them that tell us either how many watts, volts and amps they use. We can use volts and amps to calculate watts via using the equation $W = I \times V$. Loads are usually measured in watt-hours e.g. a 30 watt DVD player consumes 30 watts every hour it is turned on.

However, it is best to measure appliance consumption with a plug-in power meter (see parts description for further details) as that will give us the most precise information. This is especially important when we're thinking about powering sound equipment, as the equipment specifications don't reflect its actual consumption. You may find that sound equipment often runs at much lower wattage with higher peaks, depending upon the levels that the equipment is set to. For example, a sticker on the amp may read 200W but the amp may only use 30W at the level you require it at. On the other hand some loads may work on three times their operating power for short periods when turned on.

Check out the power consumption table below (taken from the Off The Grid book) to see power consumptions of various appliances. All of this is information is rather important if we don't want to damage our equipment and blow fuses.

Power consumption table

Device	Supply	Power
Halogen light	DC, 12/24V	5–20W
Fluorescent light	DC, 12/24V AC	8–20W 11W–40W
Fridge 225 litre 100 litre	AC AC	150–300W; 2–5kWh/day 100–200W; 1–2kWh/day
Fridge (100 litre)	DC, 12V, 24V	30–60W; 0.2-0.6kWh/day
TV, colour, new	AC	40–120W
TV, colour	DC, 12V	60W
TV, B&W	DC, 12V	10–20W
Music system	AC	30–50W
Portable stereo	DC, 6–12V	5–20W
VCR	AC	10–40W
Computer, desktop	AC	100–250W
Computer, laptop/ notebook	DC, 9–18V	10–30W
Printer, inkjet	DC/AC	15–50W, 2–6W standby
Printer, laser	AC	500–900W
Fax machine	AC	40–80W, 2–6W standby
Photocopier	AC	50W (idle), 700–1500W (operating)
Sewing machine	AC	50–80W
Blender, mixer	AC	100–300W
Vacuum cleaner	AC	500–1500W
Iron	AC	500–1500W
Washing machine	AC	300–800W (cold) 1500–3000W (hot)
VHF/UHV radio	DC, 12/24V	1–10W (standby) 25–80W (transmit)

NB. Most appliances carry a plate or stamp detailing operating voltages and power consumption.

Since powering loads with a bicycle can often be lot of effort and many loads take more than one bike to power, we need to think about ways that we can reduce our loads if possible. For example, many people would like to power a projector but it's not possible with just one bicycle as most consumer projectors require somewhere between 150W to 350W. One way to deal with this situation is to compromise the size of our screen/image quality and use an LED projector that only requires 30W.

Many loads are not possible to power with a bicycle generator as they require too much energy, these are mainly heating loads e.g. AC kettles require about 3000W, DC kettle about 200W.

DC appliances are lot more efficient as you avoid losses due to inversion of electricity from DC to AC. However, DC appliances are more expensive and harder to find. However this may be outweighed by the savings on not having to buy an inverter and fuses and RCDs and is also much safer than AC, which works at 240V.

If we're planning to plug in more than one appliance at a time into our system we need to be thinking about out total peak consumption, i.e. adding up all the watts, to make sure that our load fits within the capacity of our system.

Look at the load assessment table below (taken from the Off The Grid book) to see how you can assess your DC and AC loads.

Load Assessment Table							
	LOADS				**TIME**	**ENERGY**	
	Appliance	**AC/DC**	Number in use	Power watts	Hours of use per day	Total energy consumed Wh/day	
1	Light	DC	1	12W	x 3	= 36Wh	
2	Light	DC	1	8W	x 3	= 24Wh	
3	Stereo	DC	1	20W	x 4	= 80Wh	
4	**Total dc load load** (rows 1+2+3)					**140Wh**	
5	Sewing machine	AC	1	60W	x 0.5	= 30Wh	
6	Television	AC	1	60W	x 2	= 120Wh	
7	Video	AC	1	40W	x 1	= 40Wh	
8				Peak load **160W**	**Total AC load** (rows 5+6+7)	**190Wh**	
9	Allowance for inverter loss (approx. 20% of load)					38Wh	*= 8 x 20%*
10	Total inverter load					228Wh	*= 8 + 9*
11	**Total DC consumption**					**368Wh**	*= 4 + 10*
12	Allowances for battery losses (approx. 25% of load)					92Wh	*= 11 x 25%*
13	**Input energy to battery required per day**					**460Wh**	*= 11 + 12*
	Battery sizing						
14	Days of reserve	5 days					
15	Max depth of discharge	60%					
16	Capacity required		3833Wh	*= 13 x 14/15*			
17	At system voltage	12V	319Ah	*= 16/voltage*			
18	Average daily discharge	12%		*= 13/16*			

Storing power with a battery and supplementing bike power

Batteries come into play when we wish to store power for using later or when we're supplementing bike power with some battery power (hopefully charged up by energy from renewable sources). Bear in mind that when planning to use batteries that they are hazardous, expensive and represent a big cost in the system, as they need replacing more often than other components. Therefore, they have to be well looked after to assure that we make them last as long as possible. Badly treated batteries will work inefficiently and the electricity we've been sweating for will be wasted.

Batteries can only store DC electricity and come in 2, 6, 12, and 24V types. The most commonly used batteries are lead acid batteries. For smaller system designs you can use lithium ion battery, which are smaller and lighter, and hold a charge much longer than other types of batteries. They are less environmentally unfriendly and much lighter but still a bit more expensive.

The capacity of batteries is worked out in amp-hours (Ah). A 70 Amp-hour battery can supply 1 amp for 70 hours or 70 amps for 1 hour. Batteries can be collected in parallel (+ to + and - to -) to increase amp-hours but keep the voltage the same. This is a bit advanced and should only be done with batteries of the same type and size. To work out how much power we can store in a battery we can use our old equation W = V x I

70Ah x 12V = 840Wh => This means we can use a 70W juicer for 12 hours or 100W item for 8.4 hours.

When supplementing bike power with battery, it can provide extra energy and allow for larger loads. When using a battery, make sure that the battery has the opportunity to fully charge between loads. Deep discharges should be avoided if possible. When charging a battery you want to have your voltage output between 13.8V and 14.4V.

We have to remember that most batteries cannot withstand being completely discharged. Depending on the battery they should only be discharged to 50% to 80% of their capacity. If you have a battery that is 70 Amp-hours than you really need to see that available power as 50% (leisure battery) to 80% (deep cycle battery) of 70 depending upon the battery. The best batteries to use with bike power are deep cycle batteries as they are designed to regularly discharged between 30% to 80% of their capacity. Well-treated deep cycle batteries will last much longer than a leisure battery. When buying a new battery, the more expensive it is the better the quality.

Car batteries are not suitable to use with bike power, as they were made for short bursts of high current. They never get discharged much in the short time it takes to start a car and they are recharged immediately. Therefore deeper discharge of car batteries damages them.

We've included another excellent page from the Off The Grid book to tell you about the Hazards and care with regards to batteries and what to look out for when you're buying second hand batteries.

Summary of battery types

Battery type	Typical cost (100Ah)	Cycle life (50% discharge)	Main power uses	Pros system use	Cons	
SLI vehicle	£40	150	Starting lights and ignition	Generator starting; occasional lighting /music supply	Cheap; widely available	Very poor cycle life
Leisure	£50-70	300	Caravans, motorhomes boats	Small solar or vehicle system	Fairly cheap; available	Short cycle life
Deep cycle vented	£100-130	1300	Static RE systems; standby power; traction	Good for domestic systems	Long cycle life; durable	Expensive; maintenance required
Deep cycle VRLA	£160+	1500	Standby; small traction – wheel chairs, golf carts; RE systems	Specialised systems – medical, telecom;	Long cycle life; no acid spills; no maintenance	Expensive; precise charge control required

'On sealed-top batteries, the state of charge can be determined by checking the battery's base or open circuit voltage with a digital voltmeter or multimeter. This is done by touching the meter leads to the positive and negative battery terminals. A reading of 12.66 volts indicates a fully charged battery; 12.45 volts is 75% charged, 12.24 volts is 50% charged, and 12.06 volts is 25% charged.'

AC or DC or both

We mentioned DC power in an earlier paragraph about load assessment. If you can use DC, do it. It is safer and you'll get more out of the cyclist and get more sound if you thinking of building a sound system. In the case of sound systems, the wiring would be same as you would use in car amplifier and speakers setups. For other appliances, DC plugs and sockets are the same as the you'd find for a car cigarette lighter, in caravans and on boats.

Regular household appliances run on 230 volts AC at frequency of 50 Hz. An inverter converts low voltage DC electricity to mains power AC. The size of inverter ranges greatly from 20W to 10KW and more. If you are wishing to use AC mains powered appliances you will need to purchase an inverter. Inverters are designed to work with batteries so they usually work with voltages between 9 and 14 volts.

There are inverters with different types of waveform, which essentially try to mimic the mains supply. A pure sine wave inverter creates a smooth AC output, which is indistinguishable from mains.

There are also square wave and modified wave inverters but some devices such as motors may not work with these inverters. However, they are generally the cheaper option.

Different loads will have different tolerances to inverter characteristic and different inverters will have different tolerances to load characteristics. This is important to consider when buying an inverter e.g. some inverters can't deal well with peaks in sound equipment. Also, all inverters work inefficiently at low loads.

The things to look out for in inverter specifications (example at the back of the hand out):

- Power output
- Input voltage
- Waveform
- Efficiency
- Standby
- Surge ability
- Input Voltage
- Load sensing
- Interference suppression
- Protection mechanism
- Cost
- Recommendations

System Control

Without control mechanisms our electricity would be all over the place. Controls make sure we don't blow things, set them on fire and hurt ourselves and/or other people. Controls also get rid of fluctuations within our system. The voltage that person produces on a bicycle is variable and can be as high as 70V and that has to be kept in check by regulations.

The sorts of controls that we need to know about with bike power are:

- **Reverse input current blocking** can be achieved with a diode. Our DC motor is a two-way device, something must be in place to keep the current from going back the way it came, causing the motor to act like a motor and not like a generator (a motor performs the opposite job of a generator when it takes in current and converts it into mechanical energy). The diode will go between the generator and the battery or regulator/converter, with only the fuse between it and the battery/regulator/converter. A diode has both a positive and negative terminal. Make sure you connect positive-to-positive and negative-to-negative or the device will not work. Look at the information that came with your diode to determine which terminal is which, and if you are still having trouble, ask the supplier.

- **Voltage regulation** can be achieved with:

  A. Step down buck converter. Converters are generally used in communications technology and their use in bike power is novel but brings some disadvantages. Buck (or step down) means that the converter can only produce a voltage **lower** than that supplied to it. So, if you require an output voltage of 12V then the converter will need to be supplied with a voltage constantly equal to or greater than 12V in order to work. The voltage created by a permanent magnet (PM) motor is directly proportional to the speed that the motor is rotating (RPM). The scooter motors we use in our system are designed to provide a 24V output at 2850RPM, so in order to create a voltage constantly higher than 12V the motor must rotate at a speed of at least 1425 RPM. How fast the motor rotates depend on:

  1. The speed the cyclist is spinning his or her legs (faster = greater motor RMP)
  2. The size of the rear wheel of the bike you are using (larger = greater motor RPM)

3. What gear the bike is in (downhill gears = greater motor RMP)

The disadvantage of the converter is that with the motors we currently use the voltage can sometimes get a little bit too high if a person jumps on a bike and spins. If not careful this can blow the board. This can be overcompensated with larger roller or smaller motor. The converter also requires a heat sink attachment to dump excess power as heat. Running the converter at high loads without a heat sink can blow the board.

B. Capacitor. A capacitor can be used to smooth the output voltage from the motor and has the added benefit of providing a reservoir of energy for bass notes in sound systems for the amplifier to use on demand. As a rough estimate every 400W of sound requires 0.5 farad of capacitance.

There are a couple of disadvantages in using a capacitor. The capacitor doesn't supply a constant output voltage. Once charged it corresponds to the voltage output from the motor, which (as discussed above) is relative to its RPM. If you are using an inverter (designed to work between 9 and 14V) or sensitive 12V equipment you will need to keep an eye on the voltage across the capacitor and adjust your pedalling speed or the gear you are in to keep the voltage steady.

Capacitors can be damaged or may cause damage to those nearby if not treated with respect. The voltage rating of any capacitor will be written on it. Once the capacitor is full of charge, if a voltage higher than its rating is supplied to it can damage the capacitor. Some capacitors come with their own built in voltmeter, making monitoring of voltage easier.

C. Battery Charger. This is a slightly more advanced system that still requires the use of a capacitor in combination with a battery charger charge in diversion mode setting. The capacitor is usually wired after the bikes followed by the battery charger. Every battery charger is different and has different specifications that have to be followed when deciding about how it will work in the system. This option also requires the use of dump loads such as metal coils that heat up in the case of excess power is produced. Using battery chargers can be expensive.

- **Fuses.** If there is a surge in the electrical system that causes too much current to pass through the fuse, it pops, which creates disconnects the circuit (known as an open circuit). This break prevents current from continuing its path and keeps the device from working. It also keeps the devices from being destroyed by too much current. For the price of a fuse, we can protect our equipment. When we use batteries, 25 amp fuses are needed to protect our wiring should our system short circuit. It should be placed immediately adjacent to the positive terminal of the battery.

- **Earth leakage trip** detects the difference between current leaving and the current returning. If this becomes bigger than 30mA (the maximum safe level) it switches of the power. Earth leakage trips are RCBOs, RCDs, RCCBs and ELCBs. Read the additional pages about RCDs that are part of the hand out.

- **Earthing.** Earthing creates a link between our system and the ground. It is standard practice to earth the battery negative and the negative of the inverter. Inverters may require different earthling. Always follow the inverter manual guidance on earthling! Earthling assures no current can flow through our bodies in case we touch a live part of our system, as current will want to run to the ground**.** In most cases we'll require a galvanised rod of min length of 1.5m that we can run into the ground. We need to connect the earth rod to our battery and appliance negative using a copper conductor, with our conductor being at least as thick as the largest one in our circuit.

Distribution of power

Cables for our system are generally chosen on the basis of current-carrying capacity. Cables need to be able to carry the required current without overheating. Check out the pages below to give you guidance on the sorts of cable that you'll need.

Rule of Thumb

A useful approximation for quick cable sizing for 12 volt systems is
Cable area (mm²) ≈ Length (one way, m) x Current (A) ÷ 10
This gives a voltage drop of about 3.5%

e.g. You want to install a small light – 11W fluorescent – in an outhouse 35 metres from the battery store. At 12V, the light will draw about 1 amp.

cable size ≈ (1 x 35) / 10 = 3.5mm²

The nearest available sizes are 2.5mm² and 4mm². If the light will be in constant use, perhaps as a security light, you should opt for the larger 4mm² to save power, but if it is only to be used occasionally, e.g. a garage light, the extra losses of a 2.5mm² cable may be worth the cost saving.

Cable size in a 12 volt system

Circuit watts up to:	Current up to:	Absolute minimum cable size	Minimum conductor area for less than 5% volt drop over given length			
			3m	10m	30m	100m
36W	3 amps	0.5mm²	0.75mm²	2.5mm²	6mm²	25mm²
72W	6 amps	0.75mm²	1.5mm²	4mm²	10mm²	35mm²
120W	10 amps	1.0mm²	2.5mm²	6mm²	16mm²	50mm²
192W	16 amps	1.5mm²	2.5mm²	10mm²	25mm²	–
288W	24 amps	2.5mm²	4.0mm²	16mm²	35mm²	–
384W	32 amps	4mm²	6mm²	16mm²	50mm²	–
480W	40 amps	6mm²	6mm²	25mm²	50mm²	–

Cable size in a 24 volt system

Circuit watts up to:	Current up to:	Absolute minimum cable size	Minimum conductor area for less than 5% volt drop over given length			
			3m	10m	30m	100m
72W	3 amps	0.5mm²	0.5mm²	0.75mm²	2.5mm²	10mm²
144W	6 amps	0.75mm²	0.75mm²	1.5mm²	4mm²	16mm²
240W	10 amps	1.0mm²	1mm²	2.5mm²	10mm²	25mm²
384W	16 amps	1.5mm²	1.5mm²	4mm²	16mm²	50mm²
576W	24 amps	2.5mm²	2.5mm²	6mm²	25mm²	–
768W	32 amps	4mm²	4mm²	10mm²	25mm²	–
960W	40 amps	6mm²	6mm²	10mm²	35mm²	–

Cable size in a 240 volt system

Circuit power up to:	Current up to:	Absolute minimum area	Minimum conductor area for less than 5% volt drop over given length			
			20m	50m	100m	200m
0.7kW	3 amps	0.5mm²	0.5mm²	0.5mm²	1mm²	2.5mm²
1.4kW	6 amps	0.75mm²	0.75mm²	1mm²	2.5mm²	4mm²
2.4kW	10 amps	1mm²	1mm²	2.5mm²	4mm²	10mm²
3.4kW	14 amps	1.5mm²	1mm²	2.5mm²	6mm²	10mm²
5.8kW	24 amps	2.5mm²	2.5mm²	4mm²	10mm²	16mm²
7.7kW	32 amps	4mm²	4mm²	6mm²	16mm²	–

DC cables will need to be much thicker as the current in a DC system is much higher than 240V AC. Cables also need to be thicker because of voltage drop. Voltage drop is the loss of power as the current runs down the cable. This is due to the resistance in the copper. The loss of power occurs as heat. Voltage drops will be worse for cable stretching long distances. Voltage drop can also possibly damage appliance that are sensitive to the voltage they receive. The most efficient systems will have the smallest voltage drop. The formula for working out suitable cables is:

Volt drop (V) = 0.04 x cable length (m) x current (amps) / cable cross sectional area (mm^2)

It's also possible to knock out 25A on a bike for bursts, so our cable should be able to handle those sorts of currents too!

Safety precautions as electricity can be dangerous

Please take all safety precautions mentioned in this hand out such as earths, fuses, RCDs, and more! Read the guidance on working with batteries and be aware that the power coming out of an inverter is 240V.

This is not to scare you, but electricity when handled wrong can be deadly. Even though a 12V system doesn't pose an electrocution hazard, there are still other hazards such as electrical fires from too much current. Keep a fire blanket and a small extinguisher near by if possible. If you're not sure of anything ask an electrician. If you intend to take you generator to a public event get a certificate from a qualified electrician, which will assure that your installation is safe!

Deciding upon your budget and thinking about a system that you can afford

In the simplest terms you will need a person, a bike, a way of supporting your bike off the ground, a motor, an energy smoothing system and an inverter if you want to use your bike generator to power mains equipment.

Cost is an issue for many people. When we first stated generating electricity with bikes we were on a really tight budget. As opposed to buying stands that would cost us £50 with a bit of welding we made our own bicycle stands that came to about £15 per stand. Instead of using an aluminium roller we used old skateboard wheels.

There are many ways to do things and it's all about being resourceful. You can find motors, from old washing machines, car windshield wipers as long as they are permanent magnet 12V DC motors and within you parameter you should be fine.

You plate for mounting could be old bit of wood that you may find laying around. Stand can be put together from old discarded bikes. Many, many, many ways…………

Suppliers of parts

Bicycle (ideally with slick tyres)
Local bicycle store
Gumtree - www.gumtree.co.uk
Ebay - www.ebay.co.uk

Bicycle training stand
Cycle Store - www.cyclestore.co.uk
Cycle Sports UK - www.cyclesportsuk.co.uk
On Your Bike - www.onyourbike.co.uk
Minoura

DC permanent magnet motor
Ebay - www.ebay.co.uk - Part no. MY1068
Conrad Electronic - www1.conrad-uk.com
Science Shareware - http://www.scienceshareware.com/
Campaign For Real Events - http://www.c-realevents.demon.co.uk/

Plate or wood for mounting motor
Timber merchants
Steel stockists
DIY store

Skateboard wheel or roller
Skate shop
MR - www.magnificentrevolution.org

Multimeter
Maplin - www.maplin.co.uk
Screwfix - www.screwfix.com
DIY store

Regulator
RS - uk.rs-online.com
Maplin - www.maplin.co.uk

DC to DC converter
part 445-9787 from RS or part L22BR from Maplin.

Inverter
Maplin - www.maplin.co.uk
Outdoor GB - www.outdoorgb.com

Capacitor
Car audio store
Passion Auto - www.passionauto.co.uk
Halfords - www.halfords.com

Tristar Battery Charger
Mysolarshop.co.uk - www.mysolarshop.co.uk
Wind and Sun - www.windandsun.co.uk

Dump Load Coils
Mysolarshop.co.uk - www.mysolarshop.co.uk
Kaieter - www.kaieteur.uk.com

Heatsink
RS - uk.rs-online.com

12V Connectors x 4

RS - uk.rs-online.com
Outdoor GB - www.outdoorgb.com
12V Shop - www.the12voltshop.co.uk

12V Sockets
RS - uk.rs-online.com
Outdoor GB - www.outdoorgb.com
12V Shop - www.the12voltshop.co.uk

Fuses & Fuseholders
Maplin - www.maplin.co.uk
Halfords - www.halfords.com
Outdoor GB - www.outdoorgb.com

RCD
Wickes - www.wickes.co.uk
RS - uk.rs-online.com

Earthing System
Canford - www.canford.co.uk
Screwfix - www.screwfix.com

Battery
Halfords - www.halfords.com
Outdoor GB - www.outdoorgb.com

System housing e.g. wooden box
DIY store
RS - uk.rs-online.com

Cable & connectors
Maplin - www.maplin.co.uk
RS - uk.rs-online.com

Screws, nuts and bolts
DIY store
Maplin - www.maplin.co.uk
Screwfix - www.screwfix.com
RS - uk.rs-online.com

Tools e.g.
- Crimp tool
- Soldering iron & solder
- Terminal blocks
- Electrical tape
- Electrical screwdriver
- Spanner
- Needle nose pliers
- Wirecutters and strippers
- Allen keys
- Plug in power meter

DIY Store
Maplin - www.maplin.co.uk

For more information check out these books:

Off The Grid, Managing independent renewable electrical systems – Duncan Kerridge, CAT Publications, ISBN: 978-1-902175-56-0

Advanced Electrical Installations – C Shelton, Addison Welsey Longman, ISBN: 0-582-24618-0

Electronics for Dummies – Gordon McComb & Earl Boysen, Wiley Publishing, ISBN: 0-7645-7660-7

The 12 Volt Bible For Boats – Miner Brotherton, McGraw-Hill, ISBN: 0-07-139233-5

Using a digital multimeter (DMM)

The digital multimeter (DMM) is the most useful tool for checking on the health of the power system. It's like an electrical stethoscope and is an essential item in your tool-box. Multimeters will measure the main electrical properties of a system – voltage, current, resistance and AC frequency. Learning what and where to measure will let you make on the spot performance readings and trouble shoot problems and faults. Digital multimeters are typically pocket-sized plastic boxes with a liquid crystal display, a selector dial and sockets for two test leads. Inside, circuitry and a battery process the readings.

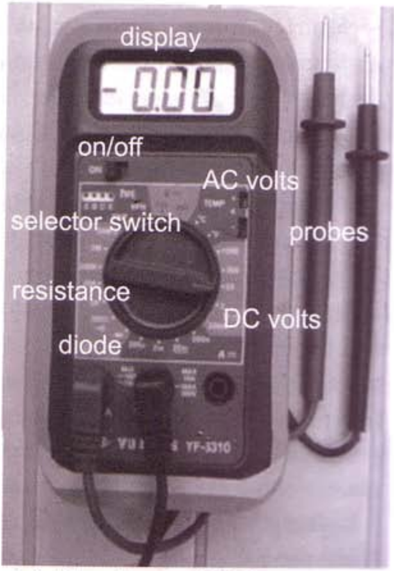
Prices run from £20 to £300 – with price comes reliability, accuracy and features. As with any tool, it is wise to get the best you can afford – there are plenty of reasonable meters available for under £100 but the really cheap ones rarely last long. Moving coil meters are far less robust.

Care

- Store in dry conditions
- Keep the instructions
- Remove and replace the battery as soon as it is flat
- Clean probes after measuring batteries
- Always check selector setting and lead sockets before measuring.
- Remember to switch off when you finish

Safety

- When measuring volts, make sure the selector is NEVER set to amps
- Repair any minor damage to the leads very carefully with insulation tape – replace them if the inner core is damaged



A digital multimeter (DMM).

- Always be very careful when checking AC voltage – it can kill you
- Take care not to short components with the probes

Features to look for

- DC/AC voltage from microvolts to at least 200V (800V for AC)
- DC/AC current from microamps to at least 10A
- Resistance to at least 0.1Ω definition and a buzzer for short circuits
- Diode test facility
- Frequency
- Warning facility when the meter's batteries are low (low batteries give unreliable readings)
- Fuse protection for current ranges and overload tolerance
- Accuracy – 1% on the main ranges is good, 2% is sufficient
- Rubber case to protect against knocks

Other useful features found on pricier models

- Autoranging – makes for a simpler dial and less scope for error
- True r.m.s. reading – the only way to get accurate AC voltage readings from inverters without pure sine wave output
- Hold button to freeze a reading
- Max/min button for variable readings and AC peaks
- Re-zero feature to filter out 'noise'
- Temperature input – you'll need a plug-in probe or thermocouple
- Capacitance and transistor testing – useful if you get into making your own circuits

Taking measurements

Before taking a reading, always check that the dial is set correctly and the probes are in the right sockets. Be sure you know where to touch the probes – blundering around can prove expensive. Place the point of the probe firmly on the contact (dirt and oxides will give misreadings). There are many measurements that are easy to understand; others will require more knowledge to interpret.

Battery voltage Select DC voltage and check the probe leads. Place the red probe on the positive terminal and the black probe on the negative terminal (if you get the polarity reversed, no damage will be done to the DMM, but the reading will be negative). Simple, but, like blood pressure in humans, an indicator of many subtleties you will come to appreciate as you learn about your system. Separate cell voltages will show up any weak cells, but you will need to disconnect one end if checking individual batteries connected in parallel.

AC voltages Take care! Non-r.m.s. meters will give inaccurate readings with all but pure sine waves. They calculate r.m.s. by applying a factor to the peak voltage assuming it is a sine wave. Measure between live and neutral for output voltage. Measuring to earth can show up appliance and earth faults. Useful for checking voltage levels on gensets and un-rectified wind generators. With 3 phase supplies use voltage between phases to check for balance.

Continuity and short circuits

Use the ohms (Ω) setting to check continuity of cables and fuses. Be sure to isolate the section first. Measuring between (isolated) conductors or earth can show short circuits.

Poor connections

If you find voltage drops of more than a few millivolts across a connection in a circuit, it needs securing. In incomplete circuits, use the resistance setting.

Diodes and rectifiers

Diodes are electrical 'one-way valves' they allow electricity to flow one way, but not the other. They are used to rectify alternating current (AC) into direct current (DC) that can be stored in the battery. They are also used to block current from feeding the wrong way and to drop output voltage. Set to diode setting (arrow and bar symbol), the meter applies a small voltage to the probes and the reading indicates which way the diode 'flows'. A healthy diode should show open circuit in reverse and 0.4 to 0.8 (the volt drop) forward – from positive probe to negative.

Frequency

If the DMM has a frequency setting you can check the regulation of AC supplies such as hydro and engine generators. The frequency of unrectified wind generator output will be proportional to the rotation speed, which can give you a rough idea of the windspeed (i.e. a high frequency will indicate high rotation speed in high winds).

or wind turbines but has nowhere to go. As with specific gravity, the relation of voltage to state of charge varies with temperature.

Battery monitors

Several manufacturers produce 'state of charge' battery meters that use microprocessors to monitor performance. Generally costing £100 or more, some monitors will even interface with a personal computer. These are the easiest way to keep close track of your system's 'fuel tank', but it is still wise to check individual cells occasionally.

Battery care

Charging protection

For good lead-acid battery life, it is essential to avoid over-charging. In all systems using lead-acid batteries it is important to limit the on-charge voltage. This will protect them against over-charging, which causes excessive 'gassing' and overheating, resulting in permanent plate damage and loss of electrolyte. Charge regulation is described later in Chapter 7 which covers control equipment. This is particularly important with sealed or 'gel' lead-acid cells which need accurate regulation of the on-charge voltage to the value recommended by the manufacturer since electrolyte lost as gas cannot be replenished.

Temperature compensation

Battery characteristics vary with temperature, storing more energy (but reducing life) as temperature increases. If the battery temperature is likely to regularly vary by more than about 8°C, battery performance and life will benefit from a controller with a temperature compensation facility that adjusts the on-charge voltage limit as the temperature varies. Battery stores should provide protection from extreme temperatures.

Discharge protection

The other essential for good lead-acid life is to avoid frequent deep-discharges (i.e. running the battery flat or nearly so). A battery will tolerate this occasionally provided that it is recharged immediately. If it is left in a discharged state, it will quickly become permanently damaged resulting in a serious loss of storage capacity. Unfortunately, this is exactly what is likely to happen in an RE system, because once you have discharged the battery, you can't turn on the sun or wind to rescue the situation! The only safe approach is never to discharge the battery fully. Fitting an automatic 'load-disconnect' relay will help avoid disasters. Many PV controllers and inverters include these as standard.

Battery maintenance

Regularly check the state of charge. The best tool to use with vented cells is a hydrometer (see page 71), which measures the specific gravity of the electrolyte in each cell. This will show if any cells have deteriorated. Alternatively, use an accurate voltmeter after disconnecting the battery and the power sources from the rest of the system (see above). If you have several batteries connected together, disconnect the positive terminals to measure each battery voltage separately. This will show up any batteries that are beginning to fail. Keeping records on each battery over time will help you to detect failing cells.

The electrolyte should be checked regularly and topped up as required with pure distilled or de-ionised water from a non-metallic container. Never top up a battery with acid!

Batteries should be kept clean and dry, as dirt and moisture can provide a path for electricity and cause discharge, and any impurities that find their way into the electrolyte will cause problems.

Battery terminals should be periodically cleaned and coated with petroleum jelly (Vaseline®) to prevent corrosion.

Check that all the vent plugs are in place, and that battery covers are sound.

Do not leave them in a discharged condition, particularly at low temperatures as a discharged battery may freeze suffering permanent damage.

Equalisation

With vented cells, it is a good idea to occasionally give them an 'equalising charge'. This involves charging them to a voltage 0.5 to 1 volt above normal. This causes gassing, which mixes the electrolyte and can dislodge sulphate deposits on the plates. Sophisticated solar charge controllers sometimes do this automatically once a month or after a low-voltage disconnection. See Chapter 7, Control and Monitoring, for more information. Do not try to equalise sealed (VRLA) batteries.

For better battery life	
DO	DON'T
Protect from temperature extremes	Flatten
Store in secure, ventilated area	Leave discharged
Keep first aid and safety kit on hand	Charge or discharge too quickly
Use charge and load controllers	Forget to use fuses
Keep clean	Mix old and new, or different types
Regularly check electrolyte and state of charge	
Equalise charge (not sealed types)	

Replacing batteries

Eventually, batteries will reach the end of their cycle life. If you have several batteries connected in parallel, one may start to fail before the others. If, as advised, they are of the same type and age, it is best to replace the whole bank in one go. Mixing old and new batteries will prevent the new ones from reaching full charge.

How long will a battery last?

If looked after properly, the main factor affecting a battery's life is depth of discharge, i.e. how far it is discharged, and how often. A period of charging and recharging is called a 'cycle'; the deeper the cycle, the shorter the battery life. If the depth of discharge can be limited, the battery will last longer. Running a battery until it is totally flat will quickly destroy it! Discharge depths of between 50% and 80% are the optimum for deep cycle batteries. Some manufacturers give an indication of how many cycles to a specified depth their batteries are expected to provide. In general, a good deep-cycle battery should give at least 1000 cycles to 50%.

Do not discharge a battery too quickly. Batteries are not 100% efficient. Their efficiency varies according to how they are treated. At higher rates of discharge (C/1 to C/5) the efficiency of the battery falls to around 60%. At lower rates of discharge (C/10 to C/100) efficiency rises to around 90%. The available capacity of the battery also varies with the discharge rate. As a rule of thumb, the rate of discharge should be no greater than C/10.

Older batteries are less efficient. As a battery is cycled, it loses available capacity, and more charging energy is lost in the cell. The battery will also be more prone to self-discharge if left without charging.

Battery life is completely dependent on how the batteries are treated, and how frequently they are cycled. However, if they are well looked after and protected from over-discharge, a new deep-cycle battery can be expected to last between five and ten years, while a 'leisure' battery should last one to three years. Batteries also have a 'shelf life' so that after twelve to fifteen years, even with minimal cycling, a battery will have lost much of its original capacity.

Buying new batteries

If you are buying your own batteries, as always, it makes sense to shop around. The web and Yellow Pages are good places to start. Auto-battery shops sometimes carry leisure batteries. Caravan and boating suppliers should have a wider range and many manufacturers are accessible online. Renewable energy suppliers usually stock deep-cycle types of battery and should be able to give you advice on what will perform best. Make a list of your requirements:

- Amp-hour capacity, system voltage.
- Estimated daily and maximum discharge.
- Size or weight restrictions.
- Mobile or low-maintenance conditions.
- Available budget.

To compare batteries, you need a specification sheet. This should contain physical properties and description, capacity at different discharge currents, a graph of voltage (and specific gravity) against state of charge with adjustment rate for temperature. The crucial information is the expected cycle life for different depths of discharge. How many times will it get you through calm cloudy days before it loses its strength? Unfortunately, many manufacturers are reluctant to commit themselves to expected lifetimes because of the impact and influence of operating conditions. At the least, the supplier should give you a convincing estimate of how long it will last at your estimated loading.