

How to Build a Practical Household Bike Generator

Belil, Gabriel Verdeil, and Manvel Arzumanyan.

We built a pedal-powered generator and controller, which is practical to use as an energy source and exercise machine in a household — and which you can integrate into a solar PV system. We provide detailed plans to build your own, using basic skills and common hand tools.



Image: The bicycle generator in the living room.

INTRODUCTION

Many people have built pedal power generators and published the manuals online and in books. However, when we set out to make a pedal power generator



We welcome technical feedback concerning further improvements.

Kris De Decker, Marie Verdeil.

Special thanks to Adriana Parra, Eris

ourselves, we found that these manuals are incomplete when making the bike generator practical to use. The focus is on building the power source itself, with comparatively little attention to what happens with the power that comes out of it.

To try and make human power production more useful, we built not just a pedal power generator but also a control panel in the form of a “dashboard” attached to the handlebars. The dashboard allows powering or charging a wide diversity of devices – no matter what voltage they run on. Furthermore, multiple devices can be powered simultaneously, allowing the cyclist to adjust the resistance on the pedals for an optimal workout.

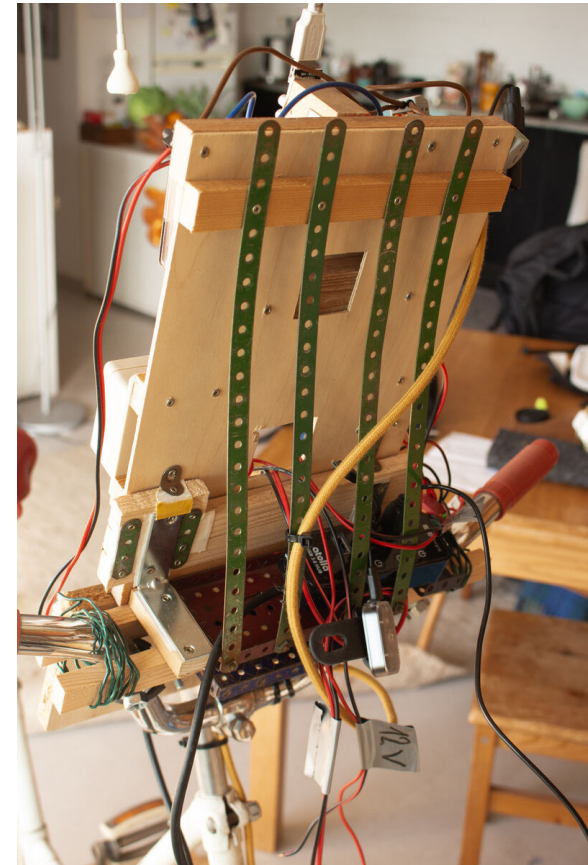
We also tried to improve the bike generator itself. Although there are good manuals available, we wanted a power source that is easy to build (no welding or complex tools required), comfortable to pedal, as compact as possible, and not an eyesore. The bike generator is set up in a small living room and used regularly. We found the solution in a vintage exercise bike with

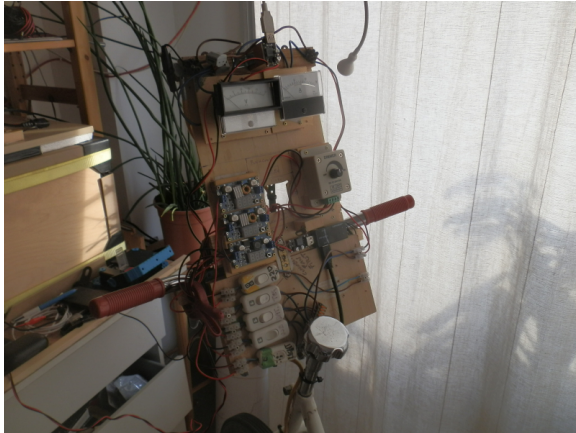
a flywheel, an approach we have not seen before.

Trial and Error

The bike generator and dashboard were designed and made in collaboration with Marie Verdeil as part of her internship at Low-tech Magazine. We could not find the technical information we were looking for, so we followed a trial-and-error approach. That was time-consuming and costly, but we gained insight and learned lessons. We made lots of mistakes that you can avoid.

We are not engineers, and we welcome technical feedback concerning further improvements. Based on that feedback and more experiments with the bike generator – which is now in use for one month – we will update and expand the manual. Our design can be adjusted and adapted to your needs. We appreciate a donation if you find our work interesting. Your support makes it possible to finance further experiments and building projects that we have in mind. Marie Verdeil will continue working with Low-





tech Magazine when she finishes her studies at the Design Academy Eindhoven later this year.

Newcomers to this website may want to read some earlier articles that this bike generator project is building further upon: The short history of pedal powered machines (2011), Pedal powered farms and factories: the forgotten future of the stationary bicycle (2011), Bike generators are not sustainable (2011), How to go off-grid in your apartment (2016), Slow electricity: the return of DC Power? (2016), Could we run modern society on human power alone? (2017), and How much energy do we need?(2018).

THE BIKE GENERATOR

There are many ways to build a bicycle generator, and each has its advantages and disadvantages. We based our pedal power plant on a vintage exercise bicycle from the 1950s. Our bike was made by Spanish brand BH but similar vintage models can be found anywhere in the industrialised world.



Image: The exercise bike dating from the 1950s. It has a heavy flywheel in front.

The Flywheel

Our approach has several advantages. The first and most important is that old exercise bikes have a large flywheel in

TOOLS YOU NEED

- * Wire cutter
- * Tiny screwdriver (to adjust voltage output on buck and boost c
- * Calculator, multimeter, tachometer
- * Soldering iron. We soldered the on/off switches and the two USI
- * Wood saw: to make the luggage rack
- * Metal saw: to cut custom threaded rods
- * Drill: to mount the luggage rack and the dashboard
- * Wrench socket set: very handy when working on a bike.

THE FIRST PROTOTYPE

The control panel can take different forms and use other tools and materials. We first built a proof of concept with scrap wood and Meccano then strapped it to the handlebars with iron wire and some wooden blocks.

Initially, we screwed the generator on a large wooden board and put the bike on top. We made holes in the board for the four legs so that the bike was always right where it had to be. This set-up worked and was handy to try out different spindle sizes, but it takes much more floor space than our final configuration.

was limited to 60 watts (12V, 5A) — but that was before we thoroughly cleaned and oiled the bike drive train. After cleaning, we discovered the bike could produce almost double that power (12V, 8-9A). That required us to make some updates.

Components get more expensive as their maximum rated amperage increases. For the 12V, 220V, and 14.4V, we stuck to a limit of 5A. Although the bike generator can produce more power, we usually combine several circuits — each limited to 5A. We added an extra 12V circuit with a 15A buck converter and thicker wires to run a more powerful appliance. This circuit bypasses the dashboard entirely. We plan to move this to the unregulated electric circuit on the dashboard (and upgrade the wiring).

- * Cables: 11A, 18A for the extra circuit
- * USB buck converters: 2A
- * 2x Buck converters: 5A
- * 1x Buck converter: 15A
- * Boost converter: 5A
- * On-off switches: 20A
- * Diode: 10A
- * Fuse: 12A
- * Connectors: 20A

front. Bike generators without flywheels — which are the majority these days — are likely to end up gathering dust in the garage because they are tiring and uncomfortable to pedal.

A flywheel is essential because pedalling a stationary bicycle is a different experience from riding a bike on the road. The power that our feet put on the pedals peaks every 180 degrees of crank rotation. On the road, this has little effect because of the inertia of the cyclist.

In contrast, on a stationary bike, this uneven power output results in jerky motion and additional stress on parts. The flywheel solves this by its large mass and rotational speed. That evens out the difference between power peaks and makes for comfortable pedalling. The rider tires less quickly and can generate more energy. A flywheel also produces a more steady voltage.

Our approach also makes it possible to build a pedal power generator with simple tools and basic skills. There is no need to cut or weld metal — the bike

remains like it is.

Neither is there a need to build a support structure – the bicycle already has one. We only had to add a so-called friction drive – a small roller attached to the generator shaft and pressed against the flywheel.



Image: The friction drive – a small roller attached to the generator shaft and pressed against the flywheel.

Our method also results in a very compact bike generator. It is just over 1m long. Finally, and although this is a matter of personal taste, it results in a bike generator that is beautiful to behold. The bicycle was bought from

- * 5V USB V&A meter: 8.50 euro
- * USB distribution hub: 30 euro
- * Total: 46.5 euro

12V circuit

- * 12V 5A buck converter (2x): 24 euro
- * 12V 5A boost converter: 8 euro
- * 12V 15A buck converter: 25 euro (extra circuit we added later)
- * Dimmer: 7.50 euro
- * Total: 64.5 euro

14.4V circuit

- * Inverter: 50 euro
- * Battery (14Ah): 31 euro
- * Wind charge controller: 34 euro
- * Total: 115 euro

Hardware

- * To fix the dashboard and the generator: +/-30 euro

Total cost

- * Grand total: 471 euro

MAX AMPERAGE

All components used must sustain the power that goes through it. The voltage is usually not a problem, but you have to watch the amperage. Power production

to secure them to the dashboard.

- * M6 Bolts. To attach the motor to the wooden board.
- * M8 Bolts. To attach the two parts of the dashboard.
- * Big door hinge. To attach the motor at an angle.
- * Metal mounting brackets (all sizes and shapes). To strengthen
- * Rubber metal clamps. To attach the dashboard to the bike handlebars.
- * Wood glue, screws (all sizes), bolts, washers and nuts (normal)
- * wooden cleats and boards, black acrylic paint, etc.

COSTS

We only include the components we effectively used:

Generator

- * Vintage exercise bike (second hand): 60 euro
- * Generator: 60 euro
- * Arbor shaft: 10 euro
- * Spindle: 3 euro
- * Total: 133 euro

Dashboard (all circuits)

- * Wires: 17 euro
- * Connectors: 25 euro
- * Analog volt meter: 9 euro
- * Analog ammeter: 9 euro
- * On-off buttons: 20 euro
- * Diode: 1 euro
- * Fuse: 1 euro
- * Total: 82 euro

5V circuit

- * 5V USB buck converter (2x): 8 euro

someone in a neighbouring village who had it standing in the living room as a decoration.

As a disadvantage, one could mention that a friction drive is less energy efficient than a gear or belt drive. However, the higher efficiency of the flywheel compensates for that. Only a combination of flywheel and gear or belt drive would do better – but that would be more difficult to build. Another disadvantage is that our machine has no switchable gears – more on that later.

Maximum Power Production

The power output (W) of a bike generator corresponds to the voltage (V) multiplied by the current (A). We obtained roughly 100 watts (12V, 8-9A) of power during a short and heavy workout. During a moderate effort – which we can sustain for a longer time – power production is between 45 and 75 watts. The power output not only depends on the bike but also on the person who operates it. Athletes could produce more power, while couch potatoes would

(initially!) generate less.

We measured the power output right after the generator. However, you need to put more power on the pedals to obtain that power output. To start with, no generator is 100% efficient. Our generator achieves its maximum efficiency (75-78%) at a power output of more than 6A (72W). Efficiency decreases when you produce less power: it drops to 60% at 3A and less than 45% at 2A.

Second, there are energy losses in the drive train between the pedals and the generator. We cannot measure these, but according to the data we found, a friction drive introduces on average 15% of extra energy losses.

Taking into account efficiency losses in both generator and friction drive, you need to put at least 150 watts on the pedals to obtain a power output of 100 watts. There are additional energy losses in the bicycle drive train. In theory, bicycle gears have low energy losses, at most a few percent. In practice, however, these energy losses can be high. We proved this unintentionally. Power production

COMPONENTS LIST

Generator

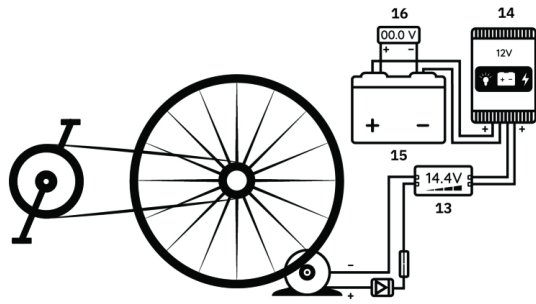
- * Motor (x1). Ampflow P40 - 250W Pancake DC. Brushed Motor 24-12V
- * Shaft arbor (x1). Threaded Shaft Arbor conversion from 8mm to 10mm
- * Wheel (x1).

Dashboard

1. Schottky diode (x1). BOJACK Diode Schottky 10SQ045 (10A 45V)
2. Fuse (x1).
3. Analog ammeter (x1). Analog Ammeter DH-670 0-5A Class 2.0 & Accuracy
4. On/Off LED Switch (x8) – KR1-5 Series Rocker ON/OFF Switch 12V
5. Wire Connector (≈16 of different formats)
6. 5V USB Led Light. Any USB flexible arm LED light will do.
7. 5V Buck converter (x2). Buck Converter MH KC24 DC-DC 24-12V Class
8. 5V USB Voltmeter & Ammeter.
9. 5V USB Multi-plug.
10. 12 V 5A Buck Converter (x1). Buck Converter DC-DC Adjustable
11. Dimmer.
12. 12V DC Socket (x1). RUIZHI DC 12V waterproof Female Car Cigarette
13. Boost Converter (x1).
14. Wind turbin charge controller (x1) – Asixx Waterproof Wind Charge
15. Battery Electronic Voltmeter.
16. 12V 15A Buck Converter (x2, one is for our test circuit) – BANG
17. Inverter (x1) – 300W or less Inverter DC 12V to AC 220-240V

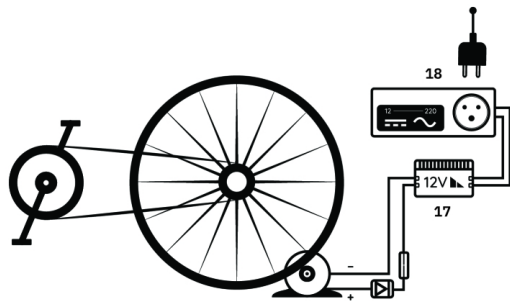
Hardware

- * M3 Bolts. They fit with the electronic components



13: Boost converter. 14: Wind turbine charge controller. 15: Lead-acid battery. 16: Battery electronic voltmeter.

220V CIRCUIT



17: Buck Converter. 18: Inverter.

doubled after we thoroughly cleaned and oiled the bicycle train. We made the mistake of cleaning the bike only at the very end. That forced adjustments to the control panel to manage the higher currents that suddenly came through it.

THE ART OF PEDAL POWER: WHAT ARE THE CHALLENGES?

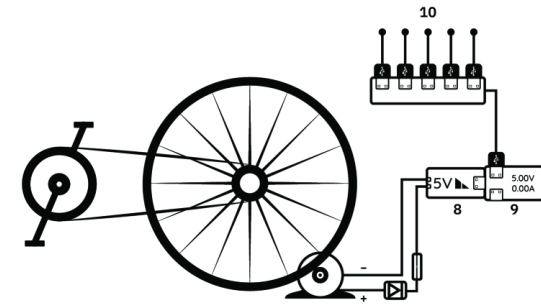
As a power cyclist, you have to match the voltage (V) and the current (A) of the device you are powering or charging. However, this is easier said than done. Electric devices run on different voltages and they have very different power demands. The voltage refers to how fast you pedal and the current to how hard you pedal.



Image: The friction drive – a small roller attached to the generator shaft and pressed against the flywheel.

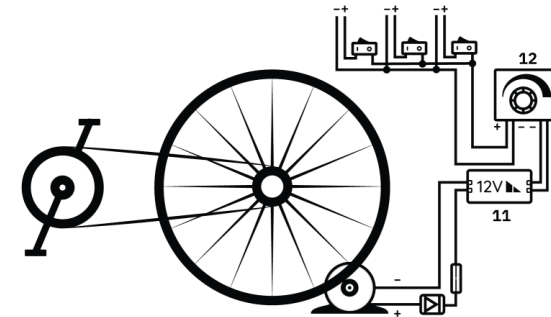
1. Matching the voltage

A bike generator produces low voltage DC power, similar to a solar PV system (12/24V). The voltage output depends on how fast the bike generator spins. The pedalling rate and the gear ratio determine the generator speed. The manual explains in detail how to set up the correct gear ratio. In short, you need to measure the outer diameter of three parts (pedal sprocket, flywheel sprocket, flywheel) and use those data



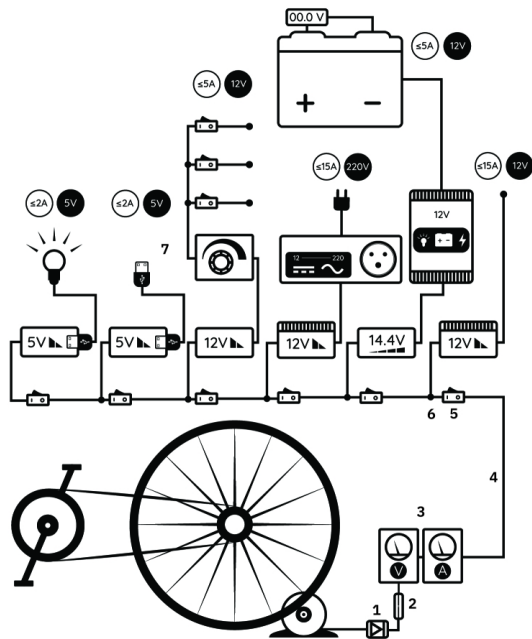
8: USB Buck converter. 9: USB Voltmeter & Ammeter. 10: USB Multi-plug and cable.

12V CIRCUIT



11: Buck Converter. 12: Dimmer.

14.4V CIRCUIT



1: Schottky diode. 2: Fuse. 3: Cables. 4: Analog ammeter and voltmeter. 5: On/Off switches. 6: Wire connectors. 7: USB Led Light.

5V CIRCUIT

to calculate the correct spindle size for the intended voltage output.

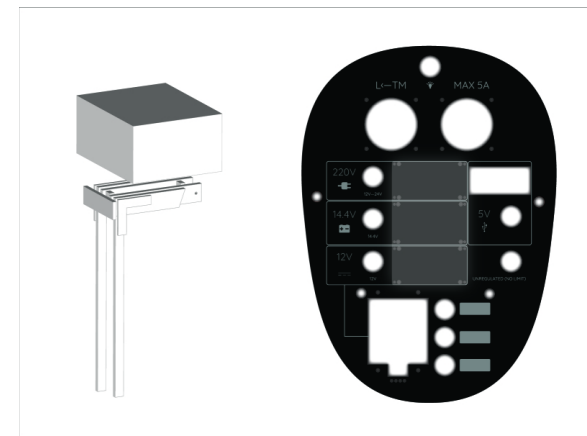
Once you have set the gear ratio, you could produce a lower or a higher voltage by pedalling slower or faster, respectively. That makes it possible to power devices on different voltages. However, assuming your generator provides 12V at average pedalling speed, you would have to pedal in extreme slow motion to produce 5V, and it will be hard to keep your feet at the pedals to provide 24V. Gears would make it easier to vary the voltage output, but our bike has none.

Running an appliance straight from the generator can be a practical solution if it needs roughly 12V. The flywheel helps to maintain a relatively steady voltage output. However, electronic devices and batteries require a precise voltage. Otherwise, they may not work or get damaged. Furthermore, running an appliance straight from the generator prevents you from powering or charging several devices with different voltages simultaneously – which is a solution to the next problem.

2. Matching the current

Electric and electronic devices can have very different power demands – even if they work on the same voltage. Unfortunately, it's much harder to adjust the current than the voltage. How hard you have to pedal depends entirely on the device you are powering. In some cases, this results in an optimal resistance. More often, the resistance at the pedals is either too low or too high.

At one extreme, resistance on the pedals is almost zero when charging a smartphone or a relatively small lead-acid battery. At the other extreme, resistance on the pedals is too high when powering a kettle or a refrigerator. Some devices have varying current demands. For example, the printer demands between 25 and 70 watts of power, depending on what it's doing exactly. There are peaks in power demand following startup and between pages, and printing images requires more effort than printing text.



HOW TO WIRE THE DASHBOARD?

temperature down by 2 degrees C before you take a shower.

Dashboard panel and fixation

We attached the control panel to the handlebars and added a luggage rack in front that holds extra parts such as an inverter, a wind charge controller, and a lead-acid battery. On top of the box are the power outputs for each circuit and a USB distribution hub. The box has an open lid and holes for the dashboard's cables to pass through (they first go inside the handlebar).

We used a laser cutter at a maker space (MADE Barcelona) to produce the panel. All components are fitted in or sandwiched between two layers of 4mm MDF. You can easily remove the front panel if something needs to be changed or repaired. A transparent acrylic plate protects the buck and boost converters. You can take it off to adjust the output voltage. We attached the dashboard to the bike handle with rubber pipe clamps, M8 cap nuts, and bolts.

3. Charging batteries

Off-grid solar PV systems often charge lead-acid batteries. Human power does not depend on the weather and the time of day, but it can be practical to store human energy in a battery for future use.

Based on 100 watts of power production, it's easy to make overly optimistic calculations about the time you need to charge a battery. For example, if it takes 100 watt-hours to charge a battery, you can do that in one hour. Right? Wrong. Even if you could sustain a power output of 100 watts for an hour, the battery limits how much power you can put into it. It's not possible to do a short workout to charge the battery faster than it allows you to.

Lead-acid batteries charge between 10 and 25% of their maximum capacity – and we obtained 10% for all batteries tested. Charging one lead-acid car battery (roughly 60-80Ah) requires you to get 85-115 watts out of the

generator, which is a heavy workout. A full charge (12V to 13V) will take five hours, not including charge & discharge losses.

However, for smaller lead-acid batteries, the low power demand is problematic. There is little or no resistance on the pedals (so no real workout), it is very inefficient (the generator has high energy losses), and still, it takes as much time as charging a much larger battery. For example, recharging a 12V battery with a storage capacity of 14Ah (similar to the one powering the solar-powered website requires only 1.4A. That is not much of a workout (20W).

The same problem occurs with USB devices. The most cited use of a pedal power generator is charging a smartphone. However, recharging a smartphone requires very little power (5-10W) compared to what the bike can produce. (Some newer models allow faster charging). You may think charging a 10Wh phone battery would take only 6 minutes at a maximum power output of 100W, but it takes just as long as when you plug

Below the V&A meter are three voltage meters for every buck and boost converter. These show the voltage output for each of the circuits. The voltage output should be 12.0V for the 12V and 220V electric circuits and 14.4V for the 14.4V circuit. The first two may fall below that value if you don't pedal fast enough, while the last one may go above that value if you pedal too quickly - the wind charge controller will also make this clear to you). There is also a voltage and current meter on the 5V circuit. That helps to maximize power production by adding as many USB devices as possible (up to 2A).

Two more instruments are not on the dashboard itself: the voltage meter of the lead-acid battery and the temperature meters of the electric kettle and the Peltier refrigerator. None of these are essential. However, they can motivate the power cyclist. On the road, your efforts result in distance covered. Stationary cycling can be boring - you are not going anywhere. The instruments help you to set goals. For example: let's get the refrigerator

meters display variations better. Above the meter, there is a USB circuit to plug in a small LED light. That allows you to keep an eye on the V&A meter when dark. It's also handy to quickly check if the system is working.

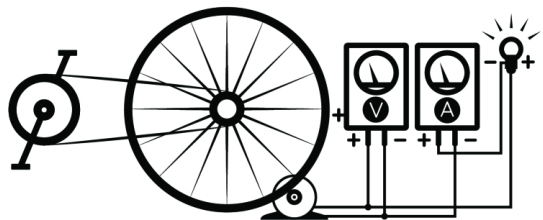
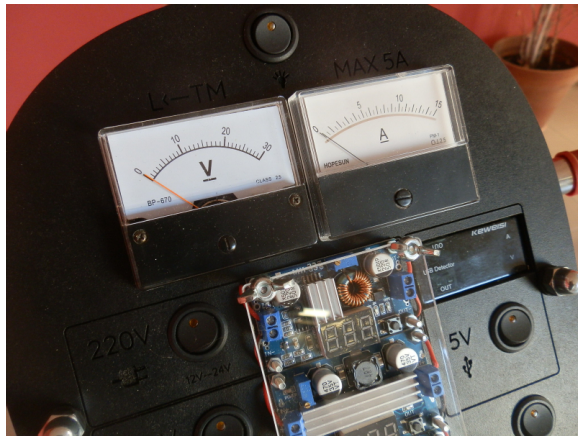
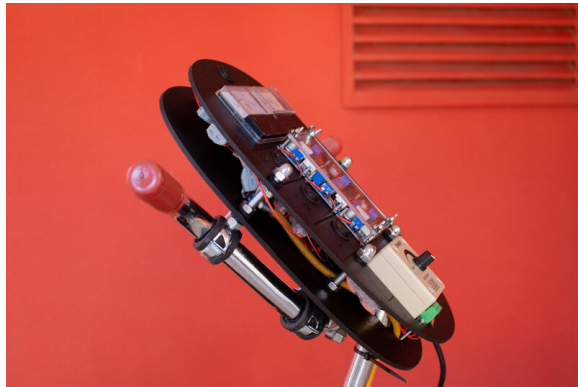
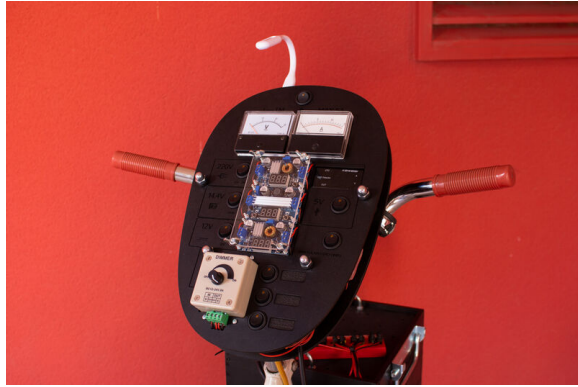


Image: how to wire the analog voltmeter and ammeter.

it into a wall socket. A much smaller hand-powered charger would be sufficient to charge a smartphone, but then you don't have your hands free.

THE DASHBOARD: HOW TO ADDRESS THESE CHALLENGES

To overcome all these problems, we built a control panel that distributes the power from the bike generator into switchable circuits with different voltages for the operation of various devices. You can use these circuits separately or in combination, which allows you to adjust the resistance at the pedals precisely for the optimal workout. You can also control some devices directly by lowering their power demand.



Matching the voltage: Buck and boost converters

There is no need to pedal faster or slower to match the voltage of different devices. Instead, you can use buck

part is essential when there are batteries attached to your system. Without a diode, the battery could power the generator (and turn the pedals) instead of the other way around. We put a Schottky diode right after the generator to prevent this. It needs to be rated for the correct amperage: above your expected power production. Our maximum power production is 8-9A, the Schottky diode takes 10A.

Dashboard Instruments

The control panel includes several displays that show the voltage and current in different electric circuits. The analog volt- and amp meter on top is the most important one. It shows how much power the generator is producing ($V \cdot A = W$). The voltmeter tells you how fast you are pedaling, the amp meter how hard you are pedaling.

Analog V&A meters are most precise in the middle of their range, so we choose a voltmeter that goes up to 30V and an amp meter that goes to 15A. A digital V&A meter is more compact, but analog

that light up when active because that quickly shows which electric circuits are in operation when starting the pedal power generator. However, lights make wiring the on-off switches more complex.

We bought switches with the wires already attached because we preferred not to solder the connections. However, we had to solder them anyways because the thick wires took too much space. On-off buttons without lights and with prefixed thinner wires simplify this part.

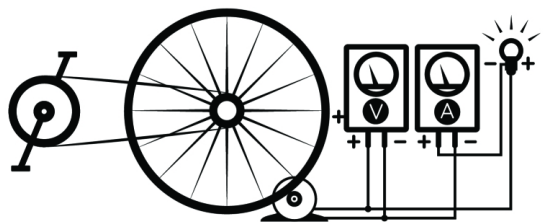


Image: how to wire the on-off switches.

Schottky Diode. A Schottky diode ensures that the current can only flow in one direction through a cable. This tiny

converters and boost converters - electronic modules that convert a fluctuating voltage input into a steady voltage output. Buck converters have a higher input voltage than the output voltage (they step down the voltage), while boost converters have a higher output voltage than input voltage (they step up the voltage). There's more information on buck and boost converters in the manual.

Matching the current: Switchable circuits & dimmers

You can build one electric circuit using only one buck or boost converter. You can then adjust the voltage by turning the tiny screw every time you power a device that requires a different voltage. However, building multiple switchable circuits with different voltages brings advantages. Not only can you easily switch between different types of appliances without the need for a screwdriver, but you can also adjust the resistance at the pedals by running

several circuits simultaneously. The control panel includes:

- * Two circuits for powering or charging USB devices (5V)
- * Three circuits for powering 12V appliances
- * One circuit for charging lead-acid batteries (14.4V)
- * One circuit for powering mains appliances (220V here in the EU)
- * One unregulated circuit where the voltage output matches the v

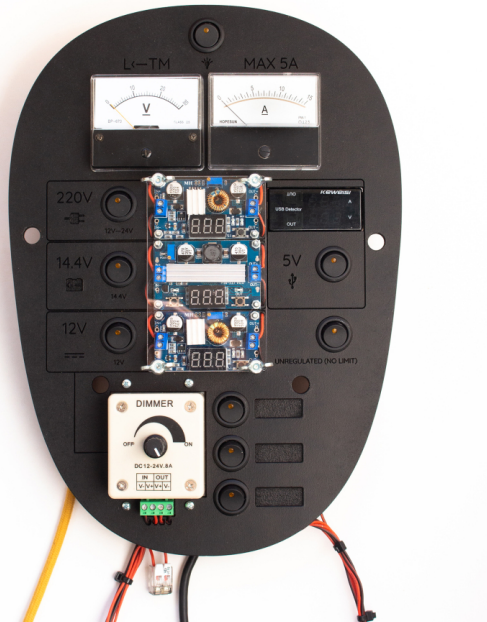


Image: the front of the control panel

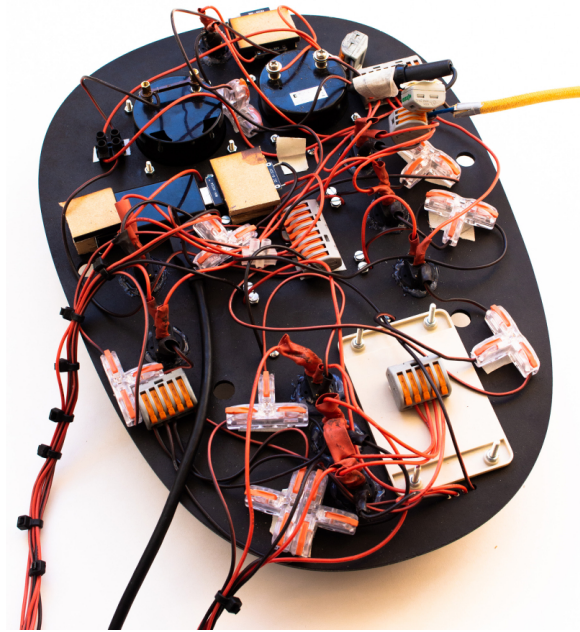
which takes 11A. A better option would have been an 18AWG 0.82mm² cable, which takes 16A. Take care when stripping the wires: if you cut too deep the cable can take less current.

Connectors. Wires can be connected using very different methods. We choose lever connectors — bulky and expensive but handy. They help to connect wires securely without soldering or screws. These connectors come with two to ten pins. Wiring the dashboard can become disorderly. Make sure you don't cut the cables too short.

Fuses. You can build a bike generator and controller without fuses, but it's not a good idea. A fuse will break the electric circuit when you exceed a current threshold, preventing fire and damage to components. We placed a 12A fuse at the entrance of the dashboard (our max power production is 8-9A). We also added fuses to most of the devices we power.

On-off switches. Switchable circuits require on-off buttons. Our dashboard has nine of them. We wanted switches

you, so here's what you need to know.



Wires. The control panel includes roughly ten meters of electric cable. However, the main thing to worry about is not the length but the thickness of the cable. Opt for too thin wires, and your dashboard may catch fire during a heavy workout. Making the right choice can be confusing because there are several standards. We wired the dashboard with a 20AWG 0.52mm^2 cable,

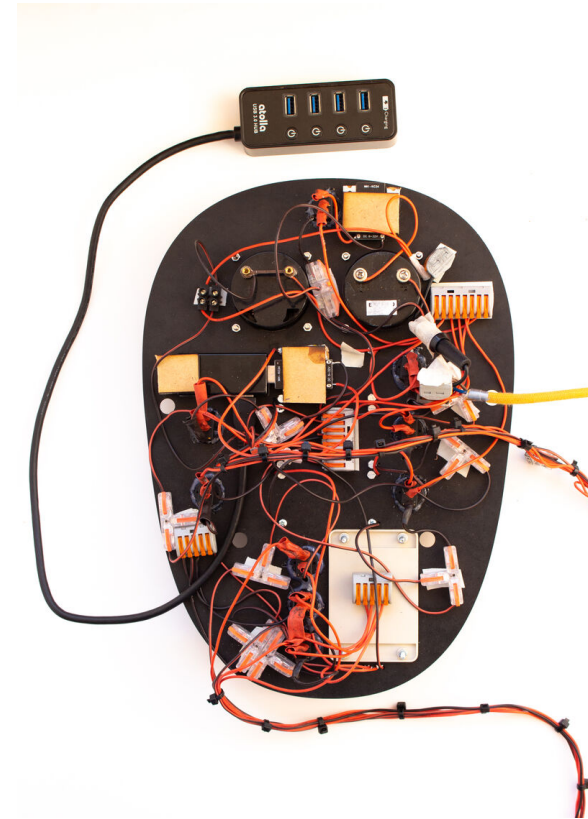


Image: the back of the control panel

If there is insufficient power demand, you can increase the resistance on the pedals by switching on more circuits. That will also increase the efficiency of the generator. To address the low

power demand of batteries, you can keep the 5V and 14.4V circuits always open. That introduces a basic electric load of roughly 20W (two to five USB devices and a 14Ah lead-acid battery). For a heavier workout, increase the load by opening other circuits and powering more devices. This approach does not shorten the time it takes to charge batteries. However, it makes your effort more worthwhile.

A dashboard with nothing but 5V USB circuits is another option. More so, you use the control panel in that way without small changes. You can hook up a handful of devices to a single USB output, with a maximum power use of 10 watts (5V/2A). Our dashboard has two 5V circuits – one serves primarily for dashboard lighting, but you can add a USB distributor hub to it for another 10W of devices.

You can add six additional USB power outputs by plugging USB connectors into the three 12V outputs, at least when you add three female 12V connectors. That brings total power demand to 80 watts – enough to recharge 10 to 15 smartphones

Wind charge controllers have three green wires to connect to the power source. You can take any two of these three wires and connect them to the plus and the minus of the power input – it doesn't matter which goes where. Most wind charge controllers commercially available are way too powerful for a pedal power generator, so get the smallest one you can find. We sent two charge controllers back to the manufacturer. One wind charge controller with a screen came without a manual, and nobody could figure out how it works. The only hybrid wind/solar controller that we tried, for now, was dangerous. The solar panel overcharged the battery. It also maintained the electric brake for half an hour whenever we crossed the threshold, thus blocking human power production.

Wires, connectors, diodes, fuses, on/off buttons

You need wires, connectors, diodes, fuses, and on-off buttons to connect everything. All these parts can confuse

should stop pedalling. Because you are the power source and thus certainly present and awake, this approach is less risky than charging a lead-acid battery from a DC power supply or a solar panel without a charge controller.

However, it's a good idea to add more security. A solar charge controller provides this security in a solar PV system. It cuts the power input whenever the voltage rises above 14.4V. However, a solar charge controller does not work when coupled to a bike generator. Instead, you need a wind charge controller, which operates the other way around. Instead of cutting the load to zero, a wind charge controller suddenly increases it and "brakes". If you use a buck converter, the wind charge controller will rarely activate the break because the buck converter will limit the voltage output to 14.4V. It will only brake when you threaten to overcharge the battery. If you use a boost converter, the wind charge controller will brake whenever you accidentally exceed a voltage output of 14.4V.

simultaneously. There's no shortage of USB devices these days: phones, tablets, ebooks, power banks, bicycle lights, cameras, wireless headphones, AA battery chargers, and so on.

Dimmer

If there is too much power demand, you can switch off one or more circuits. For some more powerful 12V devices, the dashboard also allows you to lower the current and thus the resistance on the pedals directly by using a variable resistor or potentiometer (better known as a dimmer). When you "dim" appliances like the electric kettle or the Peltier refrigerator, they work just as well, only slower. Without a potentiometer, only athletes could power these devices (100-120W). Dimming does not work for all devices. A laptop, for example, will shut down if it does not receive the power it needs.

By switching between and combining different circuits - and by finetuning the current on the 12V circuit - you can adjust the resistance at the pedals as

precisely as on an exercise bike. That optimizes endurance but also power production.

HOW TO USE THE BIKE: EXPERIMENTS

A bike generator is best suited for powering electric devices directly – without storing the energy into a battery first. That avoids charge and discharge losses (up to 30% in lead-acid batteries) and reduces the complexity and the costs of setting up a practical human power plant. For this purpose, our control panel has several 12V circuits and a 220V circuit.

used only buck converters. We used a boost converter to charge lead-acid batteries for the next version. The generator needs to produce 16-17V to obtain a voltage output of 14.4V with a buck converter. That is fine if you only want to charge lead-acid batteries because you can then adjust the gear ratio to produce 16-17V at a comfortable pedalling speed. However, if you optimize the gear ratio for lower voltages, you have to pedal very fast whenever you include the charging of batteries in your workout.

Wind charge controller

The bike generator needs to supply 14.4V to charge lead-acid batteries – the maximum voltage that a lead-acid battery needs. In principle, all you need is a buck or boost converter, but there's one caveat: you may overcharge the battery, which can lead to an explosion. You can avoid this risk in a low-tech way – by keeping an eye on the amperemeter. Once the current drops to 3% of the rated storage capacity of the battery (in Ah), the battery is fully recharged – and you

These small modules with a USB connector convert a fluctuating voltage input into a steady 5V voltage output.

If you want to power 12V devices or recharge lead-acid batteries (14.4V), both a buck and a boost converter could work. If you opt for a buck converter, the bike generator needs to have a voltage output that is slightly above 12V or 14.4V (13-14V and 16-17V, respectively). This higher input voltage is necessary to compensate for energy losses in the power conversion. If you use a boost converter, the voltage output of the generator needs to stay below 12V or 14.4V.

A buck converter will never exceed the chosen voltage output, no matter how many volts the generator produces. In contrast, a boost converter guarantees you a minimum voltage output, but it does not set a maximum output voltage. If you pedal too fast, the voltage output may exceed the set voltage output and damage the appliance or battery you are powering or recharging.

For our first dashboard prototype, we



Image: Some of the appliances that we tested: air compressor, lights, Peltier refrigerator, dot-matrixprinter, electric kettle, soldering iron.

Among the 12V devices that we powered directly are an experimental Peltier refrigerator, a water kettle, laptops – powered by a 12V adapter, and without battery or with the battery at 100% – lights, a soldering iron, a power drill, and a sander. Many more 12V devices exist, mainly aimed at truck drivers and car drivers, sailors, caravan dwellers

(and low-tech tinkerers who wire their apartment as if it was a sailboat).

These are all the devices we have powered or charged so far:

- * All types of USB devices (5V)
- * Lead-acid batteries of different sizes (14.4V)
- * Peltier refrigerator (12V)
- * Electric kettle (12V)
- * Soldering iron (12V)
- * Corded power drill (12V)
- * Corded sanding machine (12V)
- * Air compressor (12V)
- * Model railway (12V)
- * Sewing machine (220V)
- * Dot-matrix printer (220V)
- * Stereo amplifier + cd-player (220V)
- * Laptops (12V, 220V)
- * Lighting (5V, 12V, 220V)
- * Fans (5V, 12V, 220V)

Powering the lights is often more practical with a battery because that allows you to enjoy lighting without having to pedal at the same time. However, it's perfectly doable to read a book on the bike while providing the lights in real-time, especially in winter – it takes little effort, it's healthier than sitting still, and it keeps you warm. Other appliances that are well suited for “direct drive” human power production are power tools and

Also, do NOT buy a voltage regulator. This device allows you to regulate the output voltage but only in relation to the input voltage. If the voltage input changes, so will the voltage output. You want a buck or boost converter, in which the voltage input can fluctuate but the voltage output is stable.

Finally, you should check the maximum current rating before buying a buck or boost converter. Some only take 2A, which is not powerful enough for a bike generator. You need at least one that can take 5A and preferably one that can take 10A or 15A, depending on your power output.

Buck or boost converter?

Whether you opt for a buck or a boost converter depends on the voltage produced by the generator – and by the voltage of the device(s) you want to power or charge. If the bike generator puts out 12V and you want to charge 5V USB devices, you need to step down the voltage and thus use a buck converter.

You can adjust the output voltage by turning a tiny screw on the module. Some buck and boost converters come with a small digital screen that shows the output voltage. If this is not the case, you can use a multimeter to adjust the voltage output.



Note that you need either a buck or a boost converter. Do NOT use a buck/boost converter. This is a sort of micro bench supply that requires the output voltage to be adjusted every time the system is powered up. This is unpractical and risks damage to your appliances. In contrast, a buck or boost converter remembers the output voltage whenever you start it up.

heating and cooling devices.

1. Corded power tools

Although 12V power tools are widely used, they are almost always powered by lithium-ion batteries. You could recharge these batteries with human power. However, that will take a long time, is not much of a workout, and introduces significant energy losses. Therefore, it makes sense to convert these devices into corded power tools. In this way, you only need to produce power when you need it, with much higher efficiency. Furthermore, there is no more need to wait for batteries to charge – the tool is always ready to use.

Converting a battery-powered tool to a corded tool can be pretty straightforward. After removing the battery, locate the positive and the negative contacts and solder two wires to them. Note that you only get one chance to decide which one is positive or negative. For the power drill, this was very easy to figure out. For the

sander, we asked advice because the wiring is more complicated. 12V power tools with missing or dead batteries sell cheap on the second-hand market.

A corded power drill is perhaps the most versatile tool. You can use it with a whisk (to beat eggs), a stiff brush (to remove paint or clean objects), a grinding wheel (to sharpen knives), or a polishing wheel (to make chrome or other metals and materials shine). Precision tools for jewelry or model making also combine well with direct pedal power. We are still in the early testing phase for converting and using corded 12V power tools.

Hand versus foot-powered tools

Compared to human-powered mechanical hand tools, human-powered electric equipment is less energy efficient. Going electric introduces extra energy losses – in the generator, the buck converter, the wires, and the drive train. However, this is more than compensated for by a more energy-



Image: the friction drive.

MANUAL: THE CONTROL PANEL

Buck and boost converters, dimmers

Buck converters and boost converters are electronic modules that convert a fluctuating voltage input into a steady voltage output. Buck converters have a higher input voltage than the output voltage (they step down the voltage), while boost converters have a higher output voltage than input voltage (they step up the voltage).

fixed the shaft arbor with grub screws placed on the flat section of the shaft. It's an M10 threaded rod. You can secure a wheel on it with a couple of washers and a nut. A Bore Rigid Coupling could also serve as a small spindle. You can also use it to attach the generator's shaft to another axle with a wheel. However, we found this was not ideal for our setup because the set screws stick out of the coupling, damaging the flywheel.

How to fix the friction drive to the bike?

We screwed the generator to a wooden board and then pressed it against the flywheel using a wood support structure. The board is attached to the bike with a strong door hinge. That allows adapting the angle at which the spindle is in contact with the flywheel. The stand is resting on a cork wedge that buffers the vibrations. See our first prototype for another method.

efficient use of the human power source. Our legs are roughly four times stronger than our arms.

Going electric is also more ergonomic because it spares hand joints and muscles. Fixing dozens of screws by hand may be more sustainable than using a power drill, but it can ruin your wrist. A bike generator thus allows you to work faster and more ergonomically without relying on an external energy source. Mechanical hand tools keep some advantages: they are silent, more portable, and less energy-intensive to manufacture. A third option combines these advantages: pedal-powered mechanical equipment. However, it's challenging to build a compact stationary bicycle that can power many different tools. We designed the bike generator to be as compact and multifunctional as possible.

Power tools can have high power demands, but this should not stop you. The sander only needs 30 watts at most, but our power drill can demand up to 20A of current - which is too high for the bicycle generator and control panel

($12V \times 20A = 240W$). However, the machine will rarely require that power unless you use it to drill through hard materials. The power demand of a power tool will increase whenever the torque increases, so you feel when the drill bit has gone through the material or when the screw has been fixed or loosened. You can handle the tool as precisely with your feet as you can with your hands.

2. Electric kettle

Electric heating and cooling are energy-intensive. Alternatives, such as direct solar heat and fire, are more sustainable. However, heating and cooling can easily be included in your exercise routine and provide results. We apply this principle with an electric kettle and an experimental Peltier refrigerator. Both appliances are very well insulated. Consequently, converting human power into heat or cold becomes another form of energy storage – without all the drawbacks of batteries.

Electric kettles that run on grid power

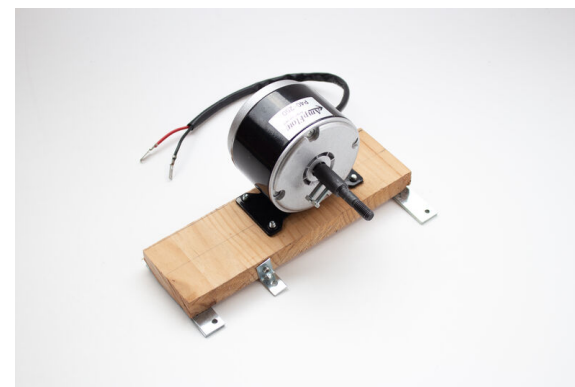


Image: the generator with a threaded shaft arbor.

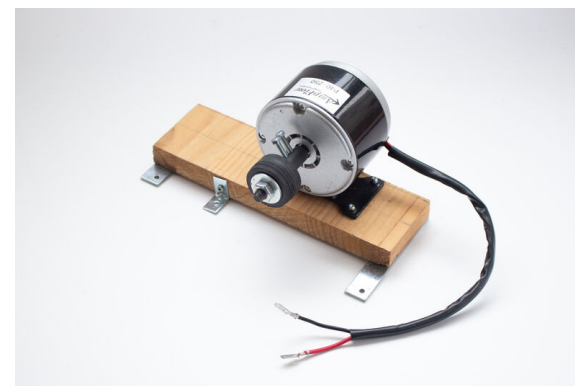


Image: The generator with the 41mm spindle.

We found that a threaded shaft arbor with set screws was the most versatile solution to test different wheels. We

How to fix the spindle to the generator?

The generator comes with an integrated sprocket or pulley drive. You need to remove it to attach the spindle. A nylon lock nut with a reverse tread holds the sprocket or pulley drive. You need to unscrew it to the right. You probably need a clamp to manage this. Our generator features an 8 mm shaft, while our spindle fits on a 10 mm shaft. Therefore, we use a two-part spindle featuring a “shaft arbor” and a wheel. To properly attach the spindle, you can take advantage of the D-cut on the shaft (a “round shaft with drive flat”). Our first try was a threaded fixation, but that did not work. Because of the reversed thread, it will come loose when the generator starts spinning.

are often very powerful and boil water in a matter of minutes or even seconds. Boiling water using a bicycle generator will take a lot more time, but it’s perfectly possible. We acquired a commercial 12V electric kettle with a vacuum insulated reservoir of one litre. During a test, boiling water for one cup of tea took slightly over one hour at an average power production of 60 watts.

The electric kettle can also prepare hot water bottles for thermal comfort. That requires more water than a cup of tea, but with a lower temperature of around 60 degrees celsius. During a test, heating one litre of water for a (small) hot water bottle took 1 hour and 30 minutes at an average power production of 60 watts. Following this effort, the last thing you need is a hot water bottle. Stronger still, during that effort, you are a space heater with an output of several hundreds of watts, and you may be able to increase the air temperature in a small room. However, the vacuum insulated kettle can be put into a fireless cooker and used up to 24 hours later when you are inactive and need warmth.

3. Peltier refrigerator

Commercial 12V refrigerators are expensive. After researching thermoelectric generators (TEGs), the idea of a Peltier refrigerator was born. A Peltier refrigerator is essentially a well-insulated fireless cooker with a TEG mounted on top. If power is applied, the module will get hot on one side and cold on the other, cooling the box interior. TEG cooling is not particularly efficient. However, it's silent, works without problematic cooling gases, and is the easiest way to make a refrigerator yourself.

The TEG refrigerator is an early prototype, which needs further testing and improvements. Powering one TEG at full power requires roughly 60 watts (12V*5A), measured right after the generator. That is a good workout, and the dimmer allows to lower the resistance at the pedals precisely. However, it quickly became apparent that one TEG is not enough for the size of the cooling space. We will add a second

Other options are small solid polyurethane wheels and rubber suspensions. Skate wheels have a larger inside diameter which is not ideal for an 8-10mm shaft. Be careful to choose a material that can handle friction: some plastic tends to heat up and melt. Keep in mind: this is a trial and error process. You won't get this right from the first time. Another route you could take is to design a custom lathed piece, as is described in magnificentrevolution.org's tutorial. A universal mounting hub can help attach wheels featuring bolt holes, such as robot wheels.

Buying a DC generator with a pre-installed spindle seems the easiest solution. For example, Pedal Power Generator offers a 360W generator with a spindle size of 37.5 mm. However, you can't choose a spindle with a different diameter. That means you cannot control the output voltage unless you replace the sprockets in the bicycle drive train. In our case, a 37.5mm spindle would produce 18V, which is too much.

need?

Figuring out the spindle size is only half of the work. It can be challenging to find a spindle with the correct diameter, made from the required materials, and compatible with the generator shaft. We tried a dozen spindles until we got the right one. A flywheel has a hard surface and requires a soft spindle made of rubber or polyurethane. We found that a solid metal and rubber buffer allowed optimal friction with our flywheel. We took it to a metal workshop where they drilled a 10 mm hole into the piece.



Image: A sample of our test spindles.

one for a heavier workout (60-100 watts).

Mains Appliances (220V)

Our dashboard also includes a 220V circuit. That makes it compatible with grid-powered devices (110V in the US, 240V in the UK). The 220V circuit requires an inverter. The inverter is too large to include in the dashboard, so we placed it in a box on the luggage rack that we built in front. A 220V socket is not necessary. Many 220V appliances have 12V (or 24V) alternatives which are more energy efficient for decentralised power production. However, we included a 220V circuit for powering devices that have not (yet) been replaced by or converted to low voltage alternatives: the dot-matrix printer, the sewing machine, the stereo system, and the router.

The dot-matrix printer and the sewing machine are challenging to operate because of their rapidly changing power demand. For example, to avoid the voltage dropping below 12V at high power

peaks while printing, you need to pedal very fast (around 20V) to provide sufficient inertia to the flywheel. A supercapacitor may be able to solve this — this is something we will try in the coming months. A foot-powered mechanical sewing machine and printer would be much more energy-efficient — but much less space-efficient.

BIKE GENERATOR WITH A WORK DESK

The control panel is designed to power a wide diversity of devices, but you can follow a similar approach with different results. For example, if you only want to charge lead-acid batteries, one 14.4V circuit is enough. You can use a buck and boost converter to create any voltage you need, for example, to build a 3V, 6V, 9V, or 24V circuit.

However, if you mainly want to run 24V appliances, it's a better idea to adjust the gear ratio. Same if you only want to charge 14.4V lead-acid batteries on a 12V system: adjust the gear ratio to

You can use the formula in different ways. You can use it to calculate the minimum RPM at the pedals for a given spindle; to calculate the generator RPM based on a given RPM at the pedals and spindle size; and to calculate the voltage that will be produced by a given configuration. Find the formulas below, followed by an example based on the configuration illustrated above:

Calculate the minimum RPM at the pedals for a given spindle size (S):

- * $\text{RPM generator} / [(PS * W) / (FS * S)]$
- * $2260 / [(190 * 525) / (60 * 41)] = 55.81$ RPM at the pedals.

Calculate the generator RPM for a given spindle size and RPM at the pedals:

- * $(PS / FS) * (W / S) * \text{RPM at the pedals}$
- * $(190 / 60) * (525 / 41) * 55 = 40.61$ (gear ratio) * 56 = 2274 RPM

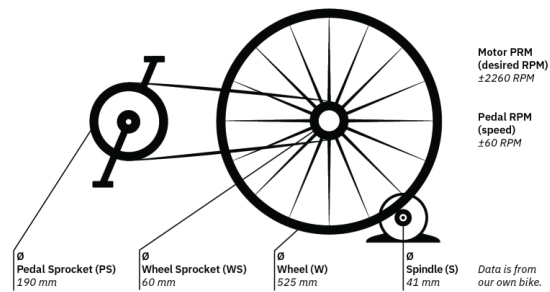
Calculate the voltage for a given RPM at the generator:

- * $\text{Generator RPM} * \text{No load RPM ratio}$
- * $2274 * (3400 / 24) = 16.1\text{V}$

What type of spindle do you

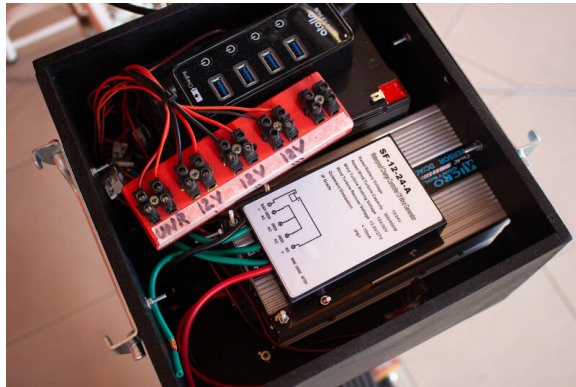
- * 12V = $(190*525*60)/(60*1700) = 58.68\text{mm}$ spindle diameter.
- * 13V = $(190*525*60)/(60*1842) = 54.15$ mm spindle diameter.
- * 14V = $(190*525*60)/(60*1983) = 50.30$ mm spindle diameter.
- * 15V = $(190*525*60)/(60*2125) = 46.94$ mm spindle diameter.
- * 16V = $(190*525*60)/(60*2267) = 44.00$ mm spindle diameter.
- * 17V = $(190*525*60)/(60*2408) = 41.42$ mm spindle diameter.
- * 24V = $(190*525*60)/(60*3400) = 29.34$ mm spindle diameter.

The exact voltage you need - and thus the exact spindle size - depends on what exactly you want to do with the bike. We address this in detail in the manual for the control panel. Imagine you want to charge lead-acid batteries (which require 14.4V). You use a buck converter (which steps down the input voltage), so you will need to produce close to 17V to make up for the losses in the voltage conversion. That results in a spindle diameter of 41.42mm. This configuration shows in the illustration below.



generate 16-17V (to compensate for energy losses in the buck converter). How to do this is explained in the manual.





Images: The luggage rack that holds the inverter, the wind charge controller, the lead-acid battery, and the power outlets.

Our choice to have a large dashboard on the handlebars has advantages and disadvantages. To have the control panel on the bike itself makes it easy to read and manipulate. It also makes the bike generator portable. If the neighbour needs emergency power, you pick up the bike, and you are there in a minute. On the downside, having the dashboard on the bike adds vibrations, which increase noise and energy losses. It also makes it necessary to adjust the voltage output from the buck and boost

First, you need to find the “no-load RPM” of your generator. This information should be provided by the manufacturer. Our generator has a no-load RPM of 3400 at 24V. This ratio is proportional – you can calculate the required no-load RPM for any voltage you want. For example, at 12V it’s 1700 RPM (3400/2412), and at 16V it’s 2267 RPM (3400/2416). Next, measure the outer diameter of the pedal sprocket, the flywheel sprocket, and the flywheel. Whether you use mm, cm, or any other unit doesn’t matter but be consistent. Now you have all the data you need to calculate the spindle size. Below is the formula, followed by the calculation for our specific case (assuming 60 RPM at the pedals):

$$\text{Spindle diameter} = (\text{PS} \times \text{RPM pedals}) / (\text{WS} \times \text{RPM generator})$$

- * PS = pedal sprocket diameter
- * W = flywheel diameter
- * RPM pedals = how fast you pedal
- * WS = flywheel sprocket diameter
- * RPM generator = the no-load RPM of the generator

Spindle diameter for our configuration (in mm) to produce different voltages:

“rounds per minute”). However, the rotating speed of the generator is not a given. It depends on how fast you pedal (the RPM of the pedals). It also depends on the gear ratio between the pedals and the generator. The average RPM of the pedals on a stationary bike – a comfortable pedalling rate that you can sustain for a long time – is roughly 60 RPM. It can be calculated precisely by a tachometer or using low-tech tricks.

Our bike generator uses a friction drive. It consists of a small wheel (the spindle) attached to the generator shaft that will spin in contact with the flywheel. Calculating the gear ratio involves measuring the outer diameter of four parts: the pedal sprocket, the flywheel sprocket, the flywheel, and the spindle. The first three are known, while the latter was for us to figure out. The spindle size you need depends on the specifications of your generator and on the exact voltage that you would like to produce. Figuring this out can be mind-boggling unless someone provides you with the right formula (thank you, Gabriel Verdeil!).

converters from time to time.

Most importantly, having such a large control panel on the bike prevents you from placing a large desk on top of the handlebars instead. That could be useful to operate power tools or a laptop while simultaneously providing power. Our present set-up is not ideal for using power tools. It requires two people – one to cycle and one to operate the power tool. Likewise, you can power another person’s laptop, but you can’t power yours while using it.

We plan to build a bike generator with a smaller dashboard – one 12V circuit and two USB ports – and a large workspace on the handlebars. Such a bike generator harks back to similar (mechanical) bicycle machines from the early twentieth century. Another option is to screw the control panel to the wall or put it on a shelf – and place the bike generator next to it. The inverter, lead-acid battery, and wind charge controller – now on the “luggage rack” – can also move away from the bike.

HYBRID HUMAN/SOLAR POWER SYSTEM

Some of you may think that our bike generator is more of a gimmick than a practical power source for the household. In part, this is true. Our human power plant is the perfect exercise machine – power production is motivating. It is also practical in emergencies, especially if enough people power is available – it can produce up to 2.4 kWh per day. However, it won't provide enough energy daily – not even for a low-tech household. In practice, there are not enough people willing to cycle.

On the other hand, a bike generator is an excellent addition to an off-the-grid solar PV system, at least in a low-energy household. The power output of the bicycle generator does not depend on the weather, the seasons, or the time of day. Human power can provide extra energy during bad weather, which reduces the need for expensive and unsustainable

Be sure to get a brushed DC motor. Brushless DC motors won't work because they need a very high rotation speed. Note that a generator is a motor working in reverse. When searching online, "DC motor" will give you more results than "DC generator". Car alternators also work, and many pedal power plants use them because they are cheap and easy to obtain. However, they are very inefficient and require a 9V battery to start.

You can scavenge DC generators from discarded electric scooters or bicycles, but we bought a brand new one: the Ampflow Pancake Motor P40-250. It has a no-load RPM of 1700 at 12V and a maximum power output of 250 watts. You can tighten it securely to a metal or wooden surface, which saves a lot of trouble.

How to calculate the gear ratio and spindle size?

The voltage created by the generator is directly proportional to the rotating speed of the generator (the RPM or



Image: the friction drive.

What type of generator do you need?

To convert the mechanical energy of the flywheel into electricity, you need a 12V/24V permanent magnet DC generator with a maximum power output of about 150-250 watts. Not any generator will do. You need one that runs at a relatively low speed (<5000 no-load rpm) to obtain 12 or 24V with a practical gear ratio (see further). Many generators need to run at higher speeds to generate 12V or 24V, and you won't be able to produce more than a few volts at an average pedalling rate.

batteries. That is especially useful in winter, when the solar PV system produces much less power, and when the effort required to operate the bike also keeps you warm. There is enough solar power in summer – when it's often too hot to use a stationary bicycle.



Image: The bike generator stands right next to the solar PV systems. The ultimate plan is to integrate both power systems.

With a power production of 50-100 watts, the bike generator is more powerful than the two solar panels that are standing on the balcony next to it: the 50 watts solar panel that is powering the lights in the living room and the 30W solar panel that runs the solar-powered website. The solar panels rarely – if ever – reach their maximum power production, and during bad weather, they produce much less power than the bike generator. With dark clouds overhead, energy production almost drops to zero, and if this lasts for two days, the lights and the website go down. One or two hours per day on the bike generator could fix this. Alternatively, pedal power could operate power tools or other devices without draining the energy storage from the solar PV system.

It's also possible to use the dashboard with a solar panel instead of a bike generator. It suffices to replace the

wind charge controller with a solar charge controller. You can then use solar energy to power devices directly – without necessarily using a solar charge controller and battery. Replace the wind charge controller with a hybrid solar/wind charge controller, and you can use both energy sources to charge batteries and power devices directly. Solar and human power can also be combined, increasing the power output.

Combining solar and human power should make it possible to take further steps towards an off-grid urban household. The plan is to add another 50W solar panel, take more devices off the grid (most notably the refrigerator) and keep the battery storage as it is.

MANUAL: THE BIKE GENERATOR