Empowering communities for sustainable rural electrification.

Locally Manufactured Small Wind Turbines
Low-cost renewable energy technologies can make small-scale electricity production more accessible to rural communities. The local manufacturing of such technologies can significantly reduce the initial costs with the use of locally available materials, tools, and manufacturing techniques, and, at the same time, it can reduce maintenance costs by providing appropriate training to the user community. Open designs, which can be adopted to local needs and supported by a global technology network, have provided successful examples of appropriate technology applications for the past 40 years, such as small and pico hydroelectric rural electrification systems in Nepal and renewable energy training centers in Mali.

A widespread technology with such characteristics is the locally manufactured small wind turbine. Designs of do-it-yourself (DIY) small wind turbines date back to the early 1970s, as in the November 1972 issue of Popular Science magazine with an article by Hans Meyer, from the Windworks cooperative in Wisconsin, on how to construct a downwind small wind turbine for electricity production (Figure 1). This technological approach was embraced by the back-to-the-land movement of the late 1970s in the United States and Europe and was developed further.

One of the first applications of locally manufactured small wind turbines in developing countries for rural electrification was initiated by the Intermediate Technology Development Group, now called Practical Action. In 2000, this group collaborated with Hugh Piggott of Scoraig Wind Electric, who had more than 20 years of hands-on experience, at the time, in harnessing electricity from the wind and had implemented many locally built designs in the off-grid rural community of Scoraig in Scotland. He was contracted to prepare a design manual, The Permanent Magnet Generator: A Manual for Manufacturers and Developers, which was aimed at the local production of a 200-W permanent magnet generator for small wind turbines in developing countries. Most of these small wind turbines were installed in rural communities in Peru and later on in Sri Lanka and Nepal. Piggott continued improving the design manual and the small wind turbines himself while organizing construction seminars in Europe and the United States, where DIY enthusiasts learned how to construct complete small wind turbines. In 2008, two design manuals presenting well-documented and highly detailed procedures of constructing and designing axial flux small wind turbines were published. One was by Piggott, the Wind Turbine Recipe Book: The Axial Flux Windmill Plans, which described the process of constructing and designing small wind turbines of rotor diameters from 1.2 m up to 4.2 m, and the other was by Dan Bartmann and Dan Fink of Otherpower, Homebrew Wind Power, which described a similar construction and design process along with some modifications for more demanding environments.

Since then, these design manuals have been a reference guide for locally manufactured small wind turbines and have proven to be valuable tools in spreading this knowledge. Rural electrification has been an obvious application of this technology; many nongovernmental organizations (NGOs) and groups have used these design manuals and locally constructed small community wind turbines in developing countries, while construction seminars for DIY enthusiasts have been organized by several groups around the world. Since 2012, the Wind Empowerment Association has managed to network most of the organizations involved with locally manufactured small wind turbines in the world, aiming at building the financial and human resources needed for the activities of these organizations and at performing joint technical research while sharing technical information. The second Wind Empowerment conference held in Athens, Greece, in November 2014, is the latest achievement of the network, with more than 40 participants from all continents exchanging experiences from the field while organizing working groups to tackle issues surrounding locally manufactured wind turbines under the themes of technology, market assessment, delivery models, maintenance, education, and measurement.

It has been estimated that more than 1,000 locally manufactured small wind turbines have been constructed based on Piggott’s design, and currently many of them are in operation around the world (Figure 2).

Open-Source Hardware

Locally manufactured small wind turbine technology is developed through a bottom-up innovation process, which is quite unique and resembles an open-source hardware (OSH) community in the making. In such bottom-up innovation processes, research and development is typically conducted by the users themselves, with an open-design approach. This increases the reconfigurability of the end product, while modifications of manufacturing techniques.
and the design itself are made faster and more effectively. In
addition, in such projects, support to users and designers is
offered by the OSH community itself through Internet
forums and/or online tools. This allows for a technological
application, for example, locally man-
ufactured small wind turbine tech-
nology, to enable a vast social support
network to assist all installed small
wind turbines of this type.

Locally manufactured small wind
turbine technology is developed
through different hubs of informa-
tion exchange. The largest online
forum of locally manufactured small
wind turbine users and designers
exists within Fieldlines.com, the
discussion board of the Otherpower
group in the United States, with 6,615
members since it was set up more
than a decade ago to exchange infor-
mation on off-grid renewable energy
systems. Other such forums exist in
the English language, such as
theBackshed.com in Australia with
2,866 members and navitron.org.uk
in the United Kingdom with 6,406
members. Smaller forums on the
topic and in the local language exist
in Finland, Germany, and France. In addition, the Wind
Empowerment Association Web site, which already hosts a
forum in English on locally manufactured small wind tur-
bines, is currently discussing the possibility of providing
access to Spanish-speaking users. Furthermore, there are
online forums, relevant blogs, and Web sites, such as
Piggott’s blog, where information on this technology is post-
ed and the Web sites of several NGOs installing locally
manufactured small wind turbines on all continents. Final-
ly, university research groups in Delft University of Technol-
ogy; the University of California, Berkeley; the Polytechnic
University of Catalonia; the Hochschule für Technik und
Wirtschaft in Berlin; and the National Technical University of Athens
(NTUA) have been working on rural
electrification, and also research cen-
ters such as the Kathmandu Alterna-
tive Power and Energy Group, have
included locally manufactured small
wind turbine designs in their
research activities.

Using these communication and
information-sharing tools, this glob-
al community of users comprising
different technical and social back-
grounds exchange experiences on
every aspect of design, construction,
installation, and maintenance phas-
es of a small wind project while
considering the technical, financial,
social, cultural, and environmental
aspects. The manufacturing tech-
niques themselves, apart from
being discussed online with the
assistance of text, videos, and con-
struction manuals, are also dis-
played in practice through practical construction seminars
organized by several groups in Europe and the United
States, and by several NGOs in Africa, South and Central
America, the Middle East, and South Asia.

**Constructing and Installing a Small Wind Turbine**
The small wind turbines discussed in this article are typi-
cally part of rural off-grid hybrid systems with installed

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**All meteorological and electrical data, such as currents and voltages, are measured and logged to provide 1-min averages, which can then be grouped according to different wind speeds using the method of bins.**

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**Figure 1.** Home-built small wind turbine plans by Hans Meyer from the Windworks cooperative. (Source: Popular Science, November 1972.)

**Figure 2.** A locally manufactured small wind turbine following the design manuals of Hugh Piggott. (Source: rurerg.net.)
capacity of renewable energy sources (RESs) of up to 10 kW. These systems usually consist of a photovoltaic generator, whose size will depend on the available wind resource, a flooded lead-acid battery bank, an inverter/charger, and possibly a diesel generator for backing up the renewable energy system. The small wind turbine itself requires a rectifier to feed its ac directly into the battery bank and also a diversion load charge controller with a resistive load for diverting excess energy when the battery bank is fully charged. The locally manufactured small wind turbines constructed for these applications by the global OSH community range in rotor diameters from 1.2 to 7 m (Figure 3) and are able to produce power from 200 W to 4 kW, respectively, at 10-m/s wind speeds, although rated power production is only an estimation due to its dependence on factors such as the cable connection to the battery bank and the adjustment of the furling tail system.

The small wind turbine is a variable-speed machine that consists of a three-blade wooden horizontal axis rotor of constant pitch angle and a coreless axial flux permanent magnet generator with a double-rotor, single-stator configuration and neodymium or ferrite magnets; it uses a passive mechanical furling tail system for rotor speed regulation and yawing to the appropriate wind direction. A metal frame supports an automobile wheel hub on which the blades and the generator’s rotor are mounted while also supporting the generator’s stator and the furling tail. In addition, the metal frame provides a simple yawing mechanism without using a bearing or brushes for connecting to the power cables running down the tower, which directly feed energy to the battery bank. The wind turbine is usually installed on top of a tower, typically made out of steel water pipes, at a height of 12 m or more, although this will depend on the location and the surrounding obstacles. The tower is a guyed mast consisting of steel wire ropes and four anchors in cement or bedrock and is usually erected using a gin pole and a wire rope hoist.

The construction of the wind turbine is achieved with simple tools that one would encounter in a rural workshop for wood and metal working and with the use of simple techniques that do not require a skilled laborer to perform. Most of the materials used can be sourced locally, while some specific materials like neodymium magnets can be ordered online, which only requires an Internet connection and a postal service within reach. The rotor blades are usually constructed with soft wood from conifer trees, such as pine in the northern hemisphere or any other types of trees with similar properties, including low density and light weight, that exhibit strength in tension.

The blades are hand carved using hand tools (Figure 4) and sometimes power tools for faster production. Specifically, the hand tools consist of a chisel, a draw knife, files, a plane, a spoke shave, a hand saw, calipers, and a square. An electric plane and a chainsaw can be used to save time, especially for the longer blades used in larger turbines. The techniques used are described in detail in the available construction manuals but mostly require simple hand-carving skills and successive measuring throughout the construction process.

The axial flux permanent magnet generator has a unique topology that facilitates local manufacturing with simple tools. Contrary to its radial flux counterpart, which consists of a cylindrical rotor and stator, the axial flux generator consists of disks. This requires the manufacturing of a two-dimensional (2-D) stator and rotor, with a thickness of a few centimeters, instead of a three-dimensional (3-D) cylindrical object. The stator coils and the rotor metal disks and magnets can be positioned in a plywood mold, consisting of a base, a lid, and a middle part, which provides the shape and the appropriate
thickness and, after being cast in vinylester resin, can produce the solid disk parts of the generator (Figure 5).

In addition, the air gap of the generator, which is the distance between the two magnet rotor disks, can be adjusted easily, which is important for the performance and long-term operation of the small wind turbine. The stator coils are wound by hand using enameled copper wire and a simply constructed coil winder (Figure 6).

The steel rotor disks, on which the permanent magnets are placed and form part of the magnetic circuit of the generator, are usually precut with laser, water jet, or oxygen torch computer numerical control routers or can also be cut with hand power tools (Figure 7).

The generator’s rotor disks are mounted on a car or trailer wheel hub, which can be new or recycled from an old vehicle, that provides a robust bearing for the axis of revolution of the turbine (Figure 8). The metal frame, which supports the car hub axle, the yaw tube, and the furling tail hinge, is constructed out of typical steel profiles and with the use of basic welding techniques and tools such as an electric arc welder. Other tools used for the construction of the generator are a jigsaw, a drill press, an angle grinder, and a hand drill, which can all be found in village workshops and are also used for a variety of rural maintenance activities.

The small wind turbine’s tail consists of a steel tube, which provides the appropriate length of the tail, and a vane made of plywood, with the appropriate area to effectively yaw the rotor blades toward the prevailing wind direction. The total weight of the tail is important as it specifies the furling operation of the turbine and, thus, its power control mechanism in higher winds.

An estimation of the total cost for construction, installation, and connection of a typical battery-charging small wind turbine of this type, with respect to rotor diameter, can be seen in Table 1. The cost of a 12-m guyed tower could amount to more than 50% of the total cost of the construction of the small wind turbine, depending on the anchoring type and the materials used. The power cables, rectifier, diversion load controller, and resistive load could amount to 30% of the total cost of the system, depending again on the location of the installation, the system dc voltage used, and the quality of the components. The cost estimations of Table 1 refer only to the materials; the labor required for the construction and the installation of the small wind turbine are considered to be provided by the users. Typically, a 2.4-m-rotor-diameter small wind turbine will require 450 working hours to be completed, with 50% of the total time allocated to carving the rotor blades. This is one of the main reasons that manufacturing open-source small wind turbines is usually a group process. Smaller turbines will require less time than larger ones, but this will not be directly proportional to the rotor diameter, as constructing a wind turbine with double the rotor diameter of the one mentioned will not require twice the amount of working hours but less. Finally, considerable amounts of labor are also required for manufacturing the tower and installing the turbine, activities that may even require as many working hours as for constructing the turbine itself, especially for larger rotor diameters.
OSH Technology Assessment at the NTUA

The Rural Electrification Research Group (RurERG), which is part of the Smart Grids Research Unit (Smart RUE) of the NTUA, has been assessing the technology of locally manufactured small wind turbines since 2009, as a part of a wider validation process of OSH renewable energy technologies used for sustainable rural electrification. The necessary experimental infrastructure for testing this small wind turbine technology according to international standards has been designed and implemented in the laboratories of the NTUA and includes an axial flux generator bench testing facility using a dc motor drive, an airfoil and rotor blade testing facility using a wind tunnel, and an outdoor test site located in the nearby windy coastal area of Rafina.

The Hugh Piggott (HP) small wind turbine has been used as the reference design of the OSH small wind turbine community since the majority of existing locally manufactured small wind turbines have been based on this design. To date, three small wind turbines have been manufactured in practical student workshops, two for battery charging and two for grid connection, with rotor diameters of 1.8, 2.4, and 4.3 m. The practical workshops are organized as parts of undergraduate dissertation projects, two for battery charging and two for grid connection, with rotor diameters of 1.8, 2.4, and 4.3 m. The practical workshops are organized as parts of undergraduate dissertation projects and are open to all students of the NTUA. During these workshops, the small wind turbines are constructed from scratch by the participating students, a process that provides practical evidence of the ability of unqualified constructors to locally manufacture this small wind turbine technology. The educational aspect of these workshops is of significant value and provides a chance to experiment with various learning processes.

The 2.4-m HP small wind turbine with neodymium magnets has been assessed for performance and robustness in the laboratories of the NTUA, as it is the size of wind turbine that is most frequently manufactured and installed. This type of wind turbine was constructed in a student workshop during the spring of 2009, following the 2005 design manual of Piggott for charging a 48-Vdc battery system.

Laboratory Experiments

Several bench tests have been conducted on the axial flux generator of the small wind turbine in question using the dc motor drive bench testing facility (Figure 9). Some of the most important of these tests are mentioned, which describe aspects of the performance of the generator as well as the impact of the manufacturing techniques used during its construction on its operation.

<table>
<thead>
<tr>
<th>Rotor diameter (m)</th>
<th>1.2</th>
<th>1.8</th>
<th>2.4</th>
<th>3</th>
<th>3.6</th>
<th>4.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small wind turbine cost (€)</td>
<td>300</td>
<td>400</td>
<td>650</td>
<td>750</td>
<td>1,000</td>
<td>1,200</td>
</tr>
<tr>
<td>12-m tower (€)</td>
<td>150</td>
<td>200</td>
<td>300</td>
<td>350</td>
<td>500</td>
<td>600</td>
</tr>
<tr>
<td>Power cable and electronics (€)</td>
<td>300</td>
<td>300</td>
<td>550</td>
<td>550</td>
<td>650</td>
<td>650</td>
</tr>
</tbody>
</table>

Table 1. The estimation of the total cost of connecting a locally manufactured small wind turbine to the 48-Vdc bus of an existing off-grid RES system. (Source: rurerg.net.)

![Figure 8. The assembly of the generator consisting of two magnet rotor disks and a stator. (Source: scoraigwind.co.uk.)](image1)

![Figure 9. The bench tests on a locally manufactured axial flux generator at the NTUA. (Source: rurerg.net.)](image2)

![Figure 10. The voltage measurements under no load at a 2.4-m HP axial flux generator. (Source: rurerg.net.)](image3)
The rotational speed of the rotor at which current starts to flow in the batteries (i.e., the cut-in speed) has been measured by measuring the generator's induced EMF voltages under no load and at different rotational speeds. This has been measured to be at 210 revolutions per minute (r/min), which is very close to the theoretical value of 215 r/min for the 2.4-m blade rotor used with this generator, and the small deviation can be attributed to differences in the actual state of charge of the battery bank. Observing the voltage measurements under no load in Figure 10, the three phases of the generator can be noted for their almost sinusoidal induced voltage waveforms, and the phase difference is measured at 119°, which is close to the theoretical value of 120° and implies a very good layout of the coils in the stator.

The efficiency of the generator has been measured while connected to a 48-V battery (Figure 11) at varying rotational speed and line currents by measuring the input mechanical power using a torque meter and the output electrical power using an oscilloscope and probes. Typically, the maximum efficiency of a coreless axial flux permanent magnet generator is high, 0.88 in this case, and occurs for lower currents and r/min, which correspond to low wind speeds, which are more frequent in rural applications.

At the same time, the temperature rise in the stator has been measured (Figure 12) with the generator producing rated power for 15 min. This provides an indication of the cooling ability of the generator, which during operation in the field will be enhanced because of stronger and cooler air flow. The stator temperature was found to stabilize at 85°C, which is below the temperature of 100°C at which the vinylester resin will start to melt.

Observing the current measurements under load in Figure 13, the three line currents of the generator phases can be noted for their distorted waveforms. This is due to harmonic distortion introduced in the system from the rectification process, where a three-phase uncontrolled bridge rectifier is used for lower cost and local availability, which increases the noise levels of the generator, especially for higher currents, and produces its characteristic "humming" noise.

The operation of the generator under load has been measured by measuring the phase voltages and line currents at different rotational speeds above cut-in r/min. When the actual power cable, in terms of length and conductor size, that would be used in a typical installation to connect the generator to the battery bank has been included in the setup, the power curve of the complete electrical system can be measured, as in Figure 14. This can then provide information on the efficiency of the complete system, from the kinetic energy of the wind to the electrical energy flowing into the batteries, when combined with measurements made in the wind tunnel for the aerodynamic efficiency of the rotor blades.

Several wind tunnel tests have been conducted on the rotor blades of locally manufactured small wind turbines to determine the rotor’s efficiency. Because of the size of the wind tunnel, experiments have been conducted with a set of 1.2-m-diameter rotor blades. Experimental results have shown a maximum aerodynamic power coefficient of 0.38–0.40 for a tip speed ratio of 5.5–6 for wind speeds ranging from 8 to 11 m/s, as seen in Figure 15. At lower wind speeds of 4–6 m/s, which are more frequent in rural applications, the aerodynamic power coefficient had a lower value at 0.35, which is still close to the typical value of 0.4 for
horizontal-axis small wind turbines. The design tip speed ratio of the 1.2-m rotor diameter blades has a value of 5 according to the design manual, while its optimal value was found to be close to 5.75 during the experiments.

Outdoor Experiments

The performance of a typical battery-charging wind energy system using a locally manufactured small wind turbine has been monitored in the coastal small wind test site of NTUA in Rafina (Figure 16). The measurements have been conducted according to the standard of the International Electrotechnical Commission 61400-12-1: Power Performance Measurements of Electricity Producing Wind Turbines, and specifically Annex H, which refers to small wind turbine testing.

The 2.4-m HP small wind turbine has been installed in a 12-m guyed tower and connected to a 48-Vdc battery bank with a 75-m-long power cable of a 4-mm² cross-sectional area. A meteorological mast is positioned a few meters away, equipped with an anemometer at hub height and a wind direction vane, along with several other sensors for determining the density of air that measure the temperature, humidity, and pressure. All meteorological and electrical data, such as currents and voltages, are measured and logged to provide 1-min averages, which can then be grouped according to different wind speeds using the method of bins.

The power curve of the 2.4-m HP locally manufactured small wind turbine for the aforementioned setup can be seen in Figure 17. The cut-in wind speed is 3 m/s, a typical value for most horizontal-axis small wind turbines, while the maximum or rated power is reached at 10.5 m/s with a value of 525 W and an uncertainty of ± 11.2 W. The furling system commences operation at 6.5 m/s by introducing a small angle between the plane of rotation of the rotor and the horizontal wind direction, which increases to 20° at wind speeds of 9-10 m/s and, thus, provides adequate rotor speed and electrical power regulation for the wind turbine. A capable furling system mechanism is essential for every small wind turbine and will protect the axial flux generator from overheating at very high wind speeds. At wind speeds higher than 10 m/s, the furling angle increases more and achieves a significant reduction in power production.

The efficiency of the whole wind energy system, from wind power to electrical power fed into the batteries, is described by the power coefficient (Cp) (Figure 18). The system efficiency peaks at 0.31 at 5 m/s, while it has values of above 0.3 for wind speeds ranging from 5 to 6.5 m/s, which is the most frequently occurring wind speed range in rural applications. At higher wind speeds, for example, while the wind turbine is operating at a rated power of 10 m/s, the system’s efficiency drops to 0.18 due to power regulation by the furling system. However, during windy conditions, the battery bank manages to achieve a full charge much more quickly, resulting in the rejection of most of the energy produced to the heat-producing resistances of the dump load, which makes a high system efficiency in high winds less significant.

The annual energy production (AEP) predictions for the wind turbine in question and for sites with mean wind speeds ranging from 4 to 10 m/s, using a Rayleigh wind speed distribution, are shown in Table 2. The uncertainties in the AEP estimations are presented in both kilowatt hours and as a percentage. For mean wind speeds greater than 8 m/s, the increase in power production is small due to overheating at very high wind speeds. At wind speeds higher than 10 m/s, the furling angle increases more and achieves a significant reduction in power production.
to the effect of the furling system, which would classify this small wind turbine as a design for low-wind-speed areas. For a typical rural installation with a 5-m/s mean wind speed, the 2.4-m HP wind turbine would be expected to produce 1,271 kWh/year with an uncertainty of ± 111 kWh, which would amount to an average of 106 kWh/month, although this prediction will depend on the constancy of the mean wind speed during the different seasons of the year.

**Operation and Maintenance**

During the field tests, many secondary aspects of the small wind turbine operation have been studied, such as the response time of the furling system and the starting wind speed of the rotor, while the maintenance procedure required in a highly corrosive coastal environment has been recorded. In addition, and because of the high mean wind speed of the test site, the small wind turbine has been operated under extreme weather conditions to observe the robustness of the design.

The response time of the furling system during strong wind gusts and the maximum power produced in this case has been examined. The maximum response time was measured to be 3 s and the maximum instantaneous power produced 1,093 W, which is an increase of 100% of the turbine’s rated power, a situation that can be taken into account when sizing the diversion load controller’s resistive loads. In addition, the starting wind speed of the rotor, defined as the wind gust needed to move the rotor from standstill, which is different from the cut-in wind speed, was measured to be 4.45 m/s (Figure 19).

The highly corrosive environment of the coast, which is one of the harshest environments a small wind turbine will have to face, has proven to increase the degradation of materials but not significantly. A yearly maintenance check of a few hours has been conducted for the past four years, during which the wind turbine is lowered from the tower. The wooden rotor blades are painted, the yaw and furling mechanisms are greased, and the metal frame is painted, if required, while it is possible to add grease to the rotor hub bearing. The back iron disks of the rotor of the axial flux generator have been hot-dip galvanized to increase resistance in corrosion and, thus, improve protection of the neodymium magnets, which are highly corrosive. The rotor blades have been constructed with European pine, which is softer than other varieties such as Oregon pine, resulting in the degradation of the leading edges of the blades due to sand particles in the wind. This requires the use of resin and fiberglass putty to act as a filler in the degraded parts before the blades are painted. Overall, the maintenance requirements of the small wind turbine have been low in terms of cost, time, tools, and skills required, especially when compared to the cost, time, tools, and skills required to construct the turbine itself.

The 2.4-m HP small wind turbine has proved its robustness in extreme weather conditions when operated continuously for two days in average wind speeds of 90 km/h, while the power curve of Figure 20 was recorded for up to 25 m/s. The highest wind gust recorded by the meteorological mast during this period was 31 m/s. For safety reasons, during storm conditions such as the ones described, it is recommended to stop the operation of the small wind turbine using its electrical brake.

**TABLE 2. The estimation of the AEP of the 2.4-m HP wind turbine according to the mean wind speed.** (Source: rurerg.net.)

<table>
<thead>
<tr>
<th>Mean wind speed (m/s)</th>
<th>AEP (kWh)</th>
<th>Uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>751.61</td>
<td>9.9</td>
</tr>
<tr>
<td>5</td>
<td>1,270.85</td>
<td>7.94</td>
</tr>
<tr>
<td>6</td>
<td>1,747.85</td>
<td>6.76</td>
</tr>
<tr>
<td>7</td>
<td>2,124.21</td>
<td>6.05</td>
</tr>
<tr>
<td>8</td>
<td>2,392.87</td>
<td>5.62</td>
</tr>
<tr>
<td>9</td>
<td>2,569.72</td>
<td>5.34</td>
</tr>
<tr>
<td>10</td>
<td>2,673.97</td>
<td>5.13</td>
</tr>
</tbody>
</table>
OSH Research and Development at the NTUA

In addition to assessing this OSH technology, further research and development has been carried out on the topic of locally manufactured small wind turbines. The axial flux generator has been modeled and simulated using finite element open-source software, such as Finite Element Method Magnetics (FEMM), with the accuracy of the simulations reaching 2–5% when compared with experimental results. Higher accuracy is difficult to achieve since the generators are manufactured with low-precision equipment and techniques resulting in nonuniformity of the construction. These simulation models, along with different optimization techniques, have been used to perform low-cost optimizations for axial flux generator design in battery-charging and grid-connected applications of locally manufactured small wind turbines. The connection of the small wind turbine to the battery bank with a power cable has also been modeled, and the AEP of the small wind turbine has been maximized by choosing the appropriate conductor size for the specific application. The models described are currently being developed as online software tools to assist the OSH community in further developing this technology and also to provide information for constructors and installers to better configure their specific wind energy systems.

One of the main advantages of OSH designs, and of the open design culture in general, is the adaptability of the designs produced. OSH small wind turbine technology can be adapted to better suit different environments such as coastal areas with high corrosion. An alternative design approach to the axial flux generator has been developed in the OSH community with the use of a different magnetic material than neodymium, specifically ferrite, which overcomes the typical problems of neodymium such as corrosion and price fluctuations. A ferrite magnet axial flux generator for the 2.4-m-diameter rotor has been developed at the NTUA (Figure 21) to demonstrate the adaptability of OSH designs. Ferrite generators are typically higher in...
weight and volume than their neodymium counterparts because of their weaker magnetic field, but they have a lower and stable cost and are not prone to corrosion.

Another aspect of the adaptability of the OSH design is the ability to use parts of the design in other OSH applications. This is the case of the OSH pico-hydroelectric system developed in NTUA, which is a hybrid design between the locally manufactured axial flux permanent magnet generator described by Piggott in the design manual Small Wind Turbine Recipe Book and the locally manufactured small hydrocasing and turgo runner designs of Joseph Hartvigsen. The specific design is a grid-connected 350-W hydroelectric system that has been driven with a pump in the OSH pico-hydroelectric system (Figure 22) with satisfactory results. A battery-charging prototype of the same design has been in operation for one year in a rural installation in Greece.

Figure 22. The OSH pico hydroelectric system developed at the National Technical University of Athens, Greece. (Source: rurerg.net.)

Conclusion
Locally manufactured small wind turbines, and OSH technologies in general, provide a very promising technological approach that can support sustainable rural electrification schemes in remote parts of the world. Open-source technologies are developed by communities of designers and users, with the distinction between the two often being nonexistent. Through such design approaches, highly flexible, reliable, and scalable technologies are developed that provide low-cost products that are easy to maintain and repair and are well adapted to the social and environmental systems in which they operate.

Looking into the future of locally manufactured small wind turbines, the creation of local training and manufacturing centers close to the areas where the technology will be implemented is the next step, with some organizations already working toward the materialization of this vision. Such centers of information sharing will enable local and international practitioners to meet in person and better adapt already existing designs to the electrification needs of remote communities in the area. At the same time, the development of appropriate business models and practices that strengthen local economic networks through rural electrification will further encourage local participation and ensure the economic viability of such projects.

For Further Reading


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