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SMALL WIND SYSTEMS FOR BATTERY CHARGING

A guide for development workers

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Background:

This booklet outlines the potential for using small wind generators to charge batteries – typically motorcycle, car or lorry batteries– for use in households where mains electricity has not yet reached. In many countries of the world this is the case for the majority of the population, and in some rural areas almost all the population.

The background to this booklet is a UK Government-funded project entitled '**Small Wind Systems for Battery Charging**' that was undertaken in Peru, Sri Lanka and the UK. The project demonstrated the potential market for small wind energy systems and the economic and technical viability of locally manufactured, low-cost small wind battery charging units, suitable for use in remote areas of developing countries. This booklet is one published output of the project. There are also technical manuals for generator manufacturers, blade manufacturers and installers. Most of the practical information explained in this booklet is taken from pilot installations in Peru and Sri Lanka.

This research on small wind energy systems for battery charging is the result of a collaborative effort involving numerous contributors.

The project was managed by ITDG (also known as the Intermediate Technology Development Group) under a contract to the UK Department for International Development.

The overall international project was co-ordinated by *Dr Smail Khennas*, Senior Energy Specialist from ITDG with support from Simon Dunnett. The field work in Peru and Sri Lanka was respectively managed by Teodoro Sanchez and Rohan Senerath, with support from Sunith Fernando.

Simon Dunnett, Dr Smail Khennas and Hugh Piggott (a UK technical consultant for the project), are the authors of this guide for development workers considering the use of small wind energy systems in rural households

The views expressed in this report are those of the authors and do not necessarily represent the views of the sponsoring organisations, the reviewers or the other contributors.

Cover photo: Wind Turbine, Sri Lanka Simon Dunnett.

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PREFACE

How to use this booklet

This booklet will deal with some of the non-technical aspects of promoting wind energy for rural electrification, as well as giving a guide to needs assessment, resource assessment and technology choice. Examples from Peru and Sri Lanka are used to illustrate some issues. For a more detailed look at the wind generator itself, see the technical manuals produced along with this booklet concerning generator and rotor manufacture (details are given in Appendix I).

Part 1 gives an overview of the technology of domestic scale wind generation. It looks at the technology itself as well as site and resource assessment, needs assessment and economics. Part 2 looks at the bigger picture; how small scale wind energy can be part of a sustainable supply of energy to rural areas.

INTRODUCTION

The electricity grid can provide households and communities with reliable, high quality, predictable and cheap electricity, but this is far from the norm for the majority of the world's population. Whilst being in the forefront of many governments' stated development objectives, widespread electrification is still the dream rather than the reality for most.

Electricity can bring many benefits; for those in the developed world it is taken for granted. In areas without the grid, some households use motorcycle, car or lorry batteries to power radios or TV. This small amount of energy can disproportionately improve the standard of living for the poorest. When there is enough to also provide lighting, it can improve children's opportunities in later life by enabling them to study after dark.

Such batteries are often charged in the nearest town, which can be costly in terms of money, time and convenience. At a suitably windy site (discussed in section 2) small wind generators provide a better option for charging the batteries. Automotive batteries are not ideal for this charge/discharge use, but they are a popular choice because of first cost considerations.

Why wind energy is an attractive option

There is a large market of existing battery users

In Sri Lanka, for example, it is estimated that 300,000 households use car or motorcycle batteries for radios/TV. There is a substantial market for a convenient and clean battery-charging system.



Photo 2: a 12 volt car battery used for radio and TV in Sri Lanka (Simon Dunnett,)

Batteries can be charged close to the household, saving time and money

For example, a study of villages in Sri Lanka (see appendix I) found that over half of the households use automobile batteries to power radio and TV sets. The battery sizes were 60 and 90 Ampere-hour (Ah). Recharging involved a minimum cost of Rs.30 (US\$0.50) and a trip of 6km twice per month, just for radio and maybe some black and white TV use. This cost may now (from more recent studies) be estimated at US\$1.00

The amount of energy available from the batteries can be increased, and new batteries will not have to be purchased so frequently

At a good site, and with careful energy and battery management, the average amount of energy available to be used by the household will be greater when the battery is being gradually charged, than if it is charged periodically and used until it is flat. If battery power is used for lighting, this can reduce the expenditure on kerosene and dry batteries, which is estimated at a further Rs.280(US\$5) per month in the above study. Furthermore, batteries actually suffer damage from deep discharge, and this renders them useless more quickly than if they are kept charged by a wind generator.



Photo 3: A child with an electric lamp. Kerosene is not only expensive but its fumes pollute the household air. (Simon Dunnett.)

Wind energy is more environmentally benign than many alternatives

Although energy is used in the wind generator's manufacture, once in operation it does not consume fossil fuels and does not emit greenhouse gases. Because the electricity produced and used for lighting displaces the use of kerosene, the household environment improves. Wind generators produce some noise, but for

machines designed to revolve at low rotational speeds this is much less than higher speed generators, and certainly far quieter than a diesel generator set. The visual and noise impact of the type of system described in this booklet has not caused concern at any of the test installations.

Wind energy is cheaper than the alternatives

Where the wind resource is good, energy produced in this way can be cheaper than using solar photovoltaics or diesel generator sets, particularly if the fuel supply is far from the user. If the site is located near a river or stream, hydropower should be investigated first, since this can be more competitive. Mains electricity, if it is available, is likely to be cheapest of all, on a per-unit basis. In remote areas however, the cost of connection may considerably exceed the cost of meeting local needs though wind-(or solar)-battery systems.

How can wind energy be made more attractive?

Battery power can be an intermediate step before grid connection

Grid connection is the preferred choice of most households, even if it appears unlikely to occur within the next ten years or so. If the grid is planned to arrive in the short term (within 2-3 years), it may be more prudent for the household to wait, providing initial connection charges and tariffs can be afforded. In the medium term, there may be a reluctance to invest in wind generators, especially if it is perceived that they cannot provide grid-quality electricity (230V, 50Hz). This need not be the case, however, since the output from the battery, charged by a wind generator, can be modified to run AC (alternating current – similar to mains electricity) appliances. If the grid does arrive in the future, these same appliances can be run from the mains, or the use of the wind generator continued. Second-hand wind generators can find a ready market in areas where the grid has not arrived; this can reduce the risk of purchase.

Households can share one generator

At a good site, and with a suitably-sized machine, two or three households can be connected to a battery bank to form a mini grid. If the system operates at a higher voltage (where suitable appliances are available) line losses can be reduced. A high level of co-operative spirit is required for this kind of project. One advantage is that the cost of the machine and infrastructure can be shared, making the initial investment more attractive. Larger wind generators are also more cost-effective than small ones. (Photovoltaic installations do not have this benefit of scale.) Maintenance can be easier – with a greater pool of people to draw from both tasks, and the cost of outside help, can be shared if necessary. It may be possible to add extra power sources to the system if it is large enough. Extra diversity from solar or engine-driven sources will improve the reliability of the supply during calm periods.

Locally manufactured machines can be maintained more easily and provide local employment

Small wind generator technology is well established internationally, so what are the advantages of manufacturing systems locally? There are four good reasons to take this approach rather than to rely on imported technology.

Firstly, locally produced machines are likely to be cheaper to buy, especially where foreign exchange is scarce and the local market is not large enough to negotiate discounts.

Secondly they will be easier to maintain, because local technicians will understand them. Many small wind generators have failed prematurely due to poor understanding of the technology.

Thirdly the machines will be more suited to local conditions – a machine designed to charge yacht batteries might not be suitable for inland wind regimes and car batteries.

Lastly, local manufacturing enterprises are used, which helps create jobs.

There are risks involved however. The main ones are the wider manufacturing tolerances and limited choice of raw materials in small engineering workshops where the wind generators are likely to be made. Although this has been allowed for in the design highlighted in this booklet, it does result in larger and weightier machines.

Why doesn't everyone use wind generators?

The importance of the wind regime

The most important factor in the success or failure of any wind energy installation, whether it is a commercial wind farm or small-scale battery charging, is the strength and nature of the wind resource. The average windspeed of a site is a good guide to whether it is suitable for a wind generator or not. Since the energy in the wind varies in proportion to the cube of the windspeed, a site with a windspeed of 4m/s (9 mph) can potentially only harvest half the energy of a 5m/s (11mph) site.

However, the average windspeed only gives an indication of the suitability of a site. A site with high and low seasonal winds can have the same average windspeed as a site with a steady windspeed all year round. If a generator was placed on the former site, energy may well be wasted during seasons of high wind, and batteries run flat during low wind seasons. A steady moderate wind regime is better than a high but variable one, as described in more detail in section 2.

Set-up costs can be high

In general, renewable energy technologies have to make use of resources that are not very energy-dense; that is, a large quantity of the resource has to be used to produce one unit of energy compared to fossil fuels or nuclear energy. This tends

to result in relatively large machines or systems to convert this diffuse energy into electricity, which can be relatively expensive. In the case of wind generators, a further burden is the need for a generator that revolves at the same slow speed as the blades (since this is preferable to a geared transmission). Generators are generally less efficient at low speeds, so a heavier machine is used to compensate.

In order to put the generator and blades in the path of the wind, the whole arrangement needs to be put on the top of a tower, which takes time to prepare and erect. Finally, it may be necessary to house the batteries and control circuitry in a weatherproof building that may be some distance from the user's house, which will need to be connected to the battery, using distribution cables. The whole installation process usually needs to be supervised by an expert or the manufacturer.

'Wind generators don't work here'

There is often a perception that wind generators are not suitable for use in a particular area, or even country. This is usually because bad experiences in the past and tales of poor performance have warned people away from the technology. There are commonly two reasons why wind generators get this tarnished reputation.

Aid agencies in the past have set up inappropriate pilot sites, with the best of intentions, which typically use technology imported from the donor country. Whilst this works well in the right setting, all too often the machines either fail to perform as expected or are wrecked in the first monsoon storm. The strengths and weaknesses of wind generators may have been misunderstood, and the unfamiliar technology may have been too difficult to troubleshoot.

The other main reason is the lack of available wind data. Windspeeds measured at ground level at a few sites are generalised countrywide, and the conclusion is that the wind just does not blow hard enough. Both these experiences can be avoided by using good design and research.

Lack of a holistic approach

There are other reasons why wind generators are not as widespread as maybe they should be. Chief amongst these is the lack of support for the industry and users. An elegant technical solution to a problem is unlikely to succeed without proper marketing, after-sales support and finance packages. A holistic approach needs to be taken, and this may involve some level of government regulatory backing or financial support.

PART 1: WIND ENERGY TECHNOLOGY FOR BATTERY CHARGING

1. Understanding Wind Generator Technology

The type of wind generator discussed in this booklet has been designed for use in households in moderately windy areas with no access to grid electricity. It is suitable for local manufacture, and has been designed to be as inexpensive as possible. The basic features (shown in *Figure 1*) are common to most small wind generators, but there are some original ideas in the ITDG design.

The wind system comprises; the generator, blades, and tail vane mechanism, tower, charge controller and batteries. Each component is described briefly below. For more detailed technical information please see the technical manuals that accompany this booklet (see Appendix II).

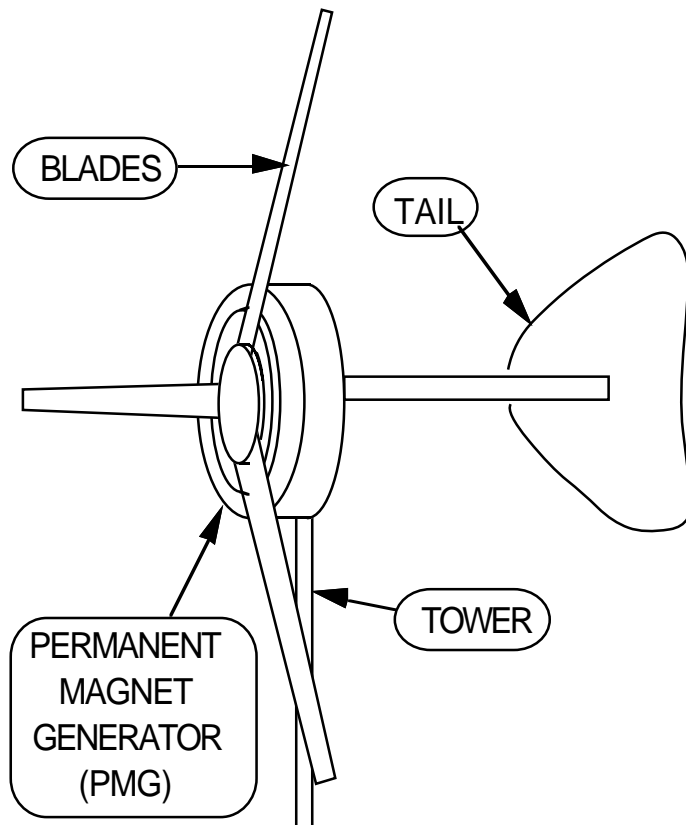


Figure 1: Parts of a typical wind generator

The Permanent Magnet Generator (PMG)

The ITDG generator is shown in exploded form in figure 2. The magnet rotor disks are mounted on a bearing hub so they can rotate on the shaft. They are directly driven by the blades of the wind generator. Almost every small wind generator on the market uses a directly driven permanent magnet generator (PMG) of some similar type. They are specially designed and built for the purpose of extracting power from the slowly turning blades with best efficiency and minimum complexity.

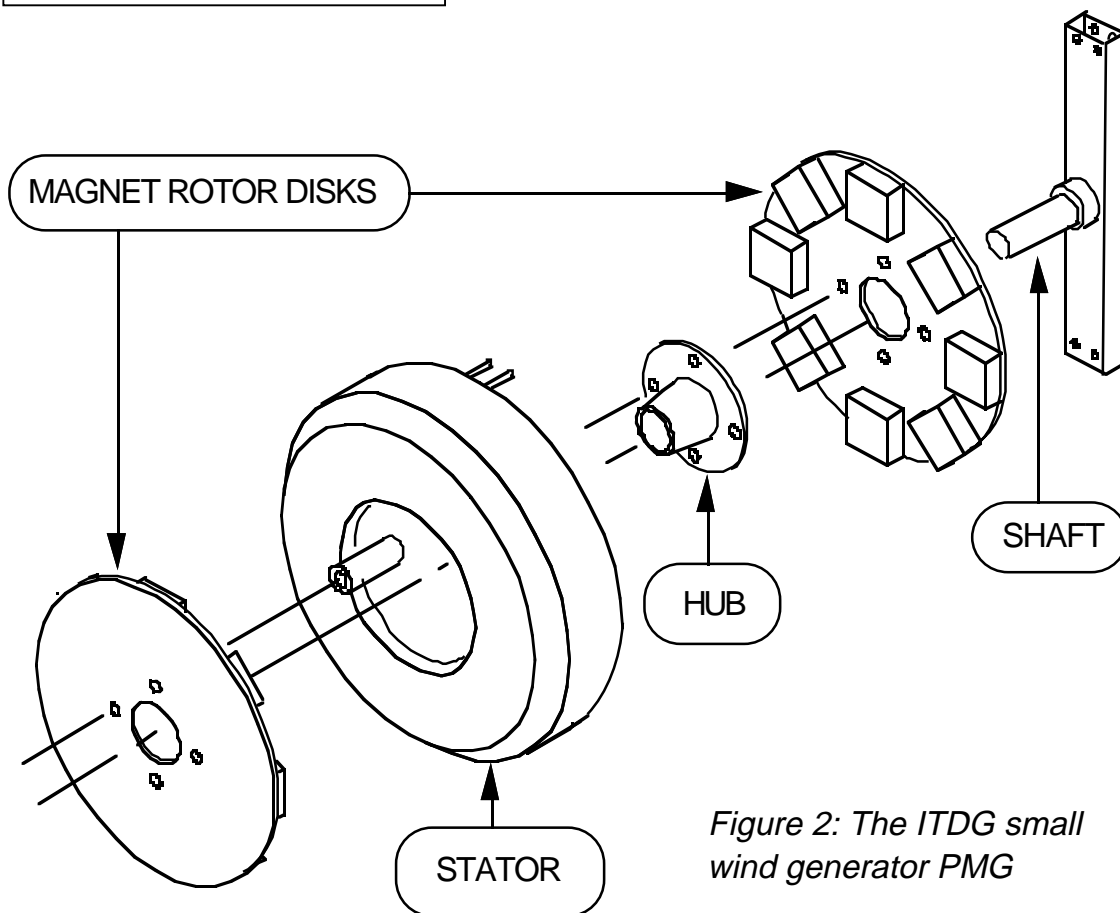
Between the rotors is a stator, cast from plastic resin, holding coils of copper wire. (Most other PMGs use a laminated steel core for the stator instead.) The ITDG PMG is constructed as far as possible using readily available materials and off-the-shelf components. It can be manufactured in a modest workshop having basic engineering equipment.



*Photo 4 : Stator
manufacture in Peru
(Hugh Piggott)*

Electricity is generated when the magnets on the magnet disks rotate past the coils embedded in the stator casting. The magnetic field induces a voltage in the coils which is ultimately fed to the batteries. At low rotational speeds the voltage is insufficient to charge the battery, but when 'cut-in' windspeed is reached, a current flows into the battery so as to charge it.

The magnetic field through the coils reverses as the magnet poles in the rotor disks pass them, so the voltage produced alternates also, which means that the generator produces alternating current, or AC. The coils are arranged 'three-phase' to make most efficient use of the space available, and



*Figure 2: The ITDG small
wind generator PMG*

deliver a smooth output. The three-phase AC is converted into direct current, or DC, so that it can charge the battery. The device which converts AC to DC is called a rectifier.

The blades

Modern wind turbine rotors usually have two or three blades. A larger number of blades would create more turning force (torque), but would not be capable of driving the PMG fast enough to generate the required voltage, because it would turn more slowly. The higher speed rotor actually catches slightly more power than the slow one would. The rotor blades and the PMG are both very carefully designed to match each other's speed and power, so as to extract the maximum energy from the wind.

The output of the wind generator over time depends more on the amount of wind swept by the blades than it does on the power rating of the PMG. Electricity generation is especially valuable during low wind periods, when the battery otherwise becomes discharged. At low speeds power output depends only on the area of wind swept by the blades. The rated power output only occurs in stronger winds, so it is not seen under these conditions.

If the PMG is not connected to a battery or other electrical load, then the blades will overspeed, like an engine at full throttle, out of gear. The machine will become noisy and may vibrate so much that parts come loose and fall to the ground. To prevent this type of problem the following things are important:

- Keep the wind generator connected to a load at all times.
- The wind generator must have an effective furling system for high winds.
- The blades should be carefully balanced so they run smoothly.

Tail vane mechanism

The tail vane is used to face the machine into the wind. It also includes a mechanism which comes into play when windspeed exceeds a certain level (usually around 10 metres per second). It 'furls' the generator and blades out of the full force of the wind, by swivelling the whole machine on a bearing (the yaw bearing) at the top of the tower. A simple mechanism using gravity on the tail vane maintains the generator and blades facing the wind when the wind is moderate, but turns it sideways-on in very strong winds. This system is essential to protect the blades from overspeed and the PMG from damage. There are



Photo 5 : Three bladed wind turbine by IT Peru. Blade diameter 1.7metres (IT Peru)

several similar mechanisms which can be employed to furl the machine in this way.

Tower

The tower raises the generator, blades and tail vane to a height where the wind is stronger and smoother than at ground level. The tower is as high as possible above all surrounding obstacles. Trees and buildings will affect the wind to a height almost double their own height, but practical considerations, such as expense, safety and maintenance limit the height to between 10m and 20m.

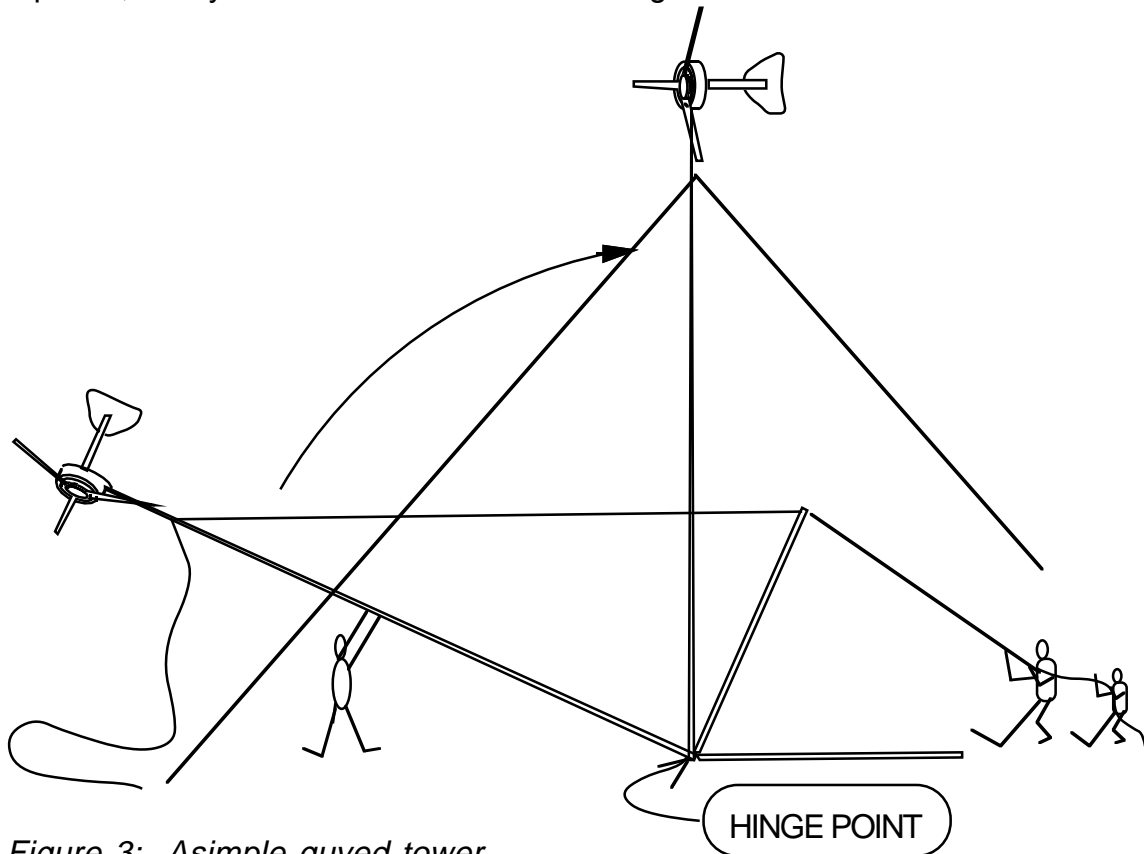


Figure 3: A simple guyed tower

The simplest towers are usually steel water pipe, held vertical by one or two sets of guy wires. The guys are anchored into the ground firmly, but the base of the tower is usually hinged to allow for the lowering of the generator for maintenance or repair; see Figure 3.



Photo 6 Raising a guyed tower with poles and ropes in Peru (Hugh Piggott)

Electrical controls

Charge controller

The charge controller is there to prevent damage to the batteries. If the batteries are near to full charge, but the wind is blowing strongly, the charging current needs to be reduced to prevent damage to the battery. The charge controller will divert some power from the generator away from the battery and into a 'dump load'. This can be anything from a series of bulbs to a heating coil – in the simplest systems this excess energy is wasted.

Charge controllers for solar PV systems are not suitable for wind generators because they unload the wind turbine by disconnecting it from the battery.

Different types of battery require different settings in the charge controller. For example, sealed batteries are charged at a lower voltage to prevent gassing, whereas vented batteries are allowed to charge more vigorously and produce gasses.

Low voltage disconnect

Batteries are easily damaged by excessive discharge. A device that cuts off the current from the battery to the user load (light and other circuits) at a pre-set low voltage can prevent this. Such a device is often called a 'low voltage disconnect'. This sort of device is recommended where users will attempt to use energy from the battery until it runs out. With education and user vigilance such devices are unnecessary.

Inverter

Inverters are used to convert the low voltage DC from the battery (usually 12V) into mains type 230/240V AC. Higher output-quality inverters are better for most purposes, but these can add substantially to the cost of the whole system. Lower cost inverters have lower output, and/or



Photo 7: Left to right: Inverter, charge control circuit, and dump load, in Sri Lanka. (Simon Dunnett,)

lower protection against abuse. Inverters generally make sense for small networks of households with a central generator, since the additional cost can be shared, and the cable runs are long enough to require the higher voltage supply.

Load control

In more sophisticated systems, and especially where there is more than one household using the batteries, an individual load, or a group of loads, can be individually controlled to match demand and supply. These different loads will be switched on and off depending on the state of the battery charge and this can be done randomly or sequentially.

Batteries

For stand-alone wind systems, where a constant supply of electricity is desirable, it is essential to have a battery to store electricity for when the wind is light. The battery also regulates the voltage of the system, which would otherwise vary wildly with windspeed and cause damage to equipment.

It is likely that car or lorry batteries will be used with the system described in this booklet, either because they are already being used or because they are cheap. However, deep cycle batteries are more cost-effective in the long run, for windpower systems.

Vehicle batteries are not ideal since they are designed to be only partially discharged before being steadily charged by the vehicle alternator. It is therefore important that they are cared for well. This means guarding against over-charge and over-discharge, and also topping up the electrolyte with pure water as required. Frequent discharge and charging of these batteries will inevitably wear them out.

The optimum battery technology is a matter for urgent debate within the



Photo 8: Wind generator control cabinet and car battery. (Simon Dunnett, Sri Lanka)

small scale renewable energy world. Where possible you should consider the option of using deep cycle batteries rather than automotive ones. They will last much longer, and ultimately give better value for money. The widespread, short-term use of automotive batteries for rural electricity supplies is likely to cause serious environmental pollution problems from lead contamination in the future.

Fuses and circuit breakers

Overcurrent protection is as important in small wind systems as in households on the grid. Fuses and breakers prevent too much current from flowing in circuits or appliances, causing damage or fire through faulty wiring. A battery can deliver very high currents under short-circuit conditions, so fuses or circuit breakers are highly recommended for fire safety.

A typical system

A typical system is shown in figure 4. The main components are the wind generator and tower, battery, charge controller and/or load controller, distribution cables, fuses, and household appliances. An inverter can be included, if necessary, to give mains voltage power. The battery and controls may be located in a powerhouse built for the purpose.

Several batteries can be connected in parallel to the same source, and will share the charging current. The most discharged battery will consume the bulk of the power. If a battery is defective, it can drain power from other batteries connected to it.

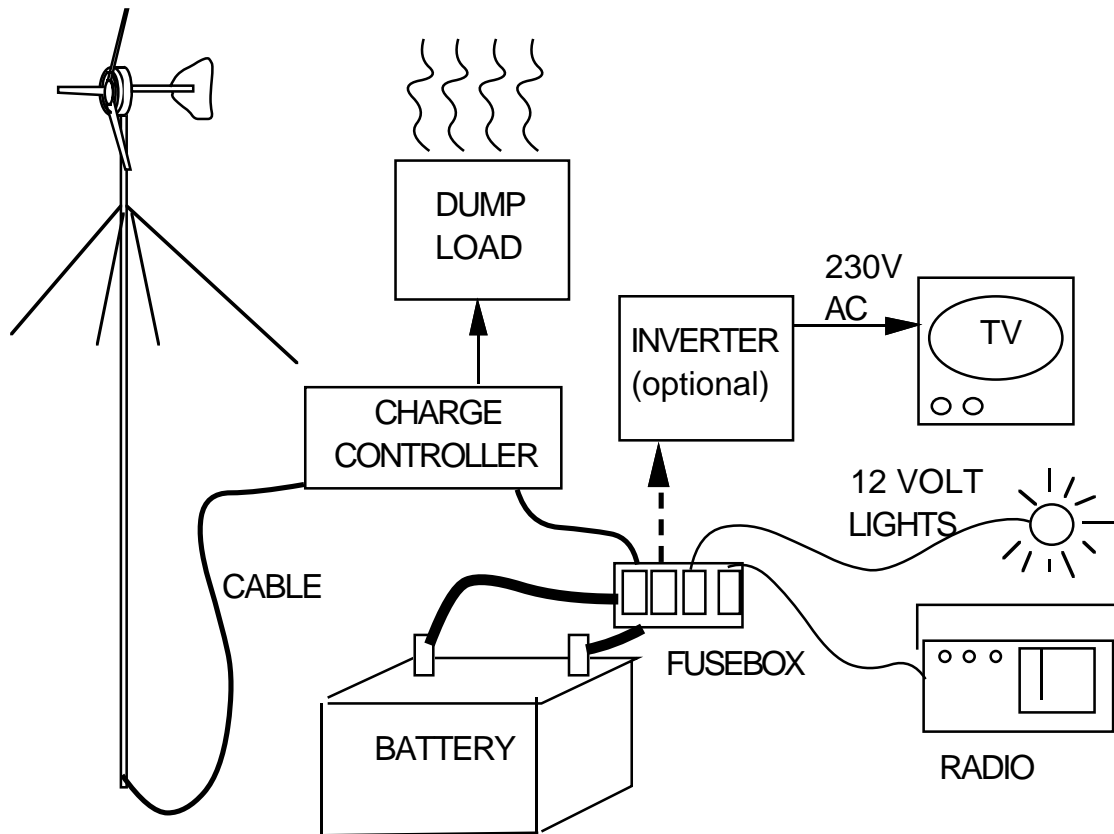


Figure 4 : A typical system

DC or AC?

DC, or direct current, is the only type of electricity that you can get straight from batteries, and is suitable for running DC appliances. It is convenient to use DC with small wind generators for charging batteries. There are two disadvantages, though.

- The range of 12V DC appliances available may not be large. It is always possible to use equipment designed for use with cars and boats, but the choice is limited.
- The other disadvantage is the higher power losses in cables associated with higher currents. (Using low voltage requires a higher current in amps, for a given power in watts, because $\text{power} = \text{volts} \times \text{amps}$. Loss increases with the square of current, which is a problem when the cable is long as there is more resistance in the system. A current of ten amps creates one hundred times the loss of a current of one amp, for example, because the square of ten is one hundred.)

The supply from the mains grid is AC electricity. There is an international standard which is 230V, 50Hz, used in many countries. Most wind generators produce non-standard AC, which is then converted into DC before it enters the battery. In order

for the household to use 230V AC, the battery supply must be reconverted into standard AC through an inverter. The inverter can be expensive and add significantly to the whole system cost, so it is important that the pros and cons are understood. This additional cost, and potential failure of the inverter, are the main disadvantages of AC, although users also need to be aware of the additional safety requirements needed with this higher voltage. The advantages are that common electrical appliances are designed for AC and the householder may prefer AC for this reason. Also, the losses due to the heating of long cables are greatly reduced, meaning more power is available for appliances. Some of this benefit is offset by power losses in the inverter incurred during conversion of DC to AC however.

Vehicle 12 volt bulbs are a little brighter than conventional 230V bulbs of the same power rating, but AC power from an inverter can be used to run 'energy efficient' compact fluorescent lamps which are many times brighter. The final decision may come down to consumer preference and available finance. Automotive light bulbs are cheap and reliable, but it would probably make sense for a group of households sharing a wind generator to invest in an inverter. The use of AC would allow households to use the same appliances if the grid were to arrive in the future.

It should be made clear that a higher voltage (230V AC) does not guarantee a more powerful electricity supply. Using an inverter may make the supply more efficient and versatile, but electricity from a small wind generator stored in an automotive battery is a very volatile resource, which ought to be used sparingly, especially during calm weather.

Matching needs, the wind and the generator

If the windspeed is low, and the energy produced by the wind generator does not meet the needs of the users, then the battery will become discharged and other sources of power will be needed. When the wind exceeds demand, then energy will be wasted in the dump load, unless efforts are made to offer battery charging services to neighbours or find other uses for the surplus power. Wind is an unreliable resource which is likely to vary over time, which leads to both of these problems.

To avoid disappointment and wasted opportunities, the system should be designed with estimates of inputs and outputs appropriately matched, and with strategies in place to deal with the variations in the resource.

In the section 2 we shall look at how to assess the potential of the wind resource and section 3 describes how to assess the amount of energy required to meet a given need.

In practice, windspeeds are not predictable, except as an approximation. User loads are also unpredictable, and will tend to grow to fit available supply. The best approach is to gain a common-sense understanding of the order of magnitude of the resource, and of the relative energy consumption levels of different types of load. If this data can be interpreted to the users, then there is a good chance of the system operating successfully.

2. THE WIND POTENTIAL

It has already been stated that the energy in the wind is proportional to the cube of the windspeed; for example, if the windspeed doubles the energy available goes up by for example a factor of eight ($2^3 = 8$). This usually means that the minimum average speed should not be less than 3m/s.

Measuring the wind

Measuring the windspeed accurately can be a difficult task when resources are limited. To do a proper job will involve erecting an anemometer (or two) at the site in question, and correlating the readings with long term meteorological data that is available for the region in question. Finding suitable data may be very difficult, especially when the entire country's windspeed data is based on a few dozen anemometers placed at head height near airstrips. Unless you are planning to install a few generators at the site you are monitoring, it may not be financially viable to invest in an anemometer at all. Fortunately, there are less precise, but more accessible, ways to tell if your site will be any use.

Anecdotal evidence.

The first method, and the least accurate, is to use anecdotal evidence. There is little possibility of being able to calculate potential energy generation figures from such unscientific data, but you may be able to get a rough picture of seasonal patterns. You may have to think twice, for example, if you are told that the wind doesn't blow at all for two months out of the year, but is more than adequate for the rest of it.

Beware of statements such as 'the wind never stops blowing here'. Even long term residents in an area can be surprisingly unobservant. Every location has some calm weather.

The local vegetation

Longer-term patterns, such as prevailing winds, are often evident from the way shrubs and trees have grown. Subjected to long-term pressure from mainly one direction, vegetation will visibly grow away from the wind. The extent of the distortion gives a strong clue as to the strength of the wind. Again, you cannot use these observations to calculate the wind's strength accurately, but they may help to build a picture.

A word of caution – make sure that you are not observing the natural tendency of vegetation to grow towards the sun rather than away from the wind! The further you travel from the equator, the lower the sun is in the sky and the more pronounced this tendency. Also, the lack of growth in one particular direction may not mean that there is no wind – simply that there is no dominant wind direction.

The Beaufort Scale

The second method uses recorded observation over a sustained period. Table 1 (based on the Beaufort Wind Scale) shows how you can tell roughly, without measuring equipment, what the speed of the wind is (in metres per second or m/s) at a particular instant.

Table 1- Beaufort Wind Scale

Beaufort number	Description	Wind Speed m/s	Observations
0	Calm	0	Tree leaves do not move; smoke rises vertically
1	Light Air	1-1.5	Tree leaves do not move; smoke drifts slowly
2	Slight Breeze	2-3	Tree leaves rustle; flags wave slightly
3	Gentle Breeze	3-5.5	Leaves and twigs in constant motion; light flags extended
4	Moderate Breeze	6-8	Small branches move; flags flap
5	Fresh Breeze	8.5-10	Small trees sway; flags flap and ripple
6	Strong Breeze	11-14	Large branches sway; flags beat and pop
7	Moderate Gale	14.5-17	Whole trees sway
8	Fresh Gale	17.5-20	Twigs break off trees
9	Strong Gale	21-24	Branches break off trees; shingles blown from roof
10	Whole Gale	24.5-28	Some trees blown down; damage to buildings
11	Storm	29-32	Widespread damage to trees and buildings
12	Hurricane	33+	Severe and extensive damage

Beaufort 1 and 2 carry no useful power. The winds which are of most interest are Beaufort numbers 3, 4 and 5. At Beaufort 6 and above, the furling system will operate.

To use the Beaufort scale correctly, it will be necessary to keep a log of the windspeed observed several times during the day, ideally over a period of at least a year.

Anemometers

A good anemometer, with datalogging equipment, will cost several hundred US dollars. This will give very full data for the windspeed on the site, enabling you to predict the performance of small wind generators with confidence. The data can also be compared with regional meteorological sources (if any) and thereby extrapolated into long term data.

Demonstration installations

A limited wind monitoring budget could be used instead to pay for a small wind system installation, which could prove or disprove the point in a much more practical way. As we shall see later, the performance of a small wind system is influenced by a multitude of factors. It is not easy to predict the available energy output of the system with confidence, even given the best possible data for the wind.

A small windpower installation serving a practical purpose can answer the question of whether the technology is effective in a given area. Care must be taken to install it according to best practice, and a degree of monitoring is essential. Much can be learned from this exercise with a minimum of financial outlay. Of course, if unsuitable equipment is chosen, then the project may fail even though the conditions are potentially favourable. This cannot therefore be seen as a complete substitute for meteorological studies.

Where to site the generator

Even in an area where you are confident of an adequate wind regime, you can still site the generator incorrectly. Perhaps more importantly, at marginally suitable sites, you can substantially improve the likelihood that the technology will succeed by placing the generator sensibly.

The higher the better

The windspeed generally increases the further from the ground you are, which is why generators are placed on towers. You can help increase the windspeed at the generator by using the local topography – site the generator on the highest bit of land nearby or on the top of an open hill if possible. Be careful not to site the machine too far from the household though, since you will have to spend more on transmission lines and some power will be lost as heat in the cables.



Photo 9: A wind generator on an open site. The tower should be as tall as possible, and well above the tree tops. (Simon Dunnett, Sri Lanka)

Out in the open

It is important (where possible) to avoid buildings and vegetation on the ground. Farmers know that a good way to shield delicate crops from the wind is to plant a windbreak. Consider the prevailing wind direction and place the generator upwind of unintentional windbreaks (i.e. before the wind is affected by them). The negative effect of the windbreak when wind is blowing from other directions must be recognised. The turbulence caused is felt a very long way downstream of obstructions, so place the generator above them if at all possible, or use a higher battery voltage (reducing the cost of the cable) to enable you to place it several hundred metres away/uphill in the open.

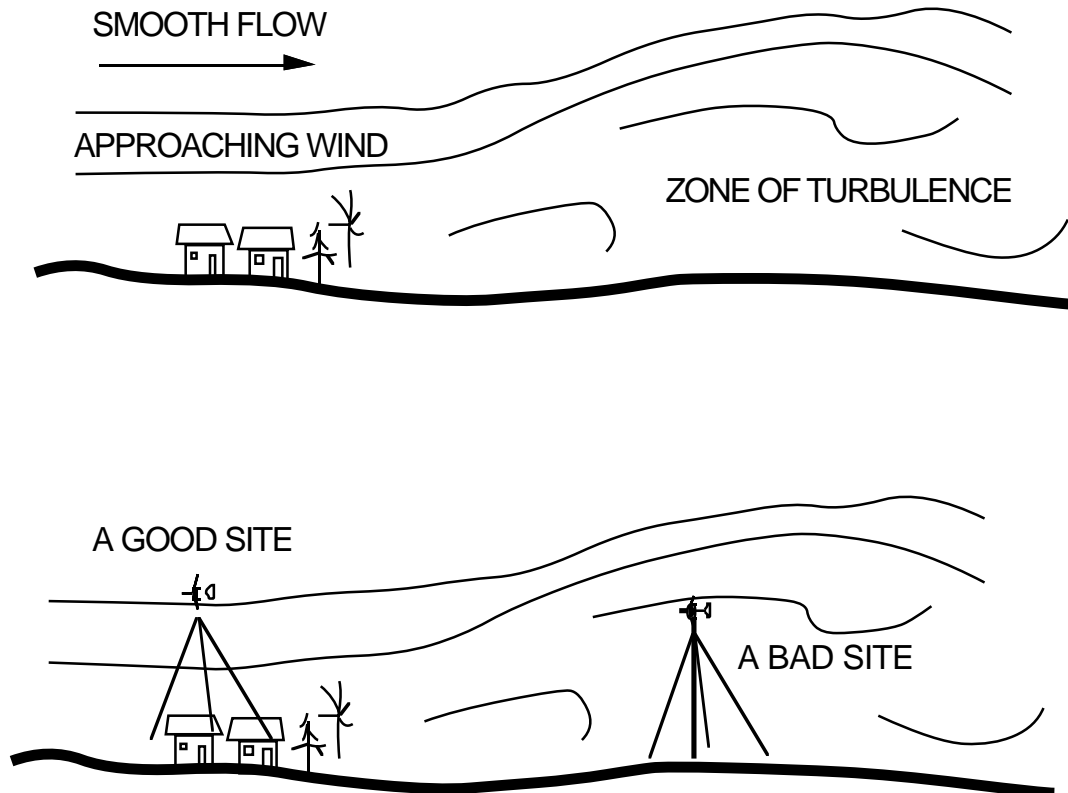


Figure 5: The zone of turbulence behind an obstacle is twice as high as the obstacle itself, and extends ten times as far downwind.

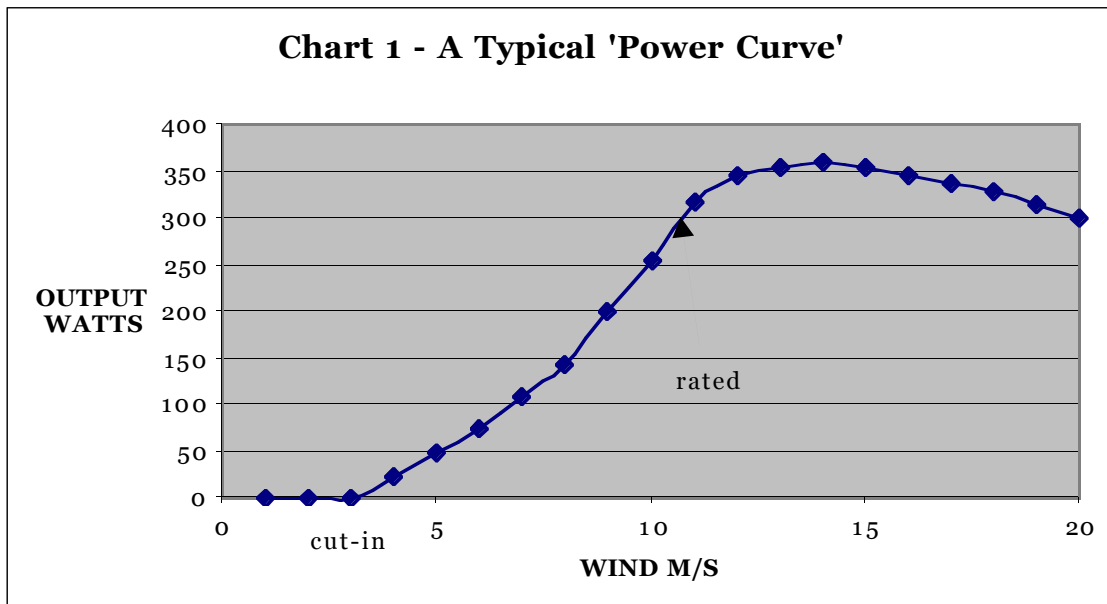
Safety considerations

Avoid siting the tower above areas where people live, work or pass by. Parts of the wind generator may fall to the ground under storm conditions, and it is not unknown for the whole tower to collapse. Make a realistic assessment of these risks when siting the tower. Where safety concerns conflict with optimum siting, safety must be paramount.

How much power will a wind generator produce?

Wind generators produce no power in at low wind speeds, below about 3m/s. Above the 'cut-in' windspeed, the power output will increase with increasing wind,

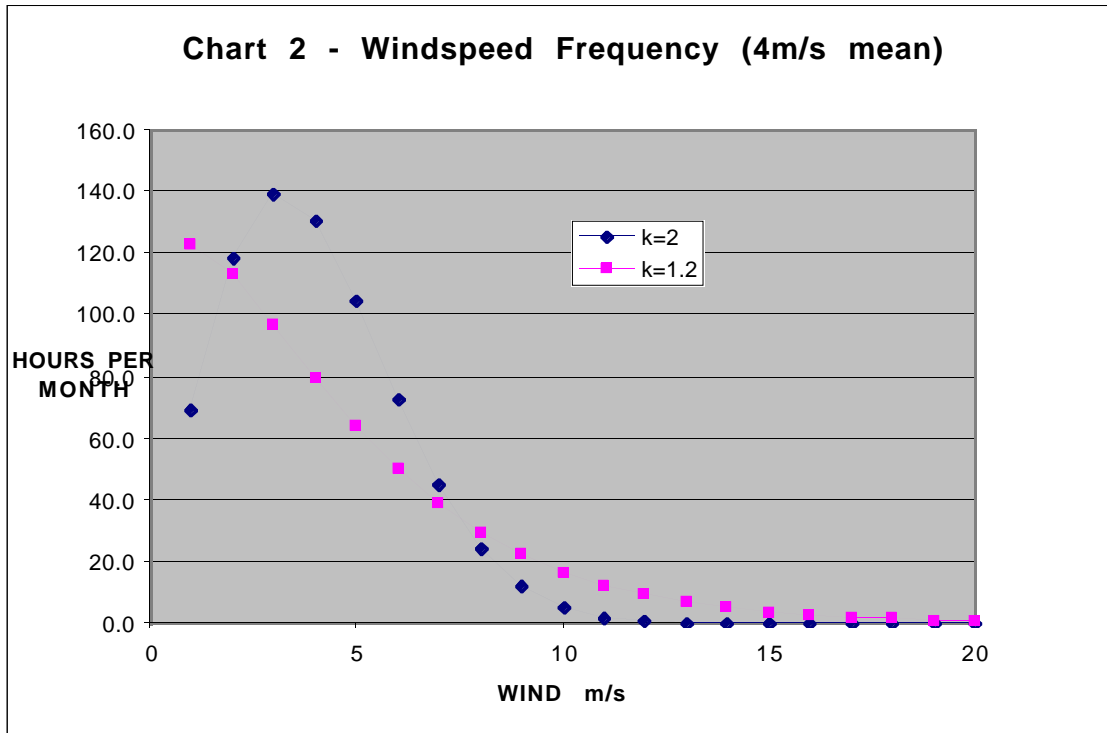
until rated power is reached. Sometimes even more power is produced at certain windspeeds, but the output tends to level off as the furling system comes into operation.



The graph of power versus windspeed is known as the 'Power Curve'. Chart 1 is an example of a typical power curve for a wind generator with 2 m rotor (blades) diameter and 300 watts rated output. It represents short term instant power levels, rather than longer term energy production (average power).

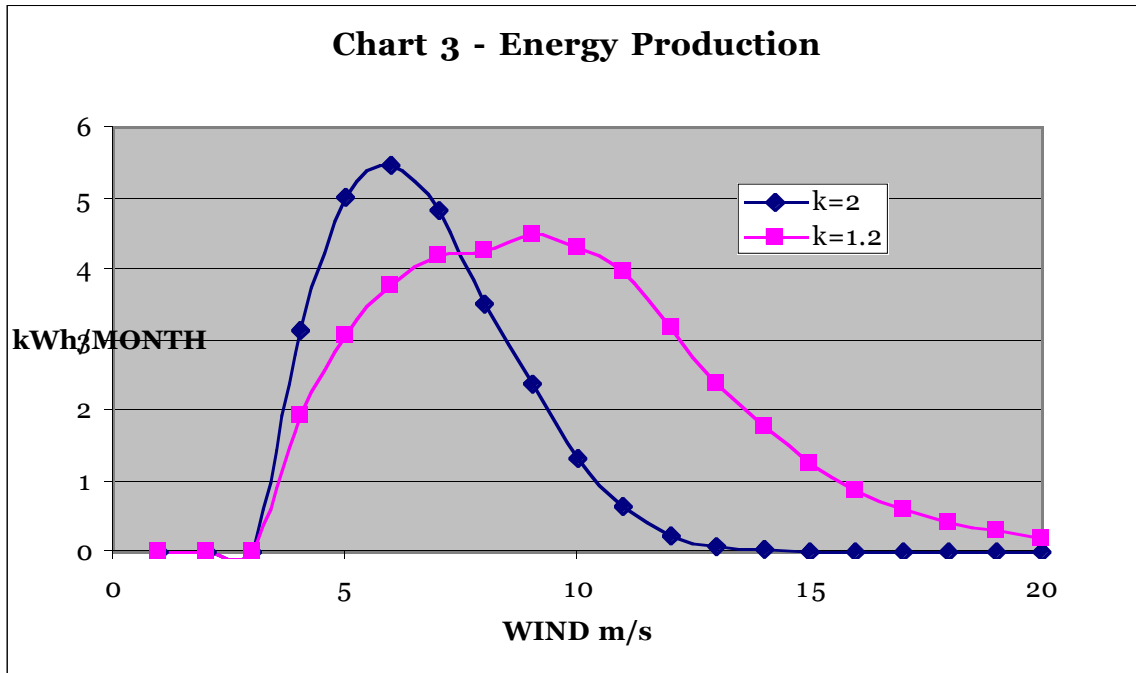
It is interesting to compare this Power Curve with the actual windspeeds encountered on low wind sites. In chart 2 showing Windspeed frequency, we take as examples two sites, both with mean windspeed 4m/s. The shape of the windspeed distributions (how much the wind varies) can be characterised by a 'shape parameter' k . The first example has the sort of windspeed variation typical in temperate climates ($k=2$) and the second has a wider ranging distribution ($k=1.2$).

In the first example ($k=2$) the wind is mostly around 2-5 m/s, so it makes sense to look at what the wind generator is doing in these conditions. The 'Rated Power' of the wind generator has little relevance to this situation. The energy captured will depend on the area of wind swept by the rotor blades.



In the second example ($k=1.2$) the wind is often very low and therefore useless. A wind generator will not be reliable as a single power source in this situation, but may work well alongside solar panels in a hybrid system. Higher winds are experienced more often than was the case in our first example, so we can expect to see the wind generator reach its rated output at times. These occasions may well coincide with cloudy weather, associated with passing storms, when the solar panels are not producing well.

The windspeed frequency chart tells us how many hours in each year a certain windspeed will occur. The Power Curve tells us how much power we can expect during those hours. By combining them we can find out how much energy is produced at each windspeed over the course of the year. The energy per month figures are simply calculated by multiplying the hours per month by the power produced at each windspeed. This is shown on the chart 3 labelled Energy production.



In the first example the total energy production over the month is 27 kWh, whereas in the second example, where the wind varies widely, a total of 41 kWh is produced. However most of the energy in the latter case comes during the relatively short periods of higher windspeed, and will be hard to exploit effectively unless the wind generator is a part of a larger system with alternative sources of power and a larger battery.

Predicting the output of a wind generator is therefore a difficult task, requiring large amounts of accurate data for both the site and the machine itself. Site data is expensive to acquire. Data for the machine is available from manufacturers, but is usually inflated. (There is no incentive for manufacturers to publish accurate data, and every incentive to select advantageous 'data'.) The curve presented in the above example is relatively modest and it yields 'real' results.

The task of calculating the available energy from a given machine on a given site is almost impossibly complex. The best approach may be to make an informed guess and then refine this in the light of practical experience. As a rule of thumb, for quick calculations, we can use this equation to estimate the energy per month:-

$$\text{kWh energy per month} = (\text{rotor diameter in m})^2 \times (\text{mean windspeed in m/s})^3 / 10$$

Table 2 gives some rough figures which can be used as the basis for such estimates.

Table 2 – Approximate Energy production in kWh per month for various sizes of wind generators on various sites.

rotor diameter	Mean windspeed for the site			
	3m/s	4m/s	5m/s	6m/s
1m	2	6	10	20
2m	10	25	50	70
3m	20	60	100	160
4m	40	100	200	280
5m	60	160	300	430

:

In the final calculations, allowance has to be made somewhere for energy losses in the system: the cables, the battery, and the inverter are all guilty of consuming energy, which therefore does not reach the end-user.

Losses are especially high at higher windspeeds, because the cables are carrying full current. Under these circumstances, the battery may well be fully charged, and the charge controller therefore would be dumping power. Power generated at low windspeeds is of much greater value to the end user, which is why it pays to choose a wind generator with large blades, rather than a high power rated generator.



Photo 10 : A 3.6metre diameter wind generator on a 3.5m/s site in rural Zimbabwe (Hugh Piggott)

3. ASSESSMENT OF NEEDS

When you have assessed how much power you may expect from a wind generator, you need to calculate how much energy you need for a given application. This will largely depend on two factors – the nature of the present and future energy needs of the household, and the number of households that are to use a single generator.

Household energy use

Things which use electrical power are called 'loads'. There is a wide variation in the amount of power used by loads. Electric heaters and cookers use too much power to be run from a battery supply, unless the wind regime is very good or a large generator is affordable. For heating loads of this type it is better to look at improved cookstoves, biogas, and improvements to household insulation in the first instance. Although the generator can be designed to 'offload' excess power through a heating element when the batteries are full, this is operated automatically for the protection of the system rather than the convenience of the user.



Photo 11: A wind powered 'compact fluorescent' is used as an outside light in Sri Lanka, to keep elephants away from the house and crops. (Simon Dunnnett)

It is possible that the household will be using automobile batteries to power lights, radio or TV already, but it is important to look at what electrical end uses would be possible in addition to the existing ones. For example, where kerosene lamps may be used in some rooms; it is likely that compact fluorescent bulbs can replace these, at least during windy periods. It may be possible to light external areas for safety or convenience also. Sewing machines, computers, and water pumps are other possible load options.

As well as determining end uses (loads), it will be necessary to estimate the total time that these appliances will be used during the day or week. This is in order to

distinguish between the power required at any particular time, and the total energy consumed.

Power and Energy

Energy is measured in watt-hours (Wh) or kilowatt-hours (kWh). It is the ability to do work.

Power is measured in watts (W) and kilowatts (kW). It is the rate at which the work is done.

So a 20W bulb running for one hour will consume as much energy as a 10W bulb running for two hours (20 Wh or 0.02kWh). If the bulbs are being supplied from a battery continuously, the 20W bulb will run the battery down twice as fast as the 10W bulb. It is therefore important to calculate exactly how much energy is required per day or week, see how many batteries will be needed (if you have a choice) and match that to the size of the generator.

Number of households

In areas where there is a good wind and there are two or more households close together, with similar energy requirements, it could make sense to share one generator and battery bank. As mentioned in the introduction, this can be advantageous financially. Calculations for the size of the system are similar to those for a single household.

It is important to ensure that each household connected to a single generator is able to manage their energy use effectively. In a simple system, where load control is not automatic, users will have to ensure that they are not excessive in their energy use. This applies to a single household with a single generator too, of course, but when more than one household is sharing a supply of electricity, the potential for disputes is present. Some ways to overcome this are:

Individual batteries for each household

Rather than charging a common battery bank, it could be possible to charge individual batteries in rotation. Without the use of electronic controls, this would need to be done manually and a suitable rotation system worked out. During windy weather it would be advisable to connect all the batteries. Windspeed varies in such a random fashion that it would be very hard to ensure equal measures of charge into each battery in the short term.

Battery charging for a fee

If a transmission line for each household is impractical (because of the cost and energy losses), or a suitable power-sharing arrangement cannot be settled on, one solution may be for each household to carry batteries to a charging point and pay a fee for each recharge. We shall look at this arrangement as a business model in a later section on economics. Although more inconvenient than a fixed supply cable, this would ensure that each household pays equally for the amount of

electricity that it consumes. It would also make the energy available to a more widely dispersed community.

The disadvantage is that the batteries will be more deeply cycled (fully charged to nearly discharged) than they would be if each household were permanently connected to the wind generator. In the latter instance the wind energy would meet the demands of the loads directly for much of the time.

Load limiters and low-voltage disconnects

Load limiters are used on small hydro (water powered) systems where the maximum power is limited. When connected to each distribution line, they ensure that a set current level is not exceeded – one household will therefore not be able to use a disproportionate amount of power. This solution will not prevent the high energy use, for example by leaving lights on overnight, so it is less suitable for a battery system.

Low-voltage disconnects

disconnect the supply line from the battery running to the household if the voltage falls below a set level. This ensures that no power is drawn from a near empty battery. Running auto batteries flat frequently substantially reduces their life.

Electronic load controllers (ELCs)

A more sophisticated form of control is to use electronic load controllers. ELCs can be used to regulate the amount of current drawn by each household, ensuring that the current lies within a maximum and a minimum value. Some ELCs work at the household level, monitoring individual loads, while others work centrally, monitoring individual households. ELCs are more common with micro- hydro installations, so advice regarding their use with wind power needs to be sought before considering their use with wind systems.

Calculating energy needs

Examples 1 and 2 describe the energy needs in Sri Lankan village households. These are rough calculations, so rounding the figures off is appropriate. Example 1 concerns an individual household; Example 2 is a small group sharing one generator.

The household in Table 3 has decided to use 12V appliances, since they have been using an old car battery for some time to power a radio and TV occasionally. They will need to purchase some low energy DC bulbs for lighting.

Table 3: Example 1, Single Household

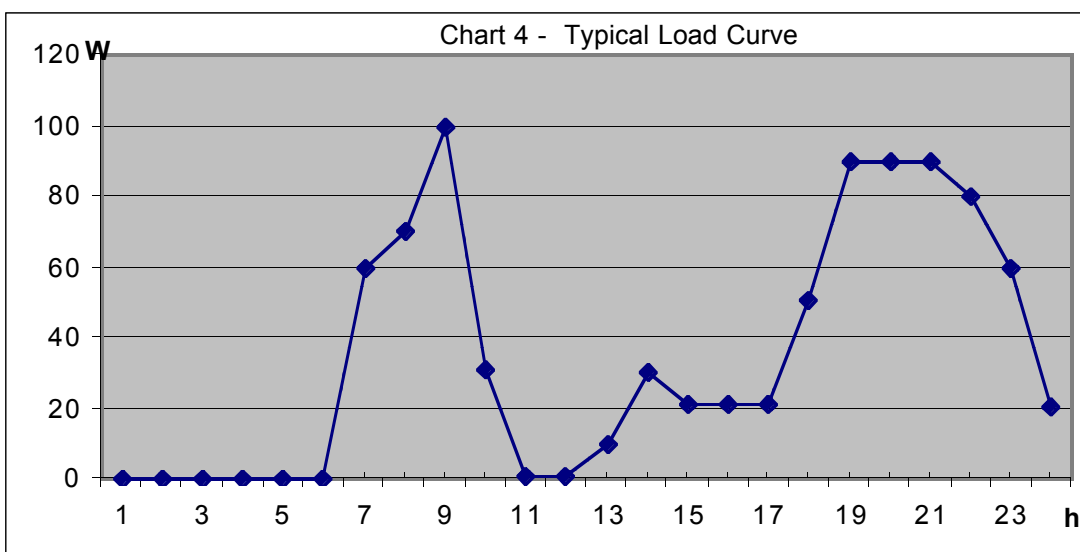
Appliance	Power rating – W	No	Hours of use per day	Daily energy demand – Wh	Monthly Energy Demand kWh
Fluorescent lamp	20	3	4	240	7
Black & White TV	30	1	4	120	4
Radio-cassette	10	1	5	50	1.5
Total energy required				400Wh	12.5kWh
Total with battery losses (x1.25)				500Wh	16kWh
Maximum power required	100W				
Average power required (Total Wh/24)				21W	

Interpretation

The first and second columns lists the appliances used, and their power ratings. The third column lists the number of each appliance. The fourth column indicates the period of time for which they are all used in hours per day. By multiplying all second third and fourth columns together we find the daily energy demand in watt-hours (Wh). The final column indicates monthly energy consumption (found by multiplying the daily energy by the number of days per month). The answer is large enough to be expressed in kilowatt hours (kWh). $7300\text{Wh} = 7.3\text{kWh}$, for example and this can be rounded off to 7kWh .

The maximum power demand in the next row is computed by adding up all the power from all the appliances. This could be helpful in choosing cables, or an inverter, to meet the peak demand.

Example 1 is a simplified table. In order to determine the peak demand it is necessary to break down the demand on an hourly basis and draw the average load curve which as follows for the single household (see Chart 4).



Finally the average power can be found by dividing the energy per day by the 24 hours in the day. Average power gives a more immediately meaningful idea of the system size than energy-per-day figures do (although they actually add up to the same thing, just using different units of measure).

Power demands won't exactly match supply at any given moment. The use of batteries effectively smoothes out this mismatch, and allows the user to draw energy when the wind is light or not blowing, and store energy when the wind is strong. So as long as the average power going into the battery is the same as the average power coming out of the battery over a period of a few hours (or as long as the capacity of the battery(ies) allows) the household shouldn't run out of electricity, even if they use more than the average power for a while. This means that the generator only needs, on average, to produce the average power requirement rather than the peak power requirement. In reality it will need to produce more than the loads consume because of energy losses in the system.

Example 2 Three Households

The same methodology applies for the three households shown in Table 4, sharing one generator, except that they preferred to use mains appliances, necessitating the use of an inverter:

<i>Table 4: Example 2, 3 Households sharing one generator</i>					
Table 4: Household 1					
Appliance	Power rating – (W)	No	Hours of use per day	Daily energy demand Wh	Monthly Energy Demand (kWh)
Fluorescent lamp	20	3	4	240	7
Black & White TV	30	1	1	30	1
Radio-cassette	10	2	5	100	3
Total energy				370Wh	11kWh
Total with battery losses (x1.25)				460	14
Total with inverter losses (x1.1)				510Wh	16kWh
Maximum power required	110W				
Average power required (Total Wh/24)				21W	

<i>Table 4 Household 2</i>					
Appliance	Power rating – (W)	No	Hours of use per day	Daily energy demand – Wh	Monthly Energy Demand (kWh)
Fluorescent lamp	20	3	4	240	7
Black & White TV	30	1	1	30	1
Radio-cassette	10	2	5	100	3
Butter churn (AC motor) (~2 hours per week)	200	1	0.25	50	1.5
Total energy				420Wh	12.5kWh
Total with battery losses (x1.25)				525Wh	16kWh
Total with inverter losses (x1.1)				580Wh	18kWh
Maximum power required	310W				
Average power required (Total Wh/24)				24W	

<i>Table 4: Household 3</i>					
Appliance	Power rating – (W)	No	Hours of use per day	Daily energy demand – Wh	Monthly Energy Demand (kWh)
Fluorescent lamp	20	3	4	240	7
Radio-cassette	10	1	5	50	1.5
Total energy				290Wh	8.5
Total with battery losses (x1.25)				365	10.6
Total with inverter losses (x1.1)				400Wh	12kWh
Maximum power required	70W				
Average power required (Total Wh/24)				17W	

Table 5 summarises this information for the three households:

<i>Table 5 : Summary of Totals for 3 Households</i>	Household 1	Household 2	Household 3	Total
Monthly energy required from batteries	16kWh	18kWh	12kWh	46kWh
Maximum power required	110W	310W	70W	490W
Average power required	21W	24W	17W	62W

Matching needs - the wind and the generator

Having done the calculations to see how much energy is required for each scenario, this demand needs to be matched to the available supply, and the battery storage requirement worked out.

Steps to be followed:

- In an ideal world you should first collect data regarding the local wind regime. Find the average windspeeds for each month of the year, so those 'lean' months can be identified and battery storage increased if practical, or backup strategies can be thought out. It is equally important to record maximum gust speeds when the wind is seasonally strong, so that the wind generator can be strengthened if necessary.
- From the average windspeed you can calculate the expected energy output from the wind generator, based on its characteristics. See the previous section 2 on 'Wind potential'.
- Compare energy needs and energy availability for the average windspeed at your site. Remember to allow for losses in the system. You can now decide whether it is viable to use a wind generator.
- Decide upon the amount of battery storage you need (and if appropriate, compare with what you already have). As a rule of thumb, it is desirable to have enough storage for up to one week using essential loads only. This is usually equivalent to about 3-5 days of normal use. Much depends on the abilities of the users to understand the limitations of the system, manage it sensibly, and use alternative energy sources (kerosene etc) where necessary to prevent excessive discharge or system shut-down.

Table 5: Available energy at two example locations	Example 1 – Single household	Example 2 – Three households
Average windspeed at site	4m/s	4.5m/s
Monthly energy needs	16kWh	46kWh
Energy available from 2m diameter wind-gen	25kWh (from table in last section)	36kWh (using 'rule of thumb')

From Table 5 it can be seen that the average windspeeds at the two locations are 4 m/s and 4.5m/s respectively. There appears to be enough wind energy available in Example 1, but not in Example 2.

The options available in Example 2 are:

- Use two wind generators. This would provide more than enough capacity.
- Use a larger wind generator. There should be other sizes available from the manufacturer. But be clear whether you are buying a prototype machine built-to-order. It is better for the customer to use a fully tested product.
- Reduce loads in all households.
- Supply two households instead of three.
- Use a load control strategy as outlined in the previous section.

Since the average windspeed has only been approximated, it may be worth going ahead anyway. An average windspeed of 5m/s instead of 4.5m/s could make the option of supplying all three households quite feasible and in any case, patterns of use are never fixed, but depend on availability and on a multitude of imponderable factors.

Battery sizing

Apart from the safety, the days of autonomy is a key parameter in *sizing and choosing the battery*.

A battery is charged and recharged over a period of hours or days. This is the 'cycle'. Two parameters are important in the life expectancy of a properly maintained battery:

- the number of cycles a battery can support.

- the change or the depth when a battery is discharged. E.g. a daily discharged of 10 % will provide a longer life expectancy if the same battery is discharged, say, with 20 %. The *maximum depth of discharge* a battery can support without being damaged depends on the types of the battery. The figures in table 6 are usually quoted;



Photo 12: A traction battery from a forklift truck can be deeply cycled over 1000 times (Hugh Piggott, UK)

Table 6
Maximum depth of discharge (DOD) according to different types of batteries

	<u>DOD</u>	<u>Technology</u>
- Car batteries	50 % (0.5)	Lead acid (30 cycles approx.)
- Special solar PV batteries	80 % (0.8)	Lead acid with special features (large reservoir of electrolyte, low antimony lead plates, space below the plates for debris to collect.(1000s of cycles at 50% DOD)
- Nickel Cadmium	up to 100 % (1.0)	Nickel Cadmium maintenance free, longer life but very costly (1000s of cycles at 100% DOD)

For renewable energy (wind and PV) systems lead acid type, long, deep cycle batteries are recommended. But car batteries are often used because they are many times cheaper, and they provide good service for a short time.



Photo 13: Deep cycle 'Solar' battery in Sri Lanka. Twelve 2 volt cells with 900 Ah capacity are connected to make one 24 volt battery with 900 Ah capacity. Height is 700mm. On the left is an inverter. (Hugh Piggott)

Sizing the batteries

Four steps must be followed:

Step 1: Calculation of the daily energy production (E_p) in Watt hours (Wh). This step has been detailed in the previous sections. (For example take the single household using 400Wh/day.)

Step 2 : The choice of autonomy (N) of the number days required by the system
About 3-5 days are typical figures for small wind systems. (Take 3 days.)

Step 3: Maximum allowable depth of discharge : D (as a decimal fraction, say 0.5
for 50% - see previous section)

Step 4: Battery Voltage : U. Usually the voltage is 12 or 24 V. (Take 12 volts)

The capacity expressed in Amp hours (Ah) will be obtained from the following formula:

$$C (Ah) = \{E_p .N\} / \{D.U\}$$

In our example

$E_p = 400$ Wh. Assuming an autonomy (U) of 3 days, and battery voltage of 12 V, the battery Amp hour capacity will have to be:

$$C (Ah) = \{E_p .N\} / \{D.U\} = \{400 \times 3\} / \{.5 \times 12\} = 200 \text{ Ah}$$

It would be appropriate to use 3 or more car batteries (60Ah) or two or more lorry batteries (90Ah) for this application. If the household has fewer batteries (say 90Ah), then the period of operation without wind will be shorter. In such cases, only essential loads (Radio) can be used from the battery during calms. During windy weather this smaller battery would soon be full, and it would be wise to offer charging services to neighbours.

Conclusion

The examples show how important it is to have an understanding of the power available in the wind, and the energy used at the household level before going ahead with a project. One of the greatest obstacles that wind energy at this scale faces is the mismatch between expectation and performance with poorly designed systems.

4. ECONOMICS OF SMALL WIND SYSTEMS

The primary target group of small wind systems are low or middle-income people in remote areas. Usually the purchasing power of this category is not high and their financial assets are modest. Mechanisms to finance up-front capital are crucial for a wider dissemination. This section looks at real examples where project teams worked on prototype systems.

Manufactured cost

To estimate the manufacturing costs and the possible selling price, project teams visited diverse workshops that work in the field of wind energy, and the manufacturers and/or distributors of the different materials used.

The itemised costs are shown in Table 6 for a generator in Peru.

Table 6: Itemised costs for generator

ITEM	Cost US\$	Total US\$
1. Rotor		
Materials	26.50	
Manufacturing	14.70	
Hub	41.20	
Moulds and Models	4.70	
Taxes and profits (38%)	33.10	120.20
2. Support and accessories		
02 Tubes 2" x 6 m	88.20	
Cable 1/4" x 75 m	41.20	150.00
Others	20.60	
3. Generator		
Materials ¹	80.00	
Manufacturing	44.20	
Taxes and profits (38%)	46.97	170.57
Total US\$		440.77
Total £		293.00

In the case of Sri Lanka the costs are slightly higher because an inverter (approximately US\$ 50) has been included in the total costs in order to obtain AC. Other costs included are the cable and the charge control regulator. Although the capital cost is around US\$ 500, credit and subsidies during the first years will be necessary to develop the market. Lessons drawn from this project show that beneficiaries who are currently using batteries are very interested in purchasing a

¹ According to the progress report for alternator design, Hugh Piggott, March 17, 1999

wind machine by instalments. This is mainly based on the savings and the convenience from the availability of local source of energy.

Financing ownership by battery charging services

The up- front capital may be difficult for a single poor household to afford if they want their wind battery charger to be of exclusive use for one family. However, it may be possible to establish a small business of battery charging for their neighbours. They then may be in a position to break even after two years. The details are as follows:-

Calculating battery charging capabilities

The batteries they currently use are car batteries (about 60 Ah), with 50% discharge each time. To recharge these batteries, with allowance for efficiency (add 25%), means $30 \text{ Amp} \times 12 \text{ V} \times 1.25$ (efficiency)= 450 Wh of energy, say roughly 0.5kWh. If we consider a 2 metre diameter wind generator on a 3.5m/s site (the lowest useful mean windspeed) the energy produced monthly is about 17kWh/month or 0.6kWh/day average. So the wind generator can charge one battery each day, as a rough average. In reality it can charge several batteries on some windy days, and none on calm days. As we have seen it would take several car batteries to make all the incoming wind energy available for use at a steady rate.

Household battery use

At present rural families who charge batteries do so once or twice a fortnight (this represents about 30Wh/day). If we assume that a poor family wants to have its wind battery charger, they can charge one day a week for themselves and 6 days a week for business. This would first of all double the amount of energy per week they can use. Also, in theory, charging two other batteries each week will allow them to have enough money to pay for the unit in less than four years (see table 7). In any case if they only have one battery, they will frequently have surpluses, and it will be no hardship to use surplus power for profit. Much will of course depend on the actual windspeed, its variability and on the availability of local customers for the service.

Payback calculation

The first and most important constraint for poorer families wishing to buy a wind generator is the availability of credit. From these assumptions (avoided costs² and sale of services to neighbours), a simple payback period³ could be calculated.

These calculations are based on very conservative figures. We are assuming that the avoided cost is just one dollar per week (recent evidence supports this figure). We have also assumed that selling battery charging services to other users

² The avoided cost is the cost that the user would have had to support if the wind generator were not available. This is in fact the price of the service currently paid for charging the battery at the nearest town.

³ The payback period (usually expressed in years) is the amount of time for a project to return the up- front capital or initial investment.

(households or small businesses) is on average available only 3 weeks out of four. One week may occur during the month when the wind regime is not sufficient enough to cover the needs of the owner and to generate a surplus electricity for sale. When wind resources are sufficient wind generators might be the preferred option as a similar investment on solar PV will not allow a surplus to be generated and sold to nearby users.

Avoided costs US\$	Income from selling services (US\$)	Up-front investment (US\$)	Payback period (years)
52	$52 \times 2 \times 0.75 = 78$	450	3.46 Year

At a good site (with 4.7m/s mean windspeed), approximately 500 kWh a year can be generated. Assuming a down time of 20 %, the annual production is estimated at 400 kWh. At a discount rate of 10 %, the levelised energy cost is US\$ 0.12 per kWh. This figure shows that when the full potential of the wind generator is used either for personal consumption and /or to sell the service to other consumers, the levelised cost per kWh compares very well with electricity from the grid. However, in almost all countries, grid electricity is subsidised which means small wind systems or other decentralised energy options should target areas which are unlikely to be connected in the mid (5 years) or long term.

A more sophisticated calculation in which the Internal rate of return (IRR) and the Net Present Value (NPV) are calculated also shows that the wind energy systems could be a profitable business if in addition to the avoided costs, the user is able to supply energy service to the neighbours.

Table 8: Financial viability of small wind generator enterprise

Parameters:

Technical parameters

Wind generator life expectancy : 20 years

Rated power: 100 W

Economic parameters

a- Investment and running costs

capital costs: US\$ 500

maintenance costs: 5 % of total investment = 25 of year 1

b-Income

- Avoided costs 1 US\$ a week

- Income generation : 78 batteries charged per year at 1 US\$ year 1

Financial parameters

Discount rate = 0.12

Escalator : 3 % applied to income and maintenance costs

Loan: 30 % of total cost, repayment over 3 years at a commercial interest rate of 18 %

Results: IRR = 21 % , NPV = 228

A positive NPV and an IRR of 21 % are indeed good indicators of the sustainability of this business. It should also give a positive signal to financial institutions, governments and donors who are willing to support alternative credible and cost-effective options to an energy model based on renewable and non-polluting resources.

PART 2: SUSTAINING THE TECHNOLOGY

FROM PILOT PROJECT TO WIDESPREAD USE

This section looks at the bigger picture; what are the factors and issues involved in moving from a few small projects to a sustainable industry where NGO's and donors are not needed? This is a demanding challenge and will be difficult to achieve without careful thought and the involvement of a wide range of stakeholders. The following sections look at institutional and organisational support, financing mechanisms, support to manufacturers and the policy environment, and how these organisations and institutions can be used to enable more households to benefit from improved electrical services.

1. THE DEVELOPMENT OF A WIND ENERGY SECTOR

This section deals with some of the factors involved in 'scaling up' from a pilot project or programme to a sustainable industry. The growth of wind energy in Denmark, where commercial wind energy began, and Mongolia, where small wind generators have been most successful, are discussed as examples of good practice. They also emphasise the need for a long-term approach.

The Danish Experience

Wind energy technology development in Denmark was achieved through the combined efforts of enthusiastic amateurs with a concern for the environment and a government concerned about the impact of the 1970's oil crisis. Most early machines were small (compared to the large wind machines in use today). The Government established a national research centre to promote common standards and to conduct future research into wind turbine technology. Danish turbine manufacturers now guarantee a 98 per cent availability rate (in other words down for maintenance for only 2% of the time) for their turbines, and statistics show that the availability rate in practice is around 99 per cent.



Photo 14 : Typical Danish wind turbine from circa 1982 (Wind-matic a/s)

The early machines of 25 kW with 10.6 metre rotor diameter may still be found in Denmark. Today the most widely sold turbines have a rated power output of 750-1000 kW, and a rotor diameter of 48-54 metres. Despite the increasing commercialisation of turbine manufacturing, more than 80 per cent of the 5,700 wind turbines in Denmark are owned by wind energy co-operatives, or individual farmers. 100,000 Danish families own wind turbines or shares in wind co-operatives. Danish power companies are obliged to pay 85 per cent of the retail electricity price for the wind energy purchased from privately owned wind turbines.

In Denmark, the interest on loans to purchase wind turbines is tax deductible from the private income of the individuals in a partnership. Wind Turbine Guilds were established to represent the mutual interests of the turbine owners to electricity boards, authorities, and manufacturers. Dialogue with manufacturers helped ensure quality, service and warranty improvements and proper insurance contracts. The second main aim of the Guilds was to share information about the potential for wind power to individuals, the press and policy makers. Even though individually owned wind turbines continued to be erected, the guild turbines were the ones that had influence on development, and they still have.

The Mongolian experience

Over 130 ,000 stand alone, small wind generators are being used by nomadic people in Inner Mongolia. The wind systems are mainly used by isolated households. The vast majority of machines are of 100 W rated capacity. A typical small system provides electricity for lighting, TV and radio (130 kWh/a). The main livelihood of these people is livestock - sheep and goats (cashmere). The Chinese government estimates that even by the year 2020, the number of households too remote for grid connection to be economically viable will be 350 ,000.

Research started in the 1970s and the first demonstration of small wind generators in Inner Mongolia was set up in 1977. After 1978 the Inner Mongolia Science and Technology Commission became involved in a second initiative which provided training and maintenance services. At this time problems with insufficient demand, quality and technical issues inhibited sales of machines. A further initiative in 1980 resulted in the setting up of a network of service centres, which now covers 60% of the region. A wider programme was run between 1984 and 1989, during which time sales took off. A subsidy of 15% of system cost was made widely available from 1986. Although still in place, this has been kept at the same monetary value, making it much less significant now. Herdsmen have always paid for wind generators using their own money; in the 1970s they received salaries, but now they generally raise income from livestock sales.

Common lessons

The Inner Mongolian story has highlighted some issues that appear to be important for the long-term stability of a small wind generator industry:

- Economics has not been the main driving force in the dissemination of wind generators, and this indicates that subsidies have not, therefore, played a major part in the success of the programme. It was the introduction of a broadcasting station in Inner Mongolia in 1980 that created a demand for TVs, and consequently a surge in demand for wind generators. This demonstrates the importance of identifying demand, and attributing a value to it.
- Effective feedback loops comprising service centres to collect information, manufacturers motivated to take action, and research centres to provide

expertise have led to products suited to the needs and capabilities of the consumers.

- A total system package should also be made available to ensure that potential benefits of the technology are realised, especially at the start of the programme. In addition, the weak link in any total system should be identified and addressed.
- Successful companies are relatively small and rely heavily on wind generator sales, so it is argued that companies should be selected on the basis of their commitment to the success of the product and their ability to respond to feedback from the market.
- The importance of demonstration projects should be stressed as almost all respondents learned of the technology from friends and neighbours or the Science and Technology Commission. The other aspect of a demonstration is that it highlights design faults, initiating the feedback loop to manufacturers.
- Another interesting feature is that no credit system was needed in Inner Mongolia. However, users have capital assets in the form of sheep and goats, which can readily be converted at the local market.
- Also, the authorities provided training at several levels, yet the most commonly reported source of information at the user level was written instructions. This shows how printed instructions can make up for shortcomings in training and extension services.

There are some interesting comparisons to be made between the two cases of Denmark and Inner Mongolia. In the first case, wind generators provide over 10% of the country's grid electricity and the technology is used world-wide. In the second case, wind generators provide electrical services to a large number of marginalised people.

The first common element is how the technology started small and developed piecemeal, rather than starting with large and high technology machines.

Secondly, there are important feedback mechanisms between consumers, manufacturers and government that lead to the better design of machines, programmes and policy.

Thirdly, wind generator owners and electricity users are often the same people, either individually or collectively. Ownership of the technology, both literally and through participation in its development, can overcome many of the social problems associated with technology that has been 'imposed' from outside.

Fourthly, the motivation for using wind energy has to be clear from the start. In the case of Denmark, the prime motivation for individuals is environmental protection; in Inner Mongolia it is access to services that need electricity.

2. INSTITUTIONAL SUPPORT

Institutional support, from an organisation established to offer services of one sort or another, advice, a regulatory environment or funding, is essential. A question often asked by sceptics, and a valid one at that, is 'if it's such a good idea, why is no one doing it already?' The answer to this question may well be the lack of institutional support in an environment where it is difficult for small business to flourish unaided, for NGOs to reach their 'target beneficiaries', for donors to feel they have spent money wisely, and for households to feel the long term benefits of development projects.

To illustrate the point, some of the agencies involved in the ITDG project are described below, in particular those in the UK and Sri Lanka. Agencies will vary, since the realities on the ground will be different in each case, and this project has been a learning experience in itself.

Institutions Involved in the ITDG Project

ITDG

ITDG is an international non-governmental organisation which specialises in helping people to use technology for Practical Answers to Poverty. It was founded in 1966 by the radical economist Dr EF Schumacher to prove that his philosophy of 'Small is Beautiful' could bring real and sustainable improvements to people's lives. ITDG had previously promoted the use of micro hydro power to enable poor communities to have access to electricity, principally in Nepal, Sri Lanka and Peru. The potential for the use of small wind generators was identified by ITDG offices in Peru and Sri Lanka, and preliminary data and experiences were collected to see whether a technology development project was feasible. A proposal, written and submitted to the UK government, was subsequently funded.



Photo 15 : IT Peru working on the Small Wind Turbines Project (Hugh Piggott)

ITDG's usefulness to the project has been twofold in this instance. Firstly, through its history of working with communities via its country offices, it has an established credibility both with donors and grassroots organisations. This was helpful to ensure that the initial idea was taken seriously, and communities were willing to work with ITDG, because they knew about the organisation. Secondly, the organisation took overall responsibility for the project management, and was able to organise and co-ordinate the separate groups and individuals that made a contribution to it.

UK Department for International Development

The UK DFID was the main funder for the project and contributed around 90% of the financial resources. As both a source of funds, and a government body, DFID required regular reports on the project progress as well as a requirement that the project fitted with their development philosophy. This imposed both a bureaucratic necessity and a measure of accountability during the running of the project that helped ensure it met its original objectives. In this case, the provision of funds was the primary reason for working with such an institution, but secondary advantages include access to a broad group of researchers in the field, international credibility and wide dissemination of project results.

Institution of Electrical Engineers (IEE), UK

The IEE were not officially connected to the project, but were a useful 'peer review' group. The IEE contains a large pool of expertise; presentations concerning some of the more technical aspects of the project were made to groups of IEE members, and their feedback was useful as the project progressed.

Imperial College, UK

Imperial College was involved at an early stage of the project. An MSc thesis was produced by a student who looked into the nature of the demand for electrical services in selected villages in Sri Lanka, based on field visits and survey data. This analysis was important in defining the wind generator specification and also pointed towards some of the social complexities on the ground.

VINIVIDA, Sri Lanka

A partner organisation with ITDG in Sri Lanka, called VINIVIDA, had been working with numerous ITDG projects for a decade. VINIVIDA has a permanent staff of about 15 persons and works in the areas of rural transportation, food processing, rainwater harvesting, agriculture, nutrition, and rehabilitation of abandoned village irrigation tanks. It also operates a revolving credit fund. VINIVIDA is an example of a local institution often called a CBO (Community Based Organisation). CBO's have links with communities, villages or households that are difficult to establish if you are a national or international institution working alone. VINIVIDA helped to carry out the project market survey and to identify potential pilot sites.

GIDES, Sri Lanka

A second partner organisation in Sri Lanka was called GIDES which has also been working with several ITDG SL projects. Formed in 1995, GIDES is registered, as a social service organisation, with the Department of Social Services and with the Provincial Council. It works in the areas of organic farming, promotion of home gardening, rural transportation, small enterprise development, wind power for rural electricity supply, and rehabilitation of abandoned village irrigation tanks. GIDES also operates a revolving credit fund which was used to provide finance for households wishing to purchase wind generators.



Photo 16: a demonstration wind/biomass project in Sri Lanka (Hugh Piggott)

REDS, Sri Lanka

REDS stands for Rural Enterprise Development Services which is a

subsidiary of the Sarvodaya Movement in Sri Lanka. REDS helped the project by establishing necessary contacts for getting fibreglass expertise for the generator manufacturer.

Wind Project Research Team, Sri Lanka

Although not a formal institution, the Wind Project Research Team comprised two academics from the University of Motaruwa, Colombo, the director of a private energy research company, and the wind project manager from ITDG Sri Lanka. The Wind Project Research Team supervised the prototype testing in Sri Lanka and provided some technical support during the design process. The University link enabled some testing to be carried out with University staff and students

Institutions in General

In general, support institutions can be divided into the following groups:

International Institutions

These include international non-governmental organisations (INGOs) such as ITDG and OXFAM; pan-national groups such as the UNDP and World Bank; and multinational companies such as Shell. International institutions are usually approached, either because they provide funds for projects or programmes or because they have a degree of influence with national government.

National Governments

National governments either provide funding for projects or programmes or establish the regulatory or legal framework in which to operate. It is therefore important to find out what support is available from government (e.g. grants, subsidies or tax credits for renewable energy schemes) or what policies are designed to help or hinder renewable energy projects.

Academic Institutions

Academia can be very useful for providing high quality, often well motivated, researchers and academics. The relationship is often complementary; on their part they can be involved with practical, field-based projects, whilst their expertise is cost effectively available to the project manager. Academia can offer both engineering and social science input and adds credibility to the project team.

Funding and Financing Institutions

Much has been written about the need for affordable credit for households and entrepreneurs. Institutions that organise and/or provide finance are very likely to be involved to some degree or another. These can take the form of state or private banks, donors or micro-credit organisations.

District Institutions

Local government is the most obvious form of district institution. They are very likely to be involved with issues such as siting of wind generators, planning of local energy services, etc. The relevant local government department needs to be aware of any activities that may touch on their area of responsibility; for example, grid-connected wind generators can pose a risk to workers doing maintenance if they are unaware of their existence.

Local Institutions

Local institutions, usually non-governmental, form the link between the project team and the beneficiary community or households. Local groups have local knowledge and are likely to be trusted by the community that they represent or serve. The chances of project success are heightened if these groups are involved throughout the project; they often form the conduit for feedback when problems occur, and are in a position to offer advice and support both ways.

Manufacturers Associations

Very new industries often work effectively in co-operation as well as competition. Manufacturer or Trade Associations are good at pooling resources to present a professional face to potential clients, and have influence at policy level. Often trade associations require that certain standards are met in order to become a member; this minimum standard can reassure customers and lead to better products or services. If they do not exist already, it is worth considering establishing them as part of the project.

Dissemination Institutions

When projects go wrong they endanger the whole sector, often by word of mouth, but good practice is much more difficult to spread. The involvement of dissemination networks and written and broadcast media can be very beneficial. Dissemination networks, often internet based, allow researchers and project workers to exchange experiences and ideas. The media can reach a widespread audience of potential customers or beneficiaries, and a well thought out dissemination strategy can give donors value for money.

How Should Institutions Become Involved?

As can be seen by the institutions outlined above, there are a large number of parties that could become involved, and this could require full-time co-ordination. The answer depends very much on the nature of the project and its ambitions. It would be difficult to persuade an organisation intent on erecting only one or two turbines at one particular site to involve the World Bank, but where a regional programme is being considered this may be necessary. Donors will often like to see involvement from many institutional 'stakeholders', so this may be a necessity if funding is required. At the very least, a checklist of institution type should be drawn up. Those that are legally obliged to be involved should obviously be included; others can be prioritised depending upon their usefulness to the success of the project. Informing as many institutions as possible of the existence of the project costs little and can have large benefits in the long run.

3. BUSINESS DEVELOPMENT

Introduction

Wind generators will ultimately be used by a large number of households if the household can perceive the benefit, the generators are affordable and they perform as expected. Development Organisations can help to publicise the benefits of wind energy through projects and pilot studies, but in the long run the technology will have to be sustained by a manufacturing sector. This section looks at ways in which this sector can be helped.

In the long term, the best situation for a manufacturer to be in is to have his or her products being bought by at least a minimum number of customers year-on-year that enables the business to be viable. It is unlikely that generous external support will be available into the mid and long term, so it is important that manufacturers can utilise available support at the early stages of production when their business is most vulnerable. This section looks at some measures that can be taken to help support a fledgling wind generator manufacturing sector.

Technology Transfer

It is unlikely that small manufacturers have the time or capacity to develop wind generator designs from scratch. They are likely to be approached by an individual or institution who has developed an idea or design and who has undertaken a selection process of suitable manufacturers. The institution may be a University, NGO, or Government Department who wish to take a prototype design a step further. The manufacturer may be asked to produce a number of different designs, or a batch of a proven design. Either way, it is important that the manufacturer understands his or her role from the start, and is paid adequately for their work. For example, it should be made clear at what stage the manufacturer is required to offer support to customers should technical problems arise; who is responsible for technical improvements to the design; who



Photo 17 : Technology transfer in a small workshop : PMG construction (Jytte Piggott)

owns design copyright, if any; who is ultimately responsible if products fail due to design faults, etc. As already mentioned, the exact level of technical backup for the manufacturer in the type of situation described is an important parameter to be understood at the beginning to avoid leaving the manufacturer feeling abandoned with an inferior design, or the institution held responsible for unauthorised manufacturer alterations.

A suitable arrangement may consist of the manufacturer keeping a performance log of customer machines and reporting back to the institution or individual regularly, in exchange for technical help for a given period. As operating experience is gained, the manufacturer should become aware of potential or actual design faults and be able to gain assistance in rectifying them. In the longer term, the manufacturer can offer an appropriate guarantee to customers based the likelihood of faults occurring.

Training

The training of manufacturers, both technical and on business matters, can be of great benefit. It is difficult for small manufacturers to keep abreast of technological developments and new products, so help in this area could be the spur for some to take up the technology. General courses on the benefits/constraints of wind energy, as well as courses looking into design and construction should be considered.

Supporting the Market

As mentioned at the start of this section, the best help for manufacturers would be a healthy market for wind generators. Although this may exist in theory, i.e. sufficient wind resources, low electrification rates, current use of auto batteries, sufficient resources or credit available to buy generators and the lack of feasible alternatives, not much will happen unless the consumer is aware of the product and the manufacturer is aware of the market. Support to the market should therefore be directed towards achieving the twin goals of consumer and manufacturer awareness raising.

Marketing

Marketing is usually low down on a small manufacturer's list of priorities. This is usually because marketing takes time and money and/or marketing skills are not available. However, at the stage when a manufacturer is confident enough in the product to think about selling it in volume, marketing is crucial to success. Help with marketing can come in several forms, from help with market research, production of marketing literature, securing advertising space, improving the company image, and better product design. Some marketing can be co-ordinated through Trade Associations to keep costs down, or focused on individual manufacturers with the help of marketing experts. Once the technical challenge of producing an appropriate product has been achieved, equal effort needs to go into its marketing.

Subsidies

If wind generators are to compete in the energy market effectively and offer remote households the chance of improved access to electricity, it may be necessary to consider a subsidy scheme. Subsidies can support manufacturers if the price charged to consumers has the subsidy element included, i.e. the wind generator is cheaper than it would otherwise be. The manufacturer can then claim the subsidy back from the body administering it, which could be an NGO or Government department. Subsidies may not be crucial, though, as was seen in the Mongolia example given earlier in this booklet. Careful thought needs to be given as to how subsidies are directed and who they are intended to benefit. For example, subsidies on manufacturing components, such as magnets or electronic components, could help the manufacturer to keep costs down and improve profitability. Whether or not these savings are passed on to consumers is up to the manufacturer (and market). Not only subsidies must be transparent but it is also important to develop a strategy to phase out the subsidies over a reasonable period of time which could be between 5 to 10 years depending on the context of each country and the competition from fossil fuels.

Fiscal Measures

Fiscal measures are those that can be implemented by national or regional government. They can help manufacturers by reducing the overall cost of owning and operating wind generators.

Tax Incentives

Tax incentives are also a form of subsidy, but are usually part of a national policy to promote renewable energy rather than for the direct benefit of manufacturers. Tax incentives only work in favour of the target group if they are paying tax in the first place. For example, a reduction in an indirect tax on renewable energy equipment, such as value added tax, could reduce the cost of wind generators to the consumer. On the other hand, reducing the rateable value of property using renewable energy will not affect those not paying rates. The overall aim should be to reduce the initial high equipment cost to the consumer, which is a characteristic of renewable energy

Net Billing

Net billing may be appropriate for more a grid connected household, or households that share a wind generator. Net billing allows excess electricity from the wind generator to be sold back to the Electricity Company via a grid connection at a market rate. This is an attractive idea, not only because it can provide a limited income, but also because it allows wind generators and the grid to work side by side. As mentioned earlier in this booklet, a major disincentive to owning and operating small wind generators is the expectation of a grid connection in the short or medium term, so allowing net billing can overcome this obstacle. Net billing is rare, though, so this option needs careful research.

Institutions

Trade Associations

Trade associations can be useful for manufacturers because they can act as a communication channel for new ideas and market intelligence, they can represent manufacturers to the Government or in the media, and they can promote the technology to the general public. They can also offer guarantee schemes and a mark of quality assurance. Trade Associations are usually independent bodies that require subscriptions from members. They may or may not have charitable status. If a wind energy programme is being run by a donor or government, Trade Associations are a useful vehicle for identifying approved manufacturers and distributing subsidies. Such associations can be set up as part of a programme, or supported if necessary if they already exist. If a large scale wind generator programme is being considered, Trade Associations can enforce standards with carrot of subsidy distribution and the stick of penalties for poor performance.

Knowledge Sharing and Disseminating Lessons Learnt

Knowledge sharing encapsulates much of the above discussion. Manufacturers need to be aware of the market potential, and households need to be aware of the opportunities afforded by wind energy, as well as its limitations. An NGO can perform a catalytic role by providing information to consumers and manufacturers. In many ways this is the most appropriate role for them to take.

Networks and Newsletters

Networks are useful for keeping Development Organisations informed about what is being done in the sector and for sharing experiences, forming partnerships, etc. For example, networks can help avoid replication of effort by the sharing of good practice and project results.

Newsletters perform a similar function, but are usually devised to inform a wide audience about the work of a single organisation or network of organisations. Newsletters can be targeted quite effectively, both at grassroots organisations and at institutions and government.

Workshops

A classic end-of-project activity is a dissemination workshop. These can be very useful, especially when genuine progress has been made in a project. The most effective workshops bring together a wide variety of stakeholders and should include household beneficiaries or their representatives. Careful thought should be given to maintaining the momentum in the days, weeks and months following a workshop, since it is easy to see this activity as a final act. It is especially

important is to maintain contact with policy makers or donors in order to help secure a future for household and wind related activities.

Publications

Distinct from newsletters, publications can provide a more thorough method of disseminating lessons learnt. Of course, this publication forms part of such an activity. Issues can be looked at in more depth and information can be referenced by a wide variety of readers. It is important that publications are useful – although this sounds like an obvious statement to make a poor publication can do similar damage to the reputation of the technology as bad design. Thought should also be given to the method of publication. Increasingly, the Internet is being used to publish material. This method can be cheap and easy, and allows the publisher to monitor where the publication is being downloaded or read from. As a compliment to traditional media, the Internet can be extremely useful.

4. THE POLICY ENVIRONMENT

If the use of wind generators to provide electrical services to those with few other options is to move from the pilot and demonstration stage to one of widespread use, it will be necessary to have policy barriers removed by government, or better still positive support. In both Denmark and Inner Mongolia, government was involved at the early stage of technology development and later stages of providing the necessary policy frameworks.

The Inner Mongolia programme had no external support (e.g. non-governmental organisations, NGOs), but it is assumed that any programme driven by an NGO would need the support of a host government. A government needs to be prepared not only to commit resources to a programme, but also to commit itself to supporting the programme over a long period of time. For the wind generators, the lead time from first research to sustainable sales was around 20 years, which is well in excess of the planning horizon for political parties in most democracies.

Since in the 1970s the power purchasing policies of the local utilities has varied wildly (offering prices between zero and the retail price of low voltage electricity). Parliament legislated a purchasing price of 85 per cent of the retail price of electricity. An incentives programme in the form of capital grants for installation of wind turbines was established in the late 1970s. The scheme was finally abolished in 1989, when a (then 10 per cent) capital grant was dropped. The basic support mechanism for wind energy in Denmark is now is a partial repayment of the CO² tax paid on wind electricity. (CO² tax is levied on all electricity regardless of its origin, thus requiring a repayment scheme to avoid hitting renewable energy sources like wind). Currently the government is studying a so-called green certificate market based scheme which will be combined with a Renewable Portfolio System requiring electricity consumers to buy an increasing share of their electricity from renewable sources.

Ten policy suggestions for the promotion of small wind systems

1. Research and Development. Establish R+D facilities for the development of locally appropriate technology
2. Provide preferable loans for renewable energy projects
3. Give incentives for community groups to power their community in the form of tax breaks, if appropriate, or grants
4. Allow small wind generators to be grid-tied in the future (if technically possible) and allow consumers to be power providers
5. Provide a preferential rate of VAT on renewable energy equipment
6. Establish electrical standards for household wiring and equipment
7. Promote wind energy through the media
8. Support the development of trade associations for manufacturers and installers
9. Provide nationwide wind data
10. Collect operational data for every generator in use.

CONCLUSION

This booklet has sought to outline some of the issues involved in using wind energy for household electrification in areas where grid electricity has not arrived. Reference has been made to an ITDG/DFID project in Sri Lanka and Peru, where small battery charging wind generators have been designed, manufactured and installed in several pilot sites. The booklet has been aimed at development organisations that are thinking about running similar projects or anyone with an interest in the subject.

Perhaps the most important conclusion to draw is the need to monitor continuously all aspects of the provision of this form of electrification. This entails ensuring that sites chosen have adequate wind; the technology has been designed thoroughly; manufacturers have a grasp of the product and the market; and users know what to expect from the technology and how to use it effectively. Research and development is a continual process, even when the technology is competing in the open marketplace.

APPENDIX I : Summary of Survey Data in Sri Lanka.

	Mahagalwena	Muthapanthiagam a	Periappaduwa
Existing lighting	Kerosene and dry batteries	Kerosene and dry batteries	Kerosene and dry batteries
Monthly Expenditure/HH	Rs280 (8%)	Rs290 (6%) [mean]	Rs290 (6%) [mean]
Percentage using auto batteries	67	71	65
Battery cost	90Ah Rs3400, 60Ah Rs3400	90Ah Rs3400, 60Ah Rs3400	90Ah Rs3400, 60Ah Rs3400
Average daily electrical consumption	70Wh	73Wh	58Wh
Charges/mnth	2	2	2
Journey time/charge	2hrs 40min	1hr 30mins	50mins
Cost per recharge	Rs40-45	Rs30	Rs35
Cost for dry batteries/mnth	Rs150		
Willingness to pay	Rs3000 initial, Rs400/mnth		

APPENDIX II : Technical manuals

Two further publications are available related to the project 'Small Wind Systems for Battery Charging':

'PMG Construction Manual', written by Hugh Piggott, details the steps necessary for a small manufacturer to produce the permanent magnet generator designed as part of this project.

'Wind Rotor Blade Construction', written by Teodoro Sanchez, Hugh Piggott and Sunith Fernando, looks at the construction of the rotor blades which attach to the generator.

These documents are available as free downloads from web sites. For hard copies of either of these publications, contact ITDG UK, Schumacher Centre, Bourton Hall, Bourton-on-Dunsmore, Rugby, UK, CV23 9QZ.