An Iskra White Paper

The Iskra AT5-1 5kW small wind turbine.

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Introduction

Designing and manufacturing a small wind turbine poses many of the same design challenges as that of a large wind turbine, but they need to be solved in a way that can be easily and cheaply manufactured. This poses additional constraints on how the turbine is designed and makes the development of a small wind turbine a very difficult challenge.

The Iskra engineering team have used their extensive experience in the wind industry, to design a 5kW small wind turbine, the Iskra AT5-1, which rises to those challenges.

The Iskra AT5-1 is a 3-bladed, 5kW wind turbine with a 5.4m diameter rotor. It is suitable for grid connection or autonomous operation. It is designed for continuous operation with a design life of 20 years.

The AT5-1 uses a patented innovative "passive pitch control" system that changes the blade pitch in line with both the rotational speed and the power being taken by the generator. The generator is also a patented design that achieves in excess of 95% efficiency across its entire operating range.

An independent report by academics from Cambridge University noted in relation to the blades:

> *"The attention to detail on the design of the aerodynamic section is impressive: taper, profile and twist are close to optimal, and the structural strength offered by the composite section is a key feature. Wind-turbine technology has been evolving over several decades and the Iskra blade section conforms to established best practice."*

This white paper gives an overview of the design challenges of small wind turbines, how these have traditionally been addressed and how the Iskra AT5-1 uses many innovative design features to become a market leading product.

The Design Challenges

Very Strong Winds

One of the most important issues that any wind turbine has to deal with, is that of too much wind. The power in the wind is proportional to the cube of the wind speed, so the power at the maximum design conditions (typically 60m/s) is 1,000 times that at "normal" operating conditions (typically 6m/s).

The turbine not only needs to survive high wind speeds but ideally without unwanted side effects, such as high noise. This requires an effective and robust mechanism for "shedding" power at high wind speeds.

The design of all the components must also be robust and be capable of surviving for many years with frequent strong winds. The most common failure in strong winds, is often not as might be expected, the blades, but "ancillary" items like covers and connectors.

Safety

Small wind turbines are generally installed close to where people live or work, and therefore safety is of critical importance. Areas that need to be addressed include; mechanical integrity, wear and fatigue, dynamics, tower and foundation strength and electrical safety.

There is an international standard for small wind turbine safety, IEC61400-2, and any good small wind turbine should be designed taking into account its requirements.

Reliability

A small wind turbine needs to be designed for continuous operation 24 hours a day for 20 – 30 years.

The turbine is likely to be owned by people with little or no capability to undertake their own maintenance, or who may depend upon the wind turbine as their main source of energy. The turbine therefore has to be designed to offer many years of trouble free operation.

Local conditions may have a significant impact on the reliability of a turbine, including:

1. Turbulence.
2. Ice.
3. Dust.
4. Extremes of temperature.

Service Life

Any wind turbine will be a significant investment, and will take many years to provide a financial pay back. The turbine must therefore be designed to last for a considerable number of years, with only minimal maintenance requirements.

Noise

Noise is one the main reasons why people object to the installation of a small wind turbine, and it is therefore essential that any turbine that is intended to be installed into an urban, or semi-rural environment, must operate as quietly as possible.

Generally there are two sources of noise generated by a wind turbine.

1. Mechanical noise produced by vibrations within the gearbox, generator, brake system and any other rotating parts.
2. Aerodynamic noise caused principally by the movement of the blades through the air, but can be caused by the blades passing through the 'wind shadow' of the tower, or misalignment of the turbine to the wind direction

Efficiency

The key to the success of any wind turbine, and indeed any type of electricity generation, is the cost per kWh. i.e. how much per year does it cost to own in relation to the amount of electricity it generates per year.

In most inland locations, at the typically low heights a small wind turbine will be installed, the average wind speed will be between 4 and 6 m/s, and for the majority of the time the wind speed will be less than 5m/s. It is therefore essential that a small wind turbine is able to capture as much energy as possible at low wind speeds. This requires an efficient design for all aspects of the system including, blades, generator and grid connection or battery charging system.

The power output from a turbine cannot simply be measured using the rated power or the size of the rotor of the turbine, and the average wind speed. There are many "real world" factors that make one wind turbine perform differently from another, apparently similar machine, the key ones being:

1. Blade design.
2. Generator efficiency.
3. Cut-in and cut-out wind speed.
4. Effectiveness of power regulation system
5. Responsiveness to changes in wind speed and/or direction.

Cost

Last, but by no means least, the turbine needs to provide a cost effective source of energy. Small wind turbines tend not to be installed in the optimum locations with very high average wind speeds, and therefore the cost of the turbine has to be kept to a minimum in order to provide a realistic pay back period to the end user.

When considering cost, the important number is the total cost, including installation, electrical connections and other items. The cost of the turbine itself, may be only 30% - 40% of the total cost to the customer of a fully installed machine.

Existing Turbine Designs

There are over fifty horizontal axis small wind turbines in the 500W – 20kW range available in the world today, and there are numerous different approaches taken to aspects of their design. Many however are old designs that do not benefit from the considerable recent advances in areas such as composite blade technology, or knowledge gained from the developments in the "big wind" industry.

Most of the smaller turbines, less than 1kW, are designed for the lowest possible cost of manufacture and are not generally optimised for maximum energy generation, and can therefore take a very simplistic approach to some of the other issues.

There are also a number of mid sized, 2 – 10kW, small wind turbines available and they take various approaches to some of the key issues.

Power Shedding

Very small turbines may not have any kind of power regulation, rather they simply rely on their strength, relative to their size, to survive strong winds, or loss of the generator off-take. Such systems are only considered suitable for very low power systems.

The most common techniques for dealing with high wind speeds in medium sized systems are coning and furling.

Coning

In coning, the blades individually lean back out of the wind. Free coning can lead to severe dynamic loads and care needs to be taken to avoid over flexing by the use of appropriate end stops.

Furling

Furling is achieved by positioning the yaw axis of the turbine off-centre. In high wind the generator yaws out of the way. Often this is achieved with a hinged tail vane that "gives" in high winds. Springs pull the machine back into alignment with the tail vane when the wind slows. Furling solutions have a number of drawbacks:

1. It leads to misalignment of the turbine to the wind direction which leads to aerodynamic noise ("helicoptering") and reduced energy capture.
2. It will be misaligned in strong winds producing high noise cyclic and rapid yawing loads
3. There may be a risk that the off-load wind turbine will accelerate slowly up to very high rotational speed without generating enough thrust to operate the furling system.

Blade Design

Very small turbines will typically have injection moulded plastic blades, often in a single piece rotor on the smallest devices. This is a very cheap, strong and long lasting method of making a rotor, but is limited to the size of an injection moulding machine, and so these types of rotors are only seen on turbines up to a few hundred watts.

Larger turbines generally have blade structure that is based on glass or wood laminates.

The aerodynamic shape of the blade is key to a number of the aspects of a turbine's operation, including efficiency, noise, loading and low wind start-up and there can be a 20% - 30% difference between an optimally aerodynamically designed blade, and a simpler shape designed for simplicity or low cost of manufacture. That is 20% - 30% less energy that is available for use.

The construction method is clearly critical in terms of the longevity and robustness of the blades, with many failures of small wind turbines occurring within the blades.

Number of Blades

The number of blades is a hotly debated topic, and designs exist for anything from one to twenty blades.

Single Blade

In principle, a wind turbine can be constructed with only a single blade, and the efficiency (energy per unit swept area) can approach that of multi-bladed rotors. This ought to lead to a cost saving, however in practice there are a number of factors that make a single bladed rotor unattractive: Although the rotor can easily be mass balanced with a counter weight, the aerodynamic loads are not balanced and this can lead to severe dynamic loading. In addition, single bladed rotors are likely to require a higher rotational speed and therefore may be noisier.

Twin Blade

A two bladed concept is easier to balance than a single bladed one, but still has some dynamic issues. In particular, the rotor may be susceptible to severe loading due to yawing. .It is also likely to have high tip speed, and therefore be noisy. Most people consider that a two bladed rotor is less attractive than three blades, and a two bladed rotor can appear to pulsate when rotating and viewed from one side.

Three Blades

By far the most common design for both small and large wind turbines as a three bladed rotor is easy to balance and yaws smoothly.

Multiple Blades

Other designs up to twenty blades are used where operation at high torque and low rotational speed is more important than overall energy generation, typically in water pumping applications.

Generators

Almost all small wind turbines use permanent magnet generators (PMG), usually of the radial flux variety. Some turbines will also have a gearbox to increase the rotational speed of the generator, but this has significant disadvantages in terms of cost, weight, efficiency and reliability and is not generally considered a very good solution for small wind turbines.

The generator is a key issue for the overall efficiency of the system both in terms of losses in the generator, and also any resistance the generator may provide to the turbine starting up in low wind conditions.

The efficiencies of a PMG can vary by as much as 10% - 15% between designs, especially across the entire range of wind speeds that the turbine is designed to operate at.

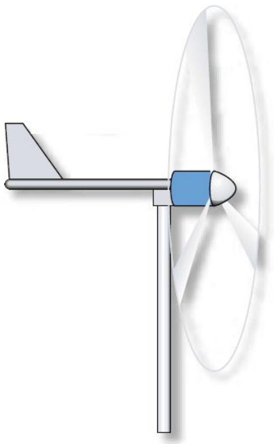
Many small wind turbines on the market today use an “off the shelf” generator, which, whilst it reduces the design time and cost, may not be optimised for the specific characteristics of the wind turbine.

Wind Direction Control

Virtually all small wind turbines use a form of passive yawing, i.e. turning into wind, whereas large wind turbines use wind direction sensors and a separate motor to turn the turbine into wind, but this is not economic or practical for small turbines.

Some turbines are of the downwind design, where the blades and rotor are “naturally” forced downwind of the yaw axis. Such a design however can be unstable in situations where wind-shear arises. Wind shear occurs where the wind speed varies with distance from the ground so that the blades experience greater aerodynamic force at the top of their path than at the bottom.

There is also the risk of a 'thud' type noise which can be heard on some downwind machines as the blades pass through the 'wind shadow' of the tower.



The majority of currently produced small wind turbines therefore are upwind devices, as illustrated on the left, and use a tail fin to force the turbine to face into wind at all times.

This is generally considered the simplest and most reliable system for small wind turbines and, if well designed, doesn’t suffer from the drawbacks of downwind designs.

Iskra’s AT5-1 Turbine

The key design features of the Iskra AT5-1 include:

1. Passive pitch control for over-speed protection and load shedding in high winds.
2. Efficient aerodynamic blade profile, all linked in pitch with a low tip speed for minimal noise
3. Integrated direct-drive generator incorporating over-speed protection brake.
4. A sleek and slender design for low visual impact.
5. Low component count and low mass for minimal production cost.

Each of these is discussed in more detail in the following sections.

Pitch Control

One of the most innovative features of the AT5-1 is the passive pitch control mechanism, which is a patented design unique to Iskra. The main features of which are:

1. The blade is normally fixed at optimum pitch
2. Centrifugal loads pitch to stall to shed surplus power and regulate speed
3. Aerodynamic torque delays power shedding in the presence of generator reaction torque

4. The blades are all linked in pitch to minimise vibrations.
5. Distributed/balanced loads minimise hub deflections
6. The rotor is always aligned with the wind

Over-speed protection and pitch control have been achieved using a clever and light-weight mechanism so as to minimize the overall weight of the elevated structure. This has positive consequences for the responsiveness of the turbine in variable wind and also for the overall cost.

Speed regulation is achieved through an ingenious geometrical arrangement with a spring preload acting against generator torque and centrifugal forces. This protects the turbine both against over speeding and against producing too much power, thus removing any requirement for “dump loads”.

This method of protection works, irrespective of how much power is being extracted by the turbine, in either a grid connected or battery charging application.

Pitch control is achieved through a linkage to ensure that all three blades have the same pitch. This ensures that the turbine is both mass and aerodynamically balanced. Cyclic pitch variation due to the action of gravity in the AT5-1 is not an issue as it is in other designs.

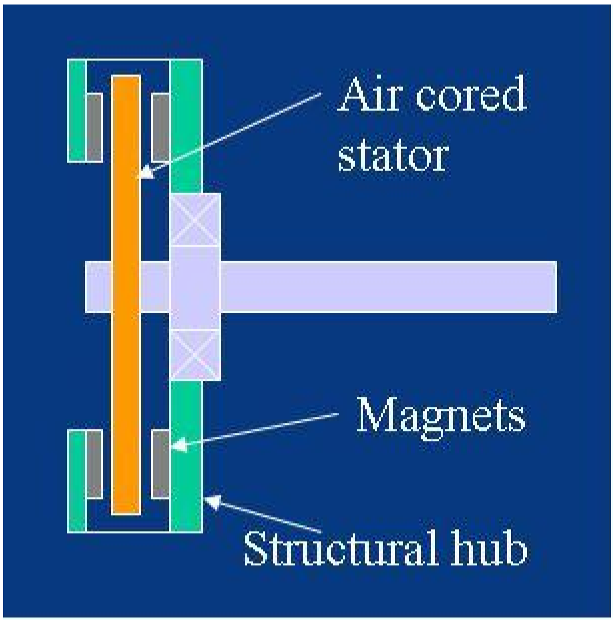
The main benefits of this innovative design are:
1. Energy capture is maximised across all wind speeds below rated wind speed.
2. It provides an effective off-load and high wind speed rpm regulation.
3. Maximum over speed can be comparable to normal running speed, thereby minimising the stress on components.
4. The rotor is always aerodynamically and mass balanced.
5. It makes it much easier to integrate the hub and the generator.
6. Cyclic aerodynamic noise due to yaw misalignment or cyclic pitching is minimised.
7. Cyclic loads are minimised.

Generator

The second major innovative feature of the AT5-1 is the Permanent Magnet Generator (PMG). This is another patented technology, unique to Iskra.

Through a number of innovations, the axial flux PMG developed by Iskra achieves a remarkably high efficiency, in excess of 95%, which has been independently tested and confirmed by members of the Cambridge University engineering department.

The main features of the Iskra generator are:
1. Air cored, so there is no magnetic attraction between stator and rotor
2. Single hub plate that provides both structure and carries the magnetic flux.
3. Innovative arrangement of coils.



This has a number of very important benefits:
1. Very little energy is lost in the generator, which naturally means that more is available to be used.
2. The generator has the capacity to act as a brake that can bring the wind turbine to rest from any operating condition.
3. The temperature rise in the generator is minimised, even at maximum power output.
4. There is a low component count, and therefore low cost of manufacture.
5. There are reduced eddy current losses, and so there is no need for an expensive laminated rotor

Blades

There are three blades per machine, each 2.7m long, which are manufactured by Resin Transfer Moulding (RTM). The blades have been designed with a very efficient aerodynamic blade profile, which both maximises energy generation and minimises noise.

The blades vary in twist and chord along their length to maximise efficiency and thus minimise noise. In particular, the blade chord has been kept as small as practicable near the tip and the blade tips themselves are carefully shaped specifically to minimise noise.

The blade structure is based on a glass/polyester composite, and has a solid core.

The process required to produce blades of this type, in a cost effective manner, is unique to Iskra and is patented.

The composite design for the blades is elaborate, but not unusual for modern wind turbines, and the chosen composite materials have an established track record within the utility sized wind turbine industry.

Brake

The Iskra AT5-1 has a simple, yet innovative brake that uses the generator itself to stop the turbine. This:

1. Can stop the wind turbine in any wind speed, any pitch angle.
2. Can be deployed automatically, or manually.
3. Torque is limited to 3 times the rated torque.
4. Is very cost effective.
5. Is an effective secondary over speed protection system.
6. Has a convenient stop/start button
7. Provides safe braking without risking drive train damage.

Visual Impact

The Iskra turbines are tree-sized devices and the long-distance visual impact is small.

Compared to many other designs, the Iskra design is seen as more pleasing to most people, as it has a sleek profile and the tail angled up is a "happy" posture, much like a dog wagging its tail.

The upwind design of the AT5-1 is preferable to the eye to the downwind design of other turbines, as it looks more natural.

Power Electronics

Key to the success of any energy generation device, is the way it delivers its power to the end user.

Small wind turbines are typically used in one of two modes:

1. On-grid, where the energy generated is used to supplement that extracted from the national grid system.
2. Off-grid, where the wind turbine is used to power only local requirements, in combination with a battery storage system.

These are two very different requirements, that need different power electronic solutions.

The Iskra AT5-1 has been integrated and tested with a number of different on-grid inverters, and the optimum curve of power versus rotational speed of the AT5-1 have been programmed into the inverters of leading manufacturers. This ensures that the maximum power output is delivered in all operating conditions.

The Iskra AT5-1 has also been integrated with an off-grid, or grid-backup, inverter (MWI) from Magnetek, which provides many unique and innovative features, specifically for off-grid and applications:

1. The wind turbine and/or the PV panels will recharge the battery pack, and the built-in 5kW inverter supplies power to the connected AC equipment.
2. If the battery pack falls below a pre-defined voltage, then the generator will be switched on and the generator will drive the connected AC equipment directly, as well as re-charging the battery pack.
3. When the battery pack returns to full charge, the generator is switched off and the loads are then once again driven by the 5kW inverter.

Serviceability

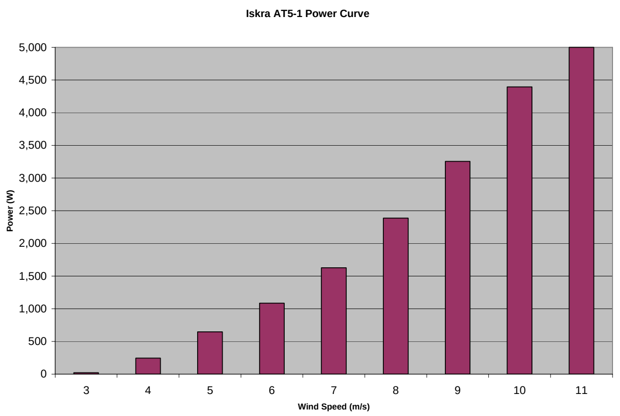
The Iskra AT5-1 has been designed for a service life in excess of 20 years, and many parts may be expected to last a lot longer.

An annual service and inspection is required to ensure that the turbine is operating normally and is not subject to unexpected wear. This however is a simple procedure, that can be carried out by a single trained technician in under an hour, and would normally only involve the re-application of grease to the main bearings.

The AT5-1 has been designed to operate in a range of environmental conditions, including extremes of temperature and wind speed, and normally no special precautions or procedures need to be applied to ensure it lasts for its designed service life of 20 years.

Power Curve

Shown below is the power curve of the Iskra AT5-1 showing how much power the turbine will generate for any given wind speed.

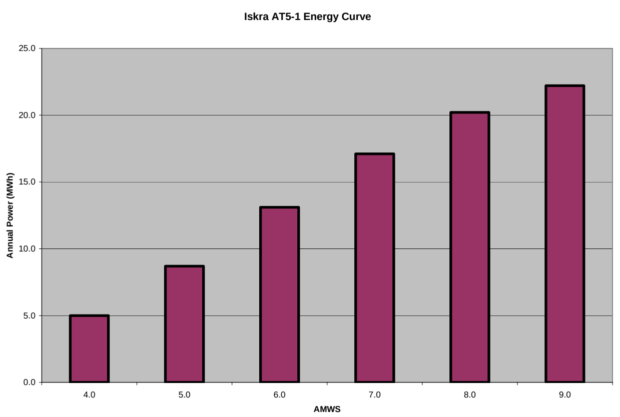


This shows that the AT5-1 reaches its maximum power at 11m/s, which compares very favourably to other turbines, but that it also generates nearly 90% of its rated power at 10m/s and 75% at 9m/s. This is crucial to the annual energy capture, as these slightly lower wind speeds occur for a significant proportion of the time.

Energy Curve

It is vital however to compare turbines, not on their power curve, but on their energy curve. This shows the annual energy that the turbine will generate for any given annual mean wind speed. This takes into account the effectiveness of all the design features of the turbine, and provides the best answer to the key cost per kWh question.

Shown below is the energy curve for the Iskra AT5-1.



Specification

Summarised below are the key specifications of the Iskra AT5-1 turbine.

Generator rating	5 kW at 11 m/s
Rotor speed	200 rpm nominal (variable)
Cut-in wind speed	3 m/s (6.7 mph)
Survival wind speed	60 m/s (134 mph)
Rotor diameter	5.4 m
Rotor orientation	Upwind
Number of blades	3
Blade material	GRP composite
Control system	Passive blade pitching
Gearbox	None
Brakes	Electro-dynamic
Generator	Permanent magnet
Yaw control	Tail vane
Tower height	From 12 or 15 m.
Tower	Free-standing or guyed.

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