Session Eight:

Remote Power Supply Case Study: Wind Turbines at Australia's Mawson Station, Antarctica

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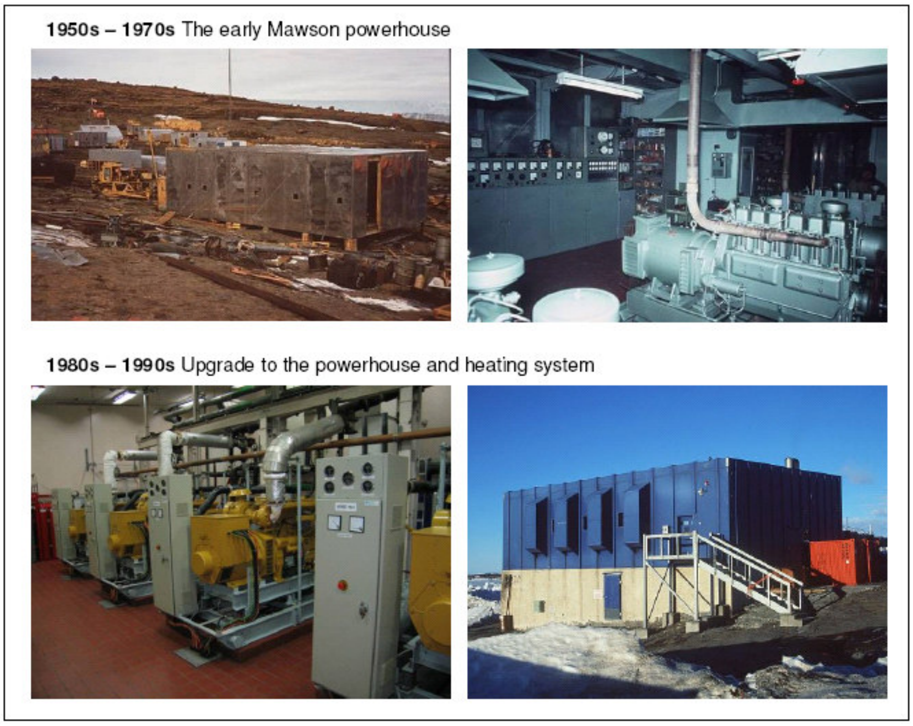
Australia's Mawson station was the first Antarctic station to derive a significant proportion of its energy from a renewable source. Two 300 kilowatt wind turbines have been providing electricity and heat to the station since 2003. This paper will give an overview of the Mawson wind turbine and power system technology, will explore some of the unique design and installation challenges which were encountered in the initial phases of the project and will also discuss the ongoing contemporary challenges of operating a wind-diesel power supply in one of the most remote and isolated places on Earth. These include the integration of the existing diesel power system with modern wind turbine technology and control systems; the trade off between achieving supply stability and achieving maximum wind penetration; and the complex and often unpredictable logistics of operating in Antarctica.

Powering Mawson Station: 1954 to 2009

Mawson is the oldest continually inhabited station on the Antarctic continent. From its inception in 1954, Mawson was powered by diesel generator sets. In the 1980s and 1990s, an extensive rebuilding programme across Australia's three Antarctic stations saw the Mawson power system upgraded to include new main and emergency powerhouses, a new ring main and a new "site services" water reticulation and central heating system. This energy system was in place when the wind turbine project commenced several years later.



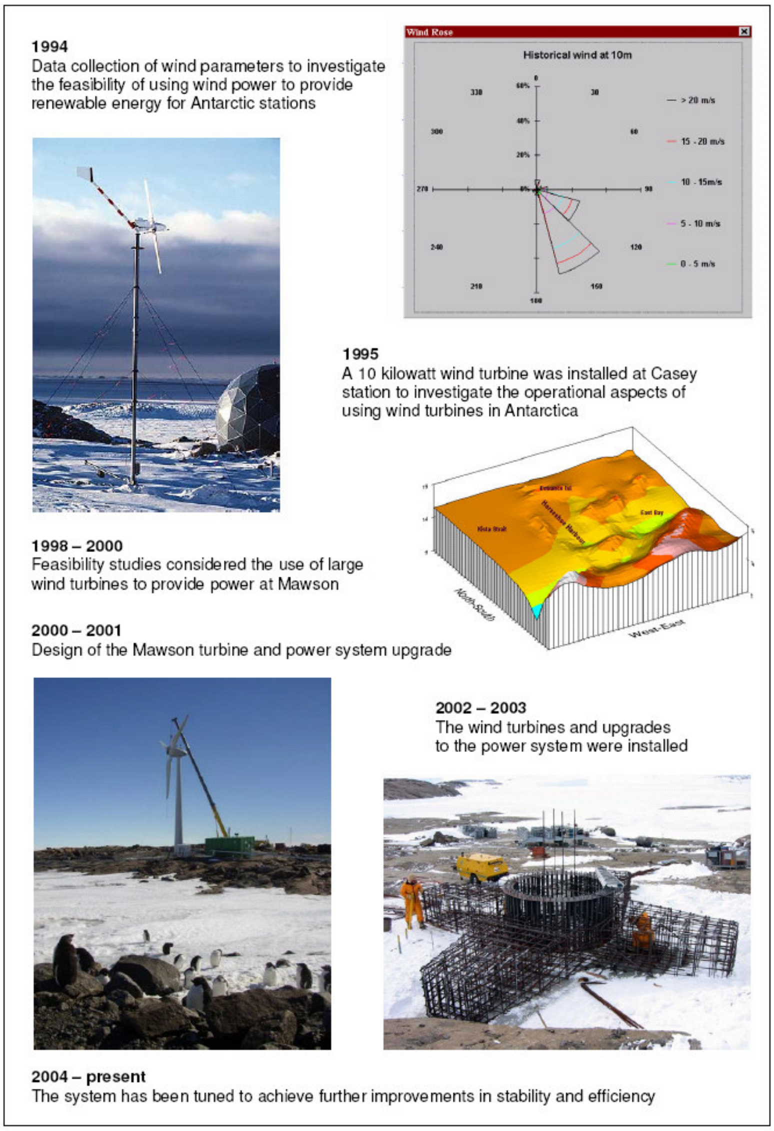


Figure 1 – Timeline of energy supply and wind turbine development at Mawson

The Driving Factor for Wind Turbines at Mawson

Mawson was selected as the best site for wind turbines because of the strong katabatic wind regime which blows at the station. Monthly average wind speed varies from 9.6 metres per second to 20 metres per second. Katabatic winds are produced when cold dense air formed over the ice cap is pushed downhill under the influence of gravity towards the coast. As air reaches the flat coastal areas and the sea beyond, the driving force of gravity is lost and the winds quickly subside. Mawson's location on a strip of rocky coast with the ice cap rising steeply behind the station makes it an ideal location to take advantage of katabatic winds for renewable energy generation.

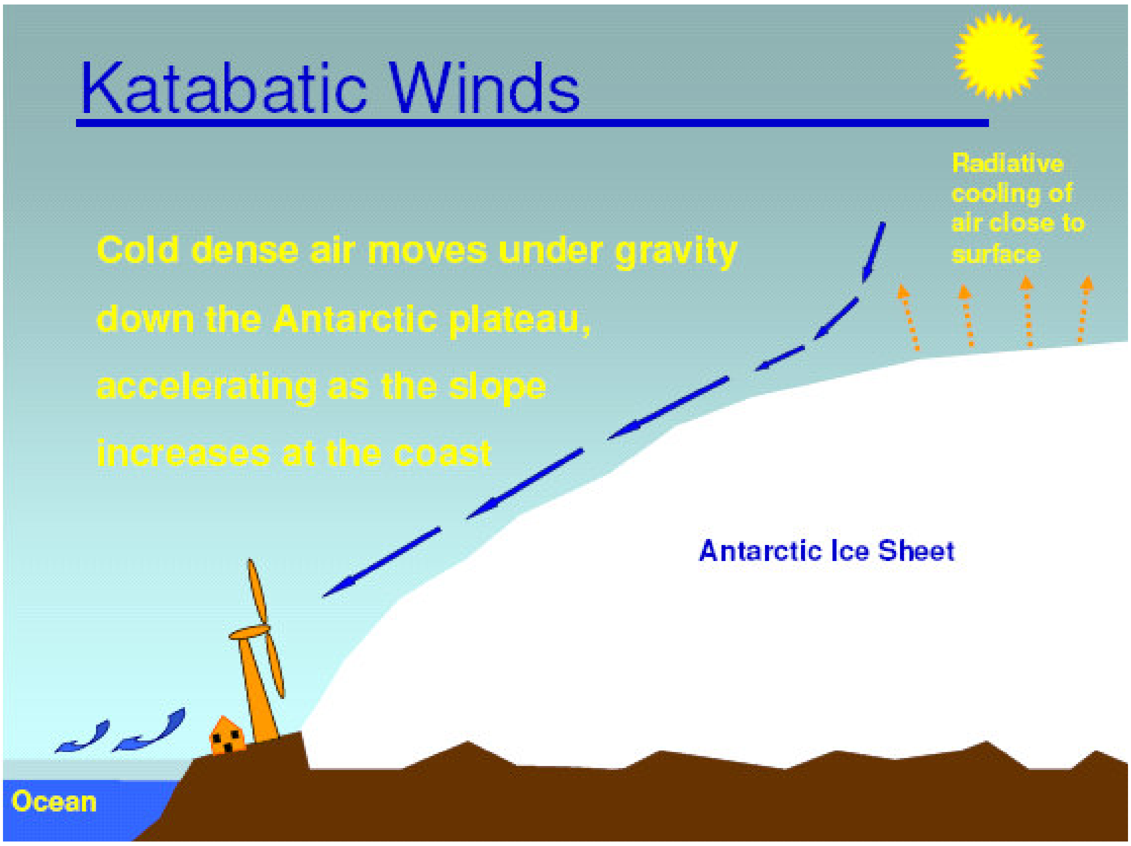


Figure 2 – Formation of katabatic winds

Each year, the Mawson wind turbines save around 160,000 litres of diesel resulting in substantial cost savings as well as reducing the station's carbon dioxide emissions by 500 to 600 tonnes per year.

As a direct result of these fuel savings, refuelling and supply delivery by ship is now required only every second year, whereas in the past it was required annually. On alternate years, personnel and light cargo are delivered by air from Davis station, resulting in significant cost savings compared to a supply voyage by ship. Reducing the number of refuelling operations also reduces the risks of fuel spills which can occur when fuel is pumped through a flexible hose over water between the ship and station.

The Original Power System

Prior to the installation of the wind turbines and the new control system, the main powerhouse comprised four 128 kilowatt diesel gensets with a sequencer to bring on as many sets as necessary to meet the station power requirements. The station electrical load was typically around 180 to 250 kilowatts, with an additional heating energy requirement of around 250 to 350 kilowatts. A large proportion of this heat was provided by a cogeneration system. Heat exchangers on the engine cooling water circuits captured excess heat produced by the gensets and this was used to heat the station buildings through a recirculating water central heating system. This cogeneration of electric power and heat provided an efficient use of diesel fuel - for every kilowatt of electrical power produced, a kilowatt of heat energy was captured. Diesel fired boilers in the powerhouse provided a boost to the central heating system when the heat from the gensets was not sufficient. The powerhouse control system comprised electronic genset speed and voltage controllers, electronic sequencing, and a programmable logic controller handling powerhouse alarms and genset fault shutdown, however there were no elements of digital control.

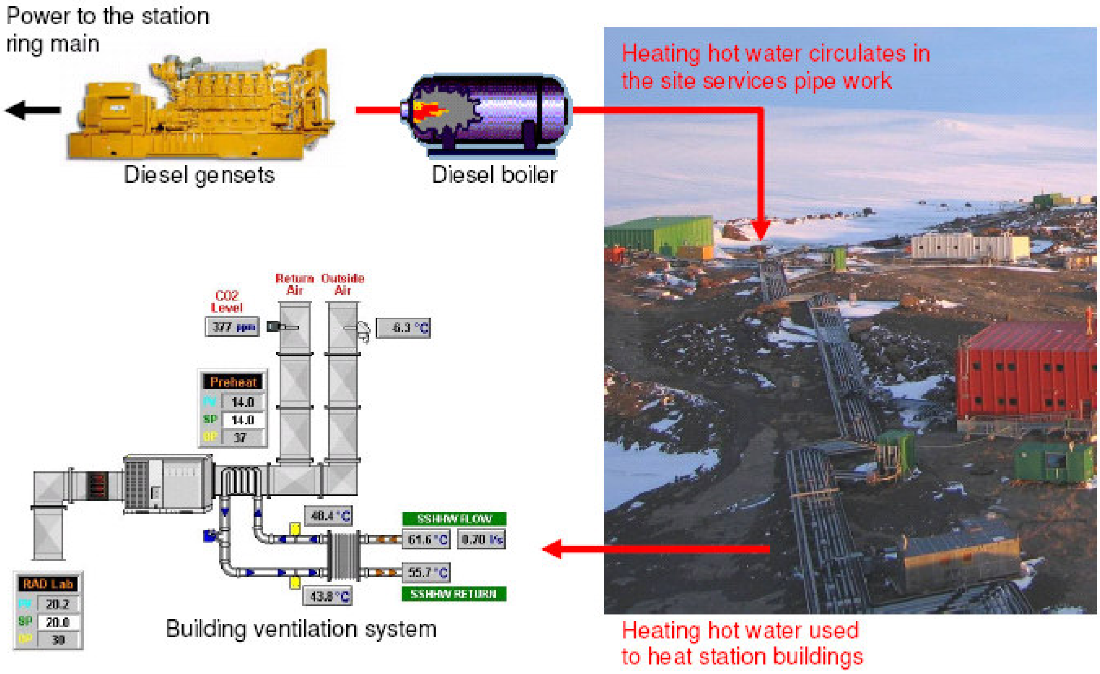


Figure 3 – The original diesel cogeneration system at Mawson

Design Considerations

A number of key considerations were identified at the beginning of the design process for the new wind farm:

- The existing main powerhouse, gensets and station heating system would be retained and integrated with the new wind turbine technology by linking these elements through a new control system.

- Due to the small ice-free area at Mawson, environmental considerations and the location of existing station buildings, only a few sites were available for the construction of wind turbines, hence the design would use a small number of large turbines rather than many small turbines.
- It was decided that the turbines had to be available "off-the-shelf', with minimal modification required for operating in Antarctica.
- Experience with the experimental 10 kilowatt turbine at Casey had highlighted potential problems with servicing or replacing the gear box in a wind turbine, so it was decided to proceed with direct drive turbines.
- The turbines and associated construction equipment had to be shipped to Mawson.

Integration Considerations

The proposed wind farm design aimed to provide a large proportion of the station's electrical energy requirements. However to account for the variability in wind speed and the resultant variability in available wind power, the design required that a diesel genset would constantly run at low power to provide spinning reserve in case of sudden drops in the wind. But with the genset running only at low power when wind energy was available, the amount of co-generated heat for the station would be substantially reduced. Thus the net benefit of the wind turbines would be reduced by the need to provide additional diesel-fired heating. This problem was addressed by incorporating a demand-managed electric boiler into the design. The boiler and its associated "Boiler-Grid Interface" (BGI) would heat the station's central heating hot water when excess wind power was available. Another feature of the BGI was its role as "pseudo spinning reserve". In the event of a sudden drop in available wind power, the electrical load of the boiler would be quickly reduced, thereby allowing the single genset and remaining wind power to supply the base station load. When available wind power increased, the boiler load would be increased again. During favourable wind conditions, the turbines would largely replace both the electrical power and the heating components of the diesel cogeneration system.

The BGI uses a power electronic converter to convert between the three phase AC mains to a DC supply to the boiler elements. The boiler load is calculated according to heating requirements and the available excess wind power. Fast load shedding is achieved through frequency sensitive control. A sudden, transient loss of wind power will result in a drop in power frequency. This is detected by the BGI which immediately reduces the boiler load. When wind power is restored and the frequency returns to normal, the heating load is returned to previous levels.

Turbine Modifications for the Antarctic Environment

While Antarctica provides the katabatic wind resource for power generation, it also presents a very harsh environment in which to install and operate machinery. Temperatures occasionally fall to -36°Celsius and winds speeds reach 200 kilometres per hour. The off-the-shelf wind turbines chosen for Mawson required a number of modifications to make them suitable for use in Antarctica.

- The tower height was reduced from the manufacturer's standard to better capture the most powerful katabatic winds.

- Brush seals were fitted around the top of the tower to prevent snow ingress into the nacelle.

Figure 4 – Brush seals between the nacelle and tower

- Low temperature steel was used in the footings, tower and internal brackets.

- The turbine was fitted with rubber bearing seals and grease designed for low temperatures.

- A heater was installed in the nacelle and the nacelle walls were insulated.

- Abrasion from blowing snow was considered when evaluating suitable turbines. The exterior coatings were considered adequate and did not require modification.

- Ice build up on the blades was also considered, but was not found to pose a problem. The dry atmosphere does not allow ice to build up.

- An extra "cold-porch" entrance was to be installed at the base of the tower. This would allow people to enter the turbine in snowy conditions without allowing snow into the base of the tower. The double door also provided redundancy and protection against snow ingress if door seals failed.

- The wind turbines were initially programmed to shut down at wind speeds greater than 15 metres per second. Since Mawson regularly experiences winds at speeds above this threshold, the turbine operational parameters and software were modified to enable them to operate in high winds. The high wind speed shutdown threshold was raised, and the turbines were programmed to extract more power from high winds through control of the excitation current and blade pitch.

Shipping and Installation Challenges

Constraints on shipping, and the facilities and plant available for turbine installation were taken into account during the project design. The capacity of the ship would impose a size limit on the turbines and with no cargo port at Mawson, equipment would have to be offloaded by the ship's crane and transported ashore by barge. There was also a limited capacity to transport large items on shore at Mawson. When all of these were considered, the limiting factor was found to be the size of the crane which would be used to construct the turbines, and this in turn was limited by the maximum lifting capacity of the ship's crane.

It was critical that the installation ran according to schedule, as only a short work window was available during the summer months. Practical difficulties included pouring concrete foundations in sub zero temperatures. Hot water is used and after pouring, the concrete has to be insulated and the surface kept heated by gas-fired fan heating. High winds posed another challenge, with the installation procedure heavily reliant on crane operations.

Figure 5 – Turbine installation

System Overview and Performance Summary

Figure 6 below gives an overview of the Mawson wind turbines and the upgraded energy system. On a typical windy day, the control system will maximise the wind turbine power output, but will also keep one genset running as spinning reserve. Heating will be provided by the electric boiler, with the BGI and control system adjusting the boiler load according to available wind power. Heat will also be captured from the genset. If wind power decreases, additional gensets will be brought online and the diesel boiler will provide a boost to the heating system if required.

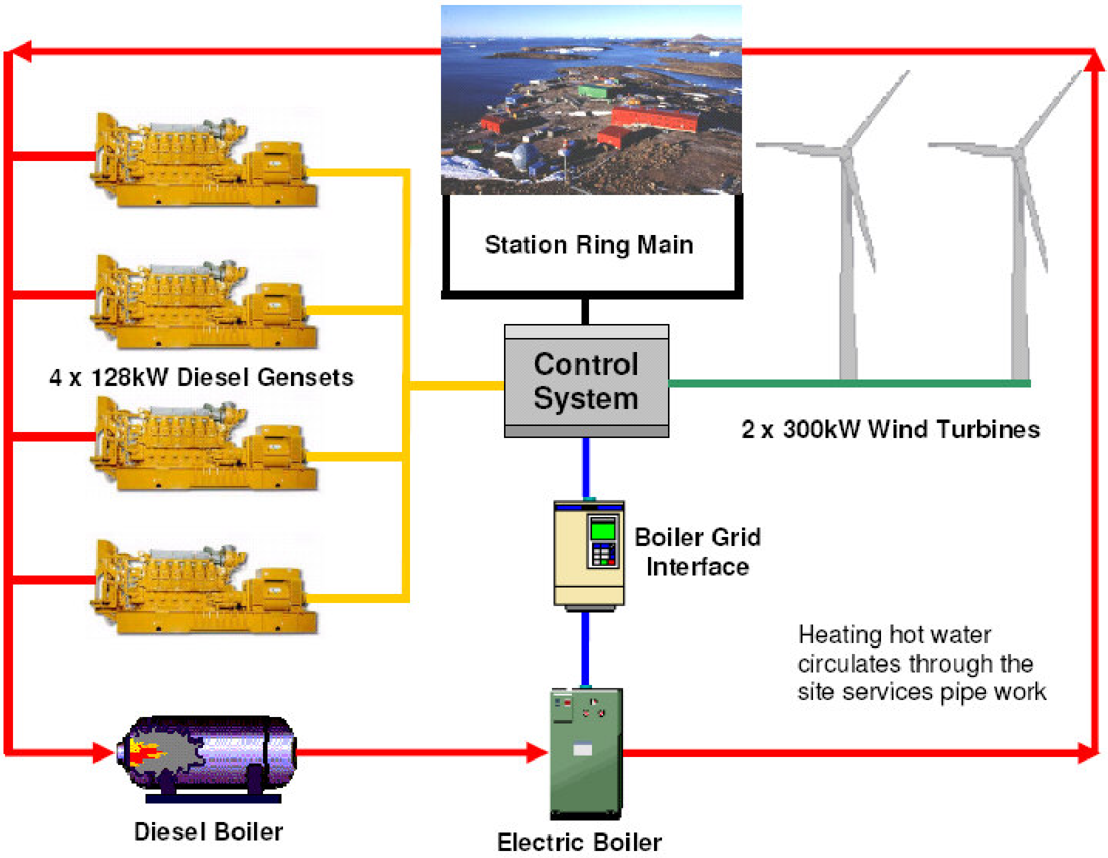


Figure 6 - Overview of the upgraded power system

In the past five years, the Mawson turbines have provided an annual average wind penetration of between 33% and 39%, with a best monthly average of 60%. These averages represent the contribution by wind power to the total station load, both electrical and heating. Figure 7 below shows the 2008 average monthly wind penetration as a percentage of total station heating and electrical load, the resulting fuel savings and the wind speed. High wind speed usually results in high wind penetration and fuel savings, however the data for July shows comparatively low penetration and fuel savings despite high average wind speeds. This behaviour was due to particularly gusty winds during July. Winds of this nature cause instability in the power system resulting in lower wind penetration. This will be discussed in more detail in the following section.

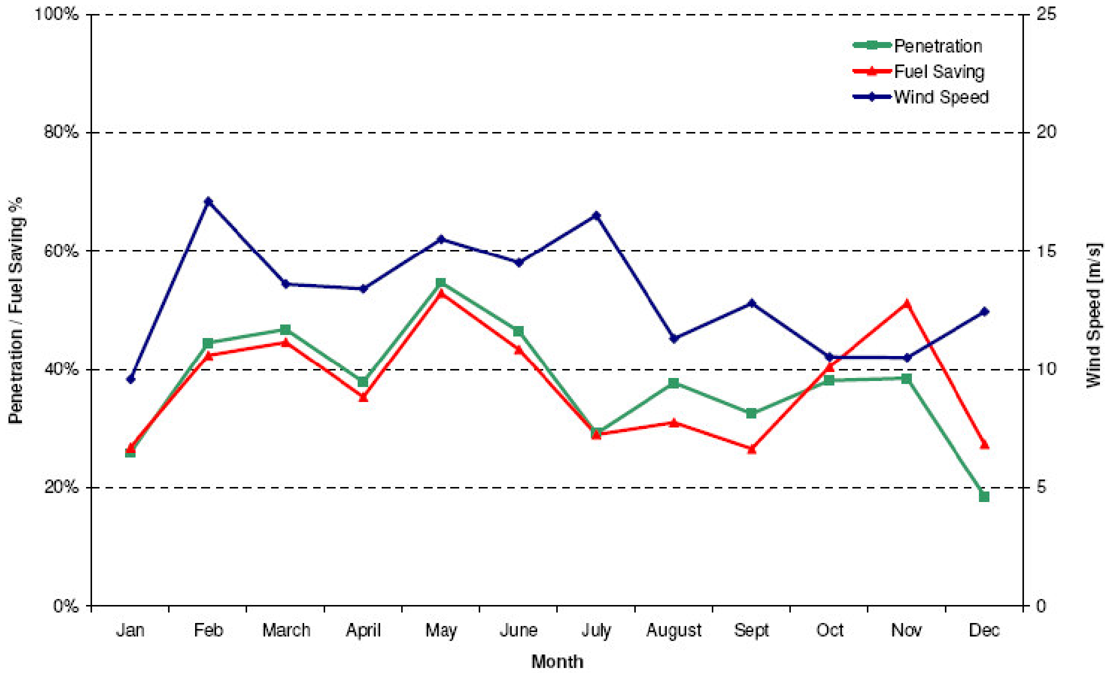


Figure 7 – 2008 wind penetration, fuel savings and wind speed monthly averages

Problems With Stability

While Mawson has very favourable conditions for operating a wind farm, the wind can be extremely gusty and unsteady. The turbines cannot maintain a steady power output when they encounter sudden lulls, nor can they respond quickly enough when the wind changes direction suddenly. This translates to an unsteady supply of available wind power. To stabilise the station supply, one 128 kilowatt diesel genset is run at all times to provide spinning reserve, typically at a minimum load of 50 kilowatts. The station load is spread across two feeders, with the demand-controlled electric boiler supplied by a third feeder. If the wind power drops, the load consumed by the electric boiler will be quickly reduced, effectively diverting more power into the station load by drawing on the "pseudo spinning reserve". If the lead genset still cannot provide sufficient power, the control system will start and synchronise a second genset. Glowing, starting and synchronising a genset takes around 30 seconds, so the control system may not be able to bring the second genset online fast enough to meet the load requirements. In this case, the control system will shed one of the station feeders and the non-essential supply will be interrupted. If the load on the remaining feeder is still too high, the station experiences a full blackout.

In most instances of dropping wind power, the control system is able maintain the supply by drawing on the spinning reserve and by bringing the second genset online in time, however power outages do occur and the rate and number of occurrences is unacceptably high.

The station is equipped to deal with power outages. Critical equipment is connected to standalone battery powered uninterruptible power supplies, and these supplies and the equipment are monitored by a fault detection and alarm system which will notify station electricians if equipment suffers a fault due to a power outage. However all power outages require manual intervention by an electrician to reset circuit breakers in the main powerhouse. Moving between station buildings at Mawson means walking outside and this can be hazardous, particularly in darkness or in windy or snowy weather. So apart from being disruptive and causing fatigue for the electricians, attending to a power outage involves an element of risk.

Figure 8 – Mawson expeditioner battling the strong wind and blowing snow

Towards a More Stable System

The most simple and immediate way to address this problem is to configure the control system to run two gensets, thus eliminating the need to start and synchronise the second genset in time to avoid an interruption to supply. This approach is currently used on station during periods of particularly gusty winds.

Some degree of stability improvement may be possible by adjusting the control system tuning parameters. The focus of this adjustment would be to speed up the electric boiler load shedding in response to a drop in wind power. Tuning efforts would also investigate the algorithms which control the issue of a start command to the second genset. While the current hardware is physically limited by the 30 second start and synchronisation time, stability improvements may be possible if the start command were issued more quickly in response to a drop in wind power. In reducing this response time, care would need to be taken to ensure that the system did not start the second genset unnecessarily, as this would result in higher fuel consumption.

Hardware upgrades to provide an increased and faster responding spinning reserve capacity would give the greatest improvements in stability. Possible upgrades include a flywheel, fast start diesels, or low load diesels. These options will be explored as the existing gensets in the station powerhouse become due for replacement.

A greater and faster spinning reserve capacity would allow the wind turbines to deliver maximum power in gusty conditions. This would improve the wind penetration and fuel savings compared to the current situation where two gensets must be run during gusty conditions. A project to upgrade hardware would also consider the possibility of running the system as a wind-only configuration with diesel backup. If this could be implemented the result would be even greater wind penetration and fuel savings.

Isolation and the People on the Ground

The isolation and difficulty of access which posed challenges for the installation of the turbines are also significant factors to consider in operating and maintaining the system. Between March and December, sea ice extends up to 80 kilometres out from the coast at a thickness of up to 2metres, making ship access virtually impossible. There is no air access to Australian Antarctic stations during the winter months. In some seasons, the sea ice remains frozen and intact throughout the summer, meaning that a planned supply voyage might not make it to the station.

Figure 9 – The icebreaker Aurora Australis en route to Mawson through sea ice

Spare parts for the turbines and specialised tools or plant for carrying out repair work must be kept on station, otherwise there may be as long as a nine month delay before there is any opportunity for delivery.

During the summer period when ship supply operations are generally possible, there are competing shipping priorities. Even when a supply delivery is planned and scheduled, factors such as bad weather can force a complete change to voyage plans meaning that supplies might not reach station.

The same uncertainties apply for delivering personnel to Mawson. The wind turbines are maintained by a small team of two three 3 electricians. Most of the preventative scheduled maintenance is undertaken during the summer months of December, January and February when there are usually three electricians on station. During winter, two electricians maintain the turbines however there are many additional demands on their time – maintaining other elements of the power system, building electrical services, fire alarm systems, lighting, control and monitoring systems and water pipe heat trace systems.

Preventative maintenance on the wind turbines is particularly important because if major faults were to develop, this might require the turbine to be dismantled for service. There is currently no crane at Mawson suitable for this task, making prevention even more important.

The Antarctic environment presents a number of difficulties for maintenance electricians. The turbine can only be ascended when winds speeds are below 8 metres per second. Long periods of calm weather are quite rare at Mawson, so a fault in the turbine may have to wait some time for a suitable weather window to allow repairs to be carried out. In winter, the low temperatures mean that electricians can only work outside for short periods of time. After taking into account the time for ascending and descending the tower there may be less than an hour for working in the nacelle. There is limited space in the nacelle, and moving around is made more difficult by the bulky warm clothing necessitated by the cold. Working on delicate machinery is difficult with gloves on. Wires, cables, metals and plastics become hard and brittle in sub zero temperatures. All of these factors mean that seemingly simple tasks are in fact difficult and take significantly more time than they would in normal conditions.

Figure 10 – At work in the nacelle

Recruiting, training and supporting electricians poses another challenge. It is no easy task to find enthusiastic people who possess a broad range of electrical experience as well as equally important interpersonal skills; who are medically fit and whose personal circumstances are suited to spending an extended period in this isolated location.

The electricians undergo an intensive period of training. Not only do they need to undergo training in wind turbines and other electrical systems, they need to be equipped with other skills which are vital to the safe operation of this small isolated community. These include fire fighting, nursing (theatre assistant and anaesthetics), boating, Antarctic vehicle travel and survival techniques, and search and rescue. These training courses are undertaken in Australia, and the electricians do not arrive at Mawson until between four and six weeks after departure, due to the long sea voyage. Upon arrival they have to quickly assume responsibility for the station electrical systems. The end result is that there may be several months between completing wind turbine training courses and actually commencing work on the Mawson turbines.

All of this adds a new dimension of complexity to managing the Mawson power system – not only does it involve Antarctic engineering issues but is closely linked to Antarctic human resources and logistics. The uncertainty and difficulty of operating in Antarctica is known within the Antarctic community as "The A-Factor".

Despite the challenges posed by cold, remoteness and isolation, the Mawson wind turbines and power system upgrade have been an ongoing success.

Design, transportation and construction difficulties were overcome to install and commission the system. The BGI has substantially increased the wind penetration by allowing the wind turbines to provide the heat previously extracted from the diesel cogeneration system. The BGI also works in its role as "pseudo spinning reserve", however the unstable winds and limitations of the original diesel gensets mean that the power supply suffers from instability and power outages. These outages cause few problems for the electrical services on station, however they do cause fatigue for the station electricians. The issue of instability will be addressed in terms of control system tuning, and hardware upgrades.

Reduced fuel consumption has provided substantial environmental benefits and cost savings. Station refuelling operations now only need to be carried out every second year, reducing the likelihood of a fuel spill, and saving on shipping costs. Operating at a wind penetration of 35%, the turbines save around 160,000 litres of fuel per year.

The engineering challenges will continue as further upgrades are undertaken to improve the system stability. These upgrades will also increase the wind penetration and hence provide even better fuel efficiency. This all points to a promising, challenging and environmentally sound future for the wind turbines and energy system at Mawson.

Australian Antarctic Division

Operations Emergency Meeting (Scenario)

INTERACTIVE SESSION

Representatives present from engineering, shipping, station management, polar medicine, human resources and executive.

20th March 2013

The wintering team of 17 people at Mawson farewelled the last ship of the season 10 days ago. The ship delivered food and supplies and picked up those people going home at the end of the summer season.

The ship was meant to deliver 300,000L of diesel fuel to the station, but refuelling could not be undertaken. During a pressure test of the fuel hose prior to refuelling, the hose ruptured. While this could have been repaired, a close inspection of the hose revealed a further eight weak points where the hose could burst and cause a fuel spill. These could not be repaired.

Calculations and predictions showed that Mawson would have sufficient fuel to last until the next resupply opportunity in November, however there would only just be enough fuel, and the calculations relied upon a large contribution to power from both wind turbines.

It was decided that the environmental risks were too great to proceed with refuelling. The station would therefore have to manage with limited fuel supplies for the winter, and the electricians would need to ensure that maximum power was provided by the wind turbines.

With the ship 10 days into the voyage back to Australia, one of the wind turbines has suffered a major fault with main rotor bearing and cannot generate power. The turbine will be out of action until the bearing is replaced.

There is a spare bearing on station, but replacement is a major undertaking and requires the nose cone and blade assembly to be removed with a crane. The crane at Mawson does not have the lifting capacity to remove the assembly in one piece, so each blade will have to be removed individually, followed by the nose cone. Repairs of this scale are usually carried out by an experienced team of 15 people. The work usually takes around 30 hours in ideal weather conditions and with a large crane which can lift the blade assembly in one piece.

The Mawson team comprises 2 mechanics, 2 electricians, 2 plumbers, 1 carpenter, the station leader (a bank manager), the doctor, the chef, 2 communications technicians, 2 weather observers, 2 microbiologists and 1 visual artist. The mechanics are licensed to operate the crane, but both only obtained their tickets just prior to coming to Antarctica, and have minimal operating experience.

Consider these three options:

1. Turn the ship back to Mawson and refuel the station

- This would make the ship at least 23 days late getting back to Hobart. The cost for exceeding the ship hire period is $150,000 per day.
- There are 104 people on the ship who are returning to Australia after an extended time in Antarctica. Some of them have been away for 18 months. Most have arranged to meet their families upon arrival in Hobart.
- Risk of fuel spill. Any spill would necessitate an immediate clean up operation. There would be long lasting environmental damage further costly clean ups for years to come.

2. Attempt to repair the wind turbine

- Consider the skills and experience available.
- At this time of year there are 6 hours of daylight and maximum temperatures are around -12 degrees.
- While the nose cone is removed, snow can enter the nacelle. If a blizzard occurred while the nacelle was open, snow ingress and wind could cause serious damage to the turbine.
- Essential station services have to be maintained, and people need to eat.

3. Manage with 1 wind turbine until November

- The heating would have to be shut down to all buildings except the living quarters. The workshops, science lab, and offices (station leader, weather, communications) would be maintained at just above freezing. The living quarters would be maintained at 15 degrees.
- The microbiologists would have to abandon their winter research project. The project requires large amounts of hot water and there simply would not be enough energy to produce this water. They have spent 4 years planning the project and preparing for this winter.
- If there is a problem with the second wind turbine then heating would have to be completely cut off to all buildings except the living quarters which would be maintained at just above freezing. This could result in frozen pipes and pumps throughout the station.