1 kW Wind Turbine (12.5 m/s)
2-Blades (Carbon fibre), 1.8 Metre Diameter
& Induction motor to PMA conversion

Abstract

A 1 kW @ 12.5 m/s (2 kW @ 17 m/s), 1.8 metre diameter wind turbine was designed and constructed using carbon fibre composites. The generator was built by converting an induction motor into a permanent magnet generator. Blade power and efficiency have been measured at different tip-speed-ratios and a maximum efficiency of 30% at a TSR of 11.6 was recorded. These results verify the accuracy of calculations from the blade calculator software. Total cost of the generator and blades was less than AU$200.

Keywords: Wind power, Permanent Magnet Generator, Induction motor to PMA conversion, 1kw wind turbine, carbon fiber wind turbine blades

LIST OF FIGURES

1. Construction of the Permanent Magnet Generator

Design of a permanent magnet generator was necessary to test and characterise the blade set. Conversion of a 40 amp car alternator to a permanent magnet generator was attempted.

The alternators rotor was turned down on a lathe to accommodate neodymium magnets.

Figure 1. 40 Amp car alternator rotor with magnets attached

- Six magnets were carefully place on a slight angle to reduce cogging of the generator.

Figure 2. 40 Amp car alternator rotor with magnets fibre glassed in place

- The magnets were fibre glassed in place with two strips of carbon fibre.

Figure 3. 40 Amp car alternator stator with shielding

Sheet metal was placed inside the stator to shield the magnetic field from aluminium.

Without the sheet metal lining, significant power was lost in the aluminium.

[Design Your Custom Wind Turbine Blades]

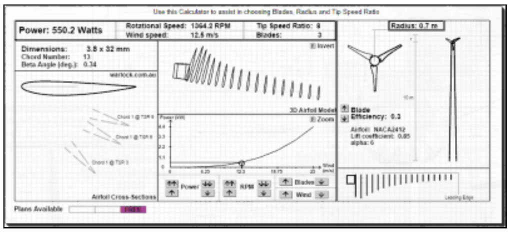


Figure 4. Completed conversion of the 40 Amp car alternator

Power output was measured to be less than 500 watts at the rpm of the designed blades. The generator will not produce enough power for the 1.8m diameter blades, it is more suited to 1.0m diameter blades with a high tip-speed-ratio.

Figure 5. Completed conversion of a 1/4 hp induction motor

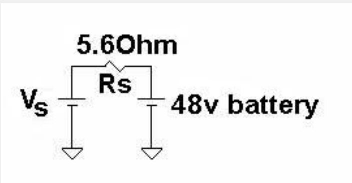
The same technique was used to convert a larger 1/4 hp induction motor into a 8 pole / 3 phase PMG.

Power output was measured to be more than 2000 watts at the rotational speed for the designed blades. This generator produces enough power for the 1.8 m diameter blades.

The generator has zero cogging, this is due to the angled magnets and the 2mm air gap between the rotor and stator. It is configured for 3 phase, each phase measuring 5.6 ohms. Output voltage is 130 Vrms at 1333 rpm, increasing linearly with rpm.

2. Calculating generator efficiency

Given: The 3 phases are isolated and connected as 3 single phase outputs. Each output is rectified to DC using a single phase bridge rectifier.



At 666rpm, generator voltage V_s = 65 Volts.

R_s = resistance of each phase of the generator (5.6 Ohms)

Voltage across R_s = 65 - 48
V_s = 17 Volts

$V = IR$ rearranged to; $V/R = I$

Current into battery = 17/5.6
I = 3 amps per phase

Calculate power using; $P = VI$

Power into battery = 48 x 3
P = 144 watts per phase
(432 watts for all 3 phases)

$P_{loss} = V^2/R$
Power Lost = 172/5.6
P_{loss} = 51.6 watts per phase

Efficiency of generator = 144/(144+51.6)
Efficiency = 73.6%

3. Design and construction of the wind turbine blades

The wind turbine blades were designed using the warlock engineering blade calculator program. The airfoil chosen was NACA2412 and a two bladed turbine was designed to have a tip-speed-ratio of 10.

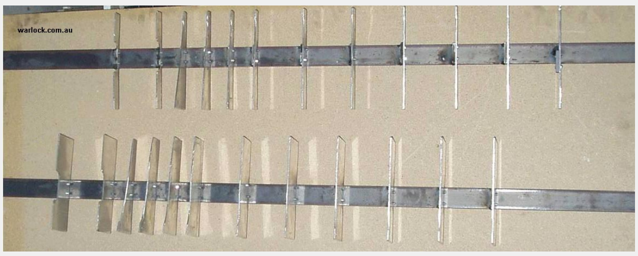


Figure 7. Wind turbine airfoil cross-sections bolted to a frame

Figure 6. Wind turbine airfoil cross-sections

The airfoil cross sections were cut out of 3mm aluminium sheets. These sheets were bolted to a steel frame, spaced at appropriate distances and aligned.

Figure 8. Positive moulds of wind turbine blades

The gaps between the airfoil sections were filled with aluminium tape and the back of the tape was fibre glassed in place. Wax and mould release was applied to it and two positive moulds were made.

The moulds were sanded down using the aluminium impressions as a guide. Wax and mould release was applied to the positive moulds (in Figure 8) and new negative moulds were made out of fibreglass and carbon fibre (Figure 9).

Figure 9. Negative moulds of wind turbine blades

Figure 10. 1.8 m blade set

Careful detailing of the positive mould produced a perfect negative mould. This final negative mould was waxed and mould release was applied. CSM fibreglass (220 g) with vinyl ester resin was applied to each mould. The two mould halves were clamped together after the resin had gelled and the blade was removed after curing.

The blades were sanded and wrapped in carbon fibre, using an additional carbon fibre layer around the hub section. The finished blades are extremely light weight.

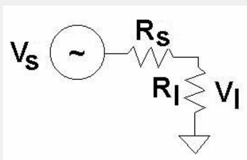
4. Testing the wind turbine

The wind turbine was bolted to a trailer and the rpm, voltage and tsr was measured by connecting the generator to a very high power multi-tap resistor. The turbine was allowed to speed up to an open circuit voltage of 65 V (666 rpm) before the resistor load was connected.

Figure 11. Turbine testing

Measurement of results from the wind turbine

Note: Our method of turbine testing generated turbulent wind, affecting efficiency. The results should be used as a guide only



R_s is the resistance of the generator windings plus the power cable; 5.75 ohms
R_l is the resistance of the load; 6.6, 10, 15, 21.5 and 25 ohms

Once the blades have been characterized a new generator will be designed.

Power generated by the blades was calculated by dividing measured power by the efficiency of the generator.

Power generated by the blades is calculated using the following method:

Voltage across the resistor load was measured (V_l),

$$V_s = V_l \times [(R_s + R_l) / R_l]$$

Power produced by blades and lost in generator, power cable and resistor load is given by;

$$P = V^2/R$$

$$P = V_s^2 / (R_s+R_l)$$

The results from the wind turbine test are included below.

	25 ohm	21.5 ohm	15 ohm	10 ohm	6 ohm
30 km/h	820	766	809		
40 km/h	1302	1363	851	645	
50 km/h	1753	1676	1489	1291	1105
60 km/h		2365	2098	1744	1607

Rotational speed (rpm)

	25 ohm	21.5 ohm	15 ohm	10 ohm	6 ohm
30 km/h	208	205	300		
40 km/h	524	649	332	252	
50 km/h	950	981	1017	1008	940
60 km/h		1953	2019	1873	1990

Power (watts)

	25 ohm	21.5 ohm	15 ohm	10 ohm	6 ohm
30 km/h	0.23	0.23	stalled		
40 km/h	0.24	0.30	0.15	stalled	
50 km/h	0.22	0.23	0.24	0.24	stalled
60 km/h		0.27	0.27	0.25	0.27

Blade efficiency

	25 ohm	21.5 ohm	15 ohm	10 ohm	6 ohm
30 km/h	278	260	275		
40 km/h	441	463	289	218	
50 km/h	595	569	506	438	375
60 km/h		803	712	592	546

Tip speed (km/h)

	25 ohm	21.5 ohm	15 ohm	10 ohm	6 ohm
30 km/h	9.2	8.7	9.2		
40 km/h	11.0	11.6	7.2	5.5	
50 km/h	11.9	11.4	10.1	8.8	7.5
60 km/h		16.1	14.2	11.8	10.9

Tip speed ratio

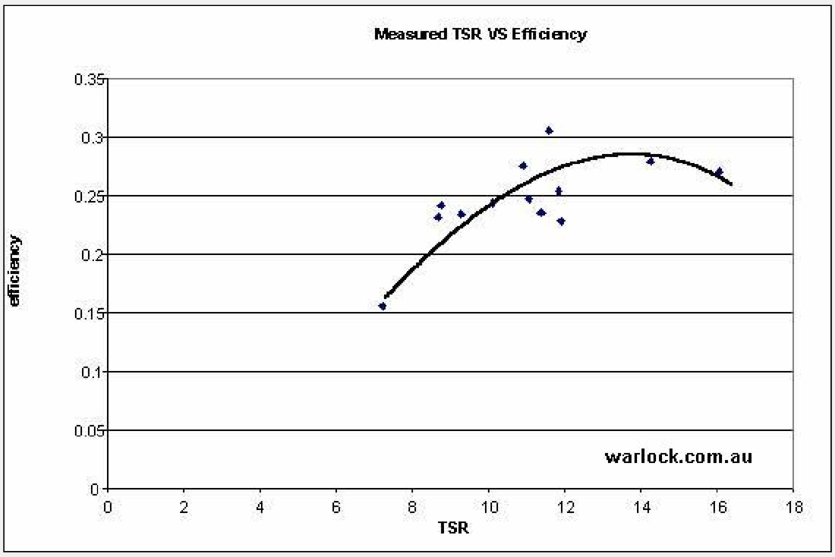


Figure 12. Efficiency vs TSR

6. Total cost of the wind turbine

System cost (AUD)

Induction motor $15
Magnets $80
Moulds $72
Two Blades $14

Total cost $181

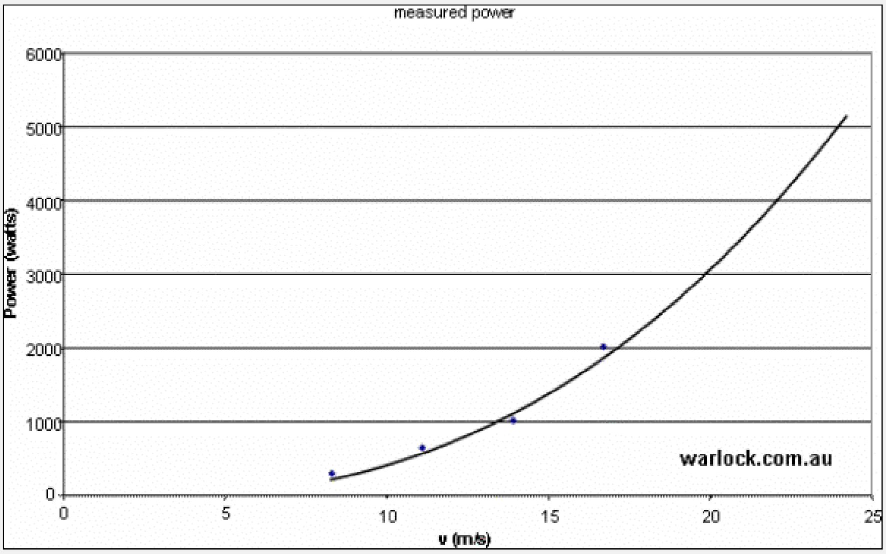
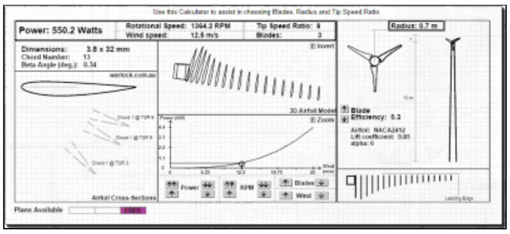


Figure 13. Measured Power. Power (Watts) vs Speed (m/s)

Conclusion

The carbon fibre blades maintained a peak efficiency of 27% for all TSR values between 10:1 and 14:1. The maximum power generated was 2.0 kW at 60 km/h wind speed.

By comparison, the typical TSR for wood carved blades is 7:1. Although they are cheaper to produce, wood blades rotate at half the RPM, reducing the generators power output to 25%



Design custom blades for your generator and calculate power output at each wind speed.

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