Wind Turbine Stator
Design Guide

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Contents

Contents ........................................................................................................................... 2
Introduction .................................................................................................................... 3
  Wind turbine operation .............................................................................................. 3
Construction .................................................................................................................. 5
  Coil design .................................................................................................................. 5
  Joining the coils ......................................................................................................... 7
  Cast the stator ........................................................................................................... 10
Parts suppliers and costs ............................................................................................. 1
Introduction

This is a guide to the design and construction for a stator for a small wind turbine. This guide was produced for SIBAT, an NGO based in the Philippines, who are implementing a 1kW (1.8m blade) small wind turbine for use in remote areas of the Philippines. The basic turbine design is from Hugh Piggott and is described in detail in his ‘How to build a wind turbine: the axial flux windmill plans’ guide, available from http://www.scoraigwind.com/.

Note: Electricity can be very dangerous. Please consult a qualified electrical engineer before implementing any systems.

Note: This is not a definitive document. Please email the author (matt@re-innovation.co.uk) if you have any comments and suggestions.

Wind turbine operation

Basically, the blades capture the wind energy. The rotational motion of the blades is converted into electrical energy through the alternator (which is comprised of the rotor disk and stator). This is then ‘rectified’ and stored within a battery bank.

The alternator is comprised of:
The rotor disks contain very strong magnets. There are two rotor disks, one on each side of the stator. The stator is comprised of a number of coils of enamelled copper wire which are contained within fibre glass and resin.

As the rotor disk magnets pass the stator coils, the changing magnetic field induces a voltage in the coil. As the magnetic field varies from one direction to the other, so does the induced voltage. This means the output from the stator coils is a sine wave with a frequency dependent upon the rotational speed of the blades.

![Coils can be seen through the resin](image)

The voltage produced at the stator coils is dependent upon the strength of the magnetic field, the rate of change of the magnetic field and the number of turns of wire in the coil.

**Note:** *This is Faraday’s law of induction in action, which states that the voltage generated is proportional to the number of turns multiplied by the rate of change of magnetic flux.*

12 coils are required. They are connected in groups of four to produce a three-phase output with three wires.

**Stator coils wiring diagram**

![Stator coils wiring diagram](image)
Construction

Coil design

The coils must be correctly designed for the required output voltage (this is the system voltage, which will be the same as the battery bank voltage. Please see ‘WT_Model_Electrical_Design’ for more details) and the correct current.

The voltage will affect the number of turns of wire, the current will affect the thickness of the wire used.

<table>
<thead>
<tr>
<th>System Voltage</th>
<th>3-Phase Current</th>
<th>Turns required per coil</th>
<th>Wire size (AWG)</th>
<th>Wire size (mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12V</td>
<td>60A</td>
<td>25</td>
<td>2 x #13</td>
<td>2 x 2.5</td>
</tr>
<tr>
<td>24V</td>
<td>30A</td>
<td>50</td>
<td>#13</td>
<td>2.5</td>
</tr>
<tr>
<td>48V</td>
<td>15A</td>
<td>100</td>
<td>#16</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Note: The reason two wires are required for the 12V coils is due to the difficulty of winding very thick wire. The wire must be thick to handle the current, but this makes it difficult to bend so two thinner cables in parallel are used. This gives the same cross sectional area but is much easier to work with.

Enamelled copper wire must be used. The enamel separates each turn of the wire. This cable is readily available as it is used for winding motors.

The dimensions of the coils are:
A coil winder is used which has been built to wind the coils to the correct size. (The coil winder has already been built but construction details are given in ‘How to build a wind turbine: the axial flux windmill plans’).

It is best to place the drums with the wire onto some kind of axle (a pole of some kind – such as a long screwdriver). These drums should be free to rotate. If two wires in parallel are required, then use two drums side by side on this axle.

The cable winder can then be set up as shown in the following diagram. It should be in line with the drums of wire. Use both hands, one to turn the winder handle and one to keep some tension in the wire. Try and keep the coils as neat and tightly wound as possible. Count each turn. Ensure there are no distractions which may mean you lose count. Take care to keep the wire straight. Ensure that no enamel is scratched off the wire.

View from above

Rotate the same direction for each coil

Ensure tension kept in these wires

Handle. (This was built using various spare parts)

This is the axle - this must be able to turn. Place through a hole in a piece of wood or metal.

The wire can catch and scrape on these bolts. It is best to wrap this in a few turns of electrical tape to provide a smooth surface.
Ensure that there is a good length (20cm) of wire at both ends of the coil. When the coil is finished, use some masking or electrical tape to wrap around each side of the coil. This will keep stop the coil unwinding.

Repeat to produce 12 coils, all as similar as possible.

One check to see if all the coils have the same number of turns is to weigh each coil in turn. Weight differences greater than 5% suggest that the coils are not the same.

**Joining the coils**

Once the coils are made they must be joined together ready for setting in resin.

Firstly, scratch off the enamel from the end 1cm of the two wires from each coil.

The coils should then be laid out as shown below, in a circle with a diameter of 205mm (8”). It is best to use a large sheet of paper with the circle drawn on to ensure the coils are kept at the correct distance.

Ensure that all the coils are positioned the same way around, with the inner wire and outer wire from each coil in the same position as others.
This shows the coil layout and electrical connections between the coils. Please note that the electrical cables have been shown spaced apart so that it is easy to see the connections to make. In practice these wires will all be bundled together and kept quite close to the coils, around the outer edge. Cable ties can be used, when the wires have been connected, to keep these wires bundled together.

Note: An even better system would be to lay the coils on a sheet of ply wood. An additional disk of wood (with a diameter of 9”) can then be used to ‘sandwich’ and clamp the coils in place. Screws can be used through the top disk into the base ply wood. See ‘How to build a wind turbine: the axial flux windmill plans’ for more details and photos.
The coils must be soldered together and insulated. To do this, first scratch off the enamel from the wire. This is best done with the blade of a knife. The end of the cable can then be ‘tinned’ by applying solder. This will make it easier to connect the two cables. Next place a piece of heat-shrink tubing over the cable. Do not forget this stage as you will not be able to add the heat-shrink without undoing the connection. The heat-shrink tubing should shrink to the appropriate size, typically 3 or 4mm diameter tubing, but check this with the size of the enamelled copper wire you are using. Remember that the join will be at least twice the size of the wire (usually a little bit larger). Then solder the connection and wait for it to cool. Then move over the heat-shrink tubing and apply heat to shrink.

The last electrical connections to make are the three output wires (L1, L2, L3). These cables should be flexible, multi-stranded cable and the correct size to cope with the current from the stator. Cable sizes suggested are:
### System Voltage 3-Phase Current Wire size (AWG) Wire size (mm$^2$)

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Current</th>
<th>Wire</th>
<th>Wire size</th>
</tr>
</thead>
<tbody>
<tr>
<td>12V</td>
<td>60A</td>
<td>#8</td>
<td>8</td>
</tr>
<tr>
<td>24V</td>
<td>30A</td>
<td>#12</td>
<td>3.5</td>
</tr>
<tr>
<td>48V</td>
<td>15A</td>
<td>#13</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Ensure that the cables are long enough to reach from the stator to the rectifier, with some to spare. 1m each should be long enough. Use cable ties to keep all the wires together and neat.

![Image of cables with cable ties and heat-shrink tubing]

**Cable ties to keep cables in the correct position**

**Heat-shrink tubing used on every connection**

### Cast the stator

Once the coils have been connected they must be cast in a resin mixture with some fibre-glass to add strength. This will provide mechanical strength and waterproofing for the stator coils.

An aluminium mould has been produced to create the stator. The mould is comprised of a base section, an outer section, a centre disk and a top lid. These can be bolted together to hold the mould in place while the stator sets.

![Image of the mould components]

**Top section**

**Base section**

**Centre Disc** (made from wood in this example)

**Outer section**

**Bolts to clamp sections together**
The stator casting process is as follows. It is best to have a ‘dry run’ without any resin to ensure that everything will go smoothly.

1. Check the mould and ensure all the pieces (base, outer, centre, lid, nuts and bolts) are ok.
2. Put a ring of silicon sealant around the base to seal the base to the outer section and the base to the centre piece. Ensure these are in the correct position by using the bolts to line them up. The silicon sealant will stop any of the resin from leaking out of the mould.

********Take photo of mould with silicon when a stator is manufactured********

3. Cover the area where the stator will be produced with scrap newspaper. Some of the resin will flow out of the mould and putting down newspaper will help with the cleaning up process.
4. The mould then requires waxing to ensure that the stator is released easily and will not stick to the mould. ‘Durawax’ is used for this purpose. This must be applied liberally with a soft cloth. Ensure all surfaces that may be exposed to resin are covered. This must then be buff dried using a clean cloth or electric buffer. Repeat this process at least five times so that a thick layer of wax is built up. The mould can then be used.
5. Next cut out two pieces of chopped strand fibre glass mat (300gsm). These should be cut to the same size as the stator, with a 8” hole in the middle. Use the mould as a template to draw on the fibre-glass mat and then cut slightly inside the line to ensure the mat fits comfortably into the mould. Any off-cuts of fibre-glass mat can also be used to help strengthen the stator in the corners where the stator mounting holes will be drilled.

![Diagram of Fibre Glass Mat](image)

It is now time to mix some resin.
**Note: Health and Safety measures:**

The process uses many different chemicals. Most of these are **TOXIC** and **FLAMMABLE**. Ensure that they kept away from flames and sources of ignition at all times. **NO SMOKING** at any point during the production process.

Wear **GOGGLES, GLOVES, MASKS** and **PROTECTIVE CLOTHES** while working with resin.

Most of the chemicals will cause agitation to the skin and cause blindness if they come into contact with the eyes. If any chemicals come into contact with the skin then wash immediately with plenty of soapy water. If any chemicals come in contact with the eyes the **IMMEDIATELY SEEK MEDICAL HELP**. Show the packaging of the chemical to the medical services.

**ALWAYS** follow the procedure shown in this guide when mixing chemicals.

**COBALT AND HARDENER MUST BE KEPT SEPARATE AT ALL TIMES.** If mixed they are explosive. This includes in syringes, mixing, cleaning and storage.

The fumes from the chemicals are **TOXIC. ALWAYS** work in a well ventilated environment. Wear a respirator mask.

The quantities for the resin batch mixtures are:

<table>
<thead>
<tr>
<th></th>
<th>Resin mix NO talc</th>
<th>Resin mix WITH talc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resin type 31-441</td>
<td>360g</td>
<td>360g</td>
</tr>
<tr>
<td>Styrene Monomer</td>
<td>40g</td>
<td>40g</td>
</tr>
<tr>
<td>Talcum powder</td>
<td>NONE</td>
<td>400g</td>
</tr>
<tr>
<td>Catalyst (cobalt)</td>
<td>2cc</td>
<td>2cc</td>
</tr>
<tr>
<td>Hardener (MKEP)</td>
<td>8cc</td>
<td>8cc</td>
</tr>
<tr>
<td>Lowilite</td>
<td>2g</td>
<td>2g</td>
</tr>
</tbody>
</table>

Use a set of scales to weigh the mixtures. The general mix and pour process is as follows:
6. Firstly mix a batch of resin with NO talcum powder.

7. Paint this resin into mould ensuring all the base of the mould is covered with resin. Use a paint brush and a ‘stippling’ (dabbing) action.

8. Lay one of the cut sheets of chopped strand fibreglass 300gsm mat into the mould. Apply more resin with a ‘stippling’ action to ensure there are no air bubbles.

9. Slide in the pre-wired coils. Ensure the spacing between the coil centres is 8” and that the coils are positioned symmetrically.

10. Ensure that the three output cables are held out of the resin. A piece of electrical conduit should be added around the three output wires for added protection. This should be long enough to reach the rectifier box. Hold the electrical conduit so that it is kept perpendicular to the mould.

Note: Image taken from ‘How to build a wind turbine: the axial flux windmill plans’ by Hugh Piggott
11. Pour over the remains of first batch of resin with no talc.
12. Mix another batch of 400g resin with talc.
13. Pour in over the coils. Ensure it soaks well into the wires of the coils.
14. Mix additional batches of resin and talc and pour into the mould until the mould is full.
15. Place small triangles of fibre glass mat (off-cuts can be used here) in the corners of the mould, where the stator lugs will go. This will help strengthen those areas.
16. Knock the mould a few times to remove any air bubbles that may be trapped.
17. Place the other cut piece of CSM on top and push into the resin.
18. Apply a thin ring of silicon sealant around the centre piece and the outer section; this is to ensure a good seal.
19. Put the lid onto the mould and tighten the bolts. This will overflow when clamped, so ensure the area is covered with newspaper to catch the overflow.
20. Leave to set (approx 8hrs or overnight).
21. Undo the bolts and remove the lid. The stator may require a few taps with a hammer to be removed. Be careful not to damage the stator.

************Take photo of the coils etc in the mould when next stator built************
22. Drill holes in correct positions for stator lugs on the chassis. Be very careful not to drill close to the coils.

The finished stator attached to a chassis (note the stator lugs)
The stator can then be painted, if required, for some protection and aesthetics.
## Parts suppliers and costs

These prices are shown in Philippine Pesos. Check these costs before confirming.

<table>
<thead>
<tr>
<th>Item</th>
<th>Supplier</th>
<th>Quantity</th>
<th>Unit</th>
<th>Cost per Unit (PhP)</th>
<th>Total cost (PhP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enamelled copper wire</td>
<td>Mayon Electrical supplies, T.Alonzo St, Quiapo - 5kg smallest</td>
<td>3</td>
<td>kg</td>
<td>966</td>
<td>2989</td>
</tr>
<tr>
<td>Heat-shrink tubing</td>
<td>Roks Electronics Centre, Gil Puyat St, Quiapo</td>
<td>2</td>
<td>m</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>Solder</td>
<td>Deeco</td>
<td>Some</td>
<td></td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Electrical tape</td>
<td>Deeco / Ace Hardware</td>
<td>2</td>
<td>Rolls</td>
<td>40</td>
<td>80</td>
</tr>
<tr>
<td>Electrical conduit</td>
<td>Ace Hardware</td>
<td>0.3</td>
<td>m</td>
<td>100</td>
<td>30</td>
</tr>
<tr>
<td>Flexible power cable (size depends upon current)</td>
<td>Roks Electronics Centre, Gil Puyat St, Quiapo</td>
<td>10</td>
<td>m</td>
<td>50</td>
<td>500</td>
</tr>
<tr>
<td>Cable ties</td>
<td>Deeco</td>
<td>40</td>
<td>pcs</td>
<td>2</td>
<td>80</td>
</tr>
<tr>
<td>Chopped strand Fibre glass mat 300gsm</td>
<td>Polymer products, 372 Commonwealth Avenue, Quezon City, 433 3588</td>
<td>1</td>
<td>m²</td>
<td>295</td>
<td>295</td>
</tr>
<tr>
<td>Resin 31-441</td>
<td>Polymer products, 372 Commonwealth Avenue, Quezon City, 433 3588</td>
<td>3</td>
<td>Kg</td>
<td>150</td>
<td>450</td>
</tr>
<tr>
<td>Styrene monomer</td>
<td>Polymer products, 372 Commonwealth Avenue, Quezon City, 433 3588</td>
<td>0.3</td>
<td>Litre</td>
<td>150</td>
<td>50</td>
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<tr>
<td>Cobalt</td>
<td>Polymer products, 372 Commonwealth Avenue, Quezon City, 433 3588</td>
<td>1</td>
<td>Bottle</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Hardener (Imported MKEP)</td>
<td>Polymer products, 372 Commonwealth Avenue, Quezon City, 433 3588</td>
<td>1</td>
<td>Bottle</td>
<td>50</td>
<td>50</td>
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<tr>
<td>Lowilite</td>
<td>Polymer products, 372 Commonwealth Avenue, Quezon City, 433 3588</td>
<td>1</td>
<td>Bottle</td>
<td>50</td>
<td>50</td>
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<tr>
<td>Talcum power</td>
<td>Polymer products, 372 Commonwealth Avenue, Quezon City, 433 3588</td>
<td>3</td>
<td>kg</td>
<td>100</td>
<td>300</td>
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<tr>
<td>Silicon sealant</td>
<td>Ace hardware</td>
<td>1</td>
<td>Tube</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Paint brush</td>
<td>Ace hardware</td>
<td>1</td>
<td>pcs</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Mix pot</td>
<td>Ace hardware</td>
<td>1</td>
<td>pcs</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Gloves</td>
<td>Ace hardware</td>
<td>1</td>
<td>Pair</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>‘Durawax’ mould release wax</td>
<td>Polymer products, 372 Commonwealth Avenue, Quezon City, 433 3588</td>
<td>Some</td>
<td></td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td>Guidance only – not including labour</td>
<td></td>
<td></td>
<td></td>
<td>5654</td>
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