

Lab 6: Wind Turbine Generators

Pre Lab

Tip speed ratio:

Tip speed ratio (TSR) is defined as: $\lambda = \frac{\text{blade tip speed}}{\text{wind speed}} = \frac{\Omega R}{U}$, where Ω =angular velocity of wind, and R =radius of rotor (blade length). If the rotational speed of the shaft of a wind turbine generator is known, TSR can be used to back-calculate wind speed. The TSR of the Air Breeze, made by Southwest Windpower, turbine isn't published. However, we can estimate it using information that is readily available.

1. What is the rated power of the Air Breeze?
2. What wind speed is necessary to achieve that rated power?
3. It was found that the Air Breeze outputs its rated power at a shaft speed of 940 rpm. What angular velocity does that correspond to?
4. Using the rotor diameter found on the Air Breeze data sheet, find its TSR.

Induction Machines:

5. Draw the equivalent circuit of an induction machine. What quantity does the most to govern the performance of an induction machine?

Lab Exercises

Induction Machines

As you found in the pre-lab, induction machines need a source VARs in order to run. The easiest source of VARs to tap is the power grid itself. VARs are one thing that complicates the starting of induction generators, frequency is the other.

In order to be connected to the grid, the frequency of the output of a generator must match that of the grid. Since the frequency of the power generated is directly proportional to the speed of the prime mover (the blades of the turbine), one can't rely on the wind to take care of the frequency requirement.

One common way to start induction generators is to bring them up to speed (so the frequency matches) as a motor, then connect to the grid. The turbine then allows the wind to spin the generator faster, creating negative slip. As you found in the pre-lab, negative slip means the machine is operating as a generator.

1. Using an aluminum mounting plate, set up two 3-phase induction machines side by side. One of these represents the generator of a wind turbine, and the other represents the spinning shaft out of the gearbox. Couple them together mechanically with a timing belt.
2. Connect one of the machines to the grid and turn it on. This will be the generator. Note which direction it's spinning.
3. Get a variable-frequency drive out of the back room and hook it up to the other machine. Turn it on and modify your connection so that the machines spin the same way when the grid or the VFD runs them. This will be the spinning shaft out of the gearbox.
4. Get a stroboscope out of the back and set it up to read the speed of the machines.
5. With the VFD OFF, turn the grid-connected machine on and use the stroboscope to determine how fast it's spinning. See your lab instructor if you don't know how to use a stroboscope.
6. Turn OFF the grid-connected machine.
7. Turn ON the VFD-connected machine. Adjust the frequency of the VFD until the machines spin at the same speed they were when connected to the grid.
8. With the VFD still on, turn the grid on. You should now be putting power onto the grid (you may need to speed the VFD machine up slightly)! How much power is the machine generating? How many VARs is the machine consuming?

9. Adjust your setup until you're supplying 100 W to the grid (per phase) and have your lab instructor verify your success. When you're done **turn off the breaker to the grid before you turn off the VFD**. How fast do the machines spin when generating that much power? What's the slip?

Permanent Magnet Generators

Since there's not an abundance of permanent magnet (PM) synchronous generators lying around the department, our next exercise will use a conventional synchronous generator instead. A PM generator has coils of wire on its stator, and a ring of magnets on its rotor, while a conventional synchronous generator has coils of wire on both the stator and the rotor. A conventional synchronous generator gets its magnetic field by passing DC current through the field winding (on the rotor), making an electromagnet. That's called "exciting" the generator. So the magnetic field of conventional synchronous generator with its excitation fixed "looks" almost the same as if it were replaced with a ring of magnets. Note: If none of this is making sense to you, review electrical machines either with a textbook, the web, or a friend. Once you've done that, see your lab instructor to fill in the gaps.

1. Using an aluminum mounting plate, set up a 3-phase induction machine and a conventional synchronous machine side by side. Couple them together mechanically with a timing belt.
2. Hook a VFD up to the induction machine. Now you'll be able to control the speed at which you turn the synchronous generator to simulate changing wind speeds.
3. Turn the synchronous machine's field rheostat all the way down and leave it there for the remainder of the lab.
4. Hook up the synchronous machine in wye. This means jumper one side of the red, black and blue terminals all together vertically.
5. Set up the LabVolt data acquisition module to watch the line to neutral voltage of one phase of the generator's output. This means watch the voltage between one of the open terminals (red, black, or blue) and the wye connection you just made. Use both the meter and the scope of the LVDAC-EMS.
6. Connect the DC power supply to the exciter (field) of the synchronous machine. Turn it on and turn it up to the rated voltage for the field.
7. Turn on the drive. Adjust the drive so that the output frequency is 40 Hz.
8. Increasing the frequency from 40 Hz to 70 Hz in 5 Hz increments, make a graph of rms voltage vs. frequency.

Name:

Time:

Is it immediately clear to you from looking at the data which quantity changes the most with load? Let's quantify it.

16. The formula for percent change is: $\% \text{ change} = \left| \frac{x - x_{base}}{x_{base}} \right| * 100\%$. Using the values at 1200 Ω as bases, calculate the percent change at every level for load, voltage, current, and frequency. For example, the percent changes in load are:

| Load | % change in load from 1200 Ω |
|------|-------------------------------------|
| 1200 | 0 |
| 600 | 50 |
| 400 | 66.667 |
| 300 | 75 |
| 240 | 80 |
| 200 | 83.333 |
| 171 | 85.75 |

17. Plot, on the same set of axes, % changes in current, voltage, and frequency against % change in load. Comment on your plot.

Name:

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Now you've made a cool graph, but it still doesn't tell you how current relates to the mechanics of the motor. As you can see from your data, the electrical power generated increased as we decreased the load resistance.

18. In terms of $P=I*V$, what electrical quantity was "responsible" for the increase in power?

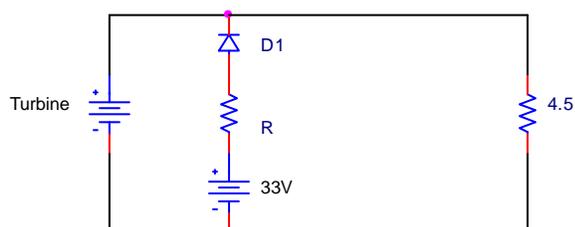
Since the electrical power increased, so too must have the mechanical power into the generator.

19. Taking into account all that you've found in this lab so far, what mechanical quantity does current depend on (hint: mechanical power equation from pre-lab)? Make an attempt to explain why that is. Again, a little EM goes a long way.

Real Wind Generator

The Air Breeze wind turbine has a permanent magnet generator in it. We have an Air Breeze exactly like the one in the lab on the roof of Rathbone Hall. Though it's designed for charging batteries, we have it connected to the grid. One of the most important pieces of information one can have when comparing different wind turbines is their power curves. Unfortunately, the Air Breeze doesn't have a published power curve.

1. Construct Circuit 1. Since the Air Breeze is designed to charge batteries, its internal circuitry won't allow it to produce and power unless it has at least 21V at its terminals. Circuit 1 provides that voltage.



Name:

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Circuit 1 Air Breeze testing circuit

Select R so that the turbine has at least 22V across its terminals. Make sure the resistor you use is rated for the current it will see.

Use the large power resistor bank with the knife switches for the 4.5Ω resistor. See your lab instructor if you need help setting it up.

2. Find the power curve for the Air Breeze as power output vs. rpm. Be sure to use the 40A input for the ammeter on the DAC, and change that input's range to high in the LVDAC-EMS program.

3. Using the TSR you found in the Pre Lab, find the Air Breeze's power curve as power vs. wind speed.

Name:

Time:

4. What is the published cut-in wind speed for the Air Breeze? How does that compare with your findings? If they're different, why do you think that is?