Power Systems Analysis in an Induction Type Wind Turbine

DESIGN DOCUMENT V.2

42
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Definitions

Induction Motor- An EC electric motor which the electric current in the rotor needed to produce torque is obtained by electromagnetic induction from the magnetic field of the stator winding. [1]

Islanding-A condition in which a distributed generator continues to power a location even though the electrical grid power is no longer present. [2]

NOTE: This template is a work in progress. When in doubt, please consult the project plan assignment document and associated grading rubric.

REC-Rural Electrical Company. This is the utility that our group is dealing with that is located where the turbine will be built.

1 Introduction

1.1 ACKNOWLEDGEMENT

A lot of the design came from Bob Zickefoose, a MSME teacher in Virginia who also has a similar 'sister' tower on his property in West Virginia. Much of the structure came from Ron Zickefoose, the client, and from Global Machine Company in Hampton, Iowa.

1.2 PROBLEM AND PROJECT STATEMENT

The client Ron Zickefoose designed and is building a wind turbine on his property to provide cheap and clean energy for his power consumption. In order to interconnect to the power grid and supply a small amount of power to the induction motor to start rotation, the power utility requires proof that the generator will not cause any islanding on the power grid. Which would cause voltage to flow back to the grid, causing a safety hazard for anyone working assuming that there is no voltage if the rest of the power grid is turned off. Once approval from the utility is established, the wind turbine should be able to supply enough power for our client's needs, and enough to sell back to the utility.

Following the set parameters for the requirement documents of interconnecting on the power grid for a functional turbine. Establish a fully functional wind turbine adjusting the tail fin of the turbine and fully building the turbine is in order. Meeting all the interconnecting criteria will prove that the wind turbine will not cause any islanding issues with the utility tests will be done on the induction motor used. To run tests on the induction generator, a second motor can be hooked up to for maximum output, and what power is needed to start the induction generator. Showing the initial power is needed and a constant supply is there while outputting power will prove that voltage can't be supplied by the motor without the reactive power from the grid. Additionally, there will be a detailed research, analysis, description of the capabilities, limitations of the induction motor. This research will allow for the wind turbine to be hooked up to the grid and supply power and income to our client.

1.3 OPERATIONAL ENVIROMENT

The wind turbine will be open to the elements. The turbine stands at 110 ft. tall and will be subjected to any wind, rain, hail, snow and ice. During lightning storms, lightning will have a large percentage of hitting the tower. Since most of the turbine is made from metal the temperature outside will affect the structure and will be subjected to expansion and contraction.

1.4 INTENDED USERS AND USES

The intended users of the wind turbine is the owner of the property that it stands on. In this case our client Ron Zickefoose is the user. The nearby utility will also be an intended user of the wind turbine as they will get electrical energy from the turbine.

The property owner will get the most use out of the turbine. They will be able to offset how much money is spend on their electricity bill from their own consumption. In addition to that any extra electricity produced will be sold to the utility. Once the utility gets electricity they will be able to generate less power and use the wind turbine to sell electricity to their customers.

1.5 ASSUMPTIONS AND LIMITATIONS

Assumptions

The air density is a constant throughout the year

That the three phase of voltage is 120 degrees apart.

Limitations

The induction motor will turn into a generator after 1800 RPM

The system must operate at 230 volts and 60 Hertz

The current will run at 20.6 Amps

1.6 EXPECTED END PRODUCT AND DELIVERABLES

Blueprints of a one line, three line and control wiring. These blueprints will show exactly how the wind turbine is set up and how it functions. This will be delivered by the end of the project on April 30th 2018.

Documentation for an interconnection agreement will be written for the local utility in the area. These documents will include some of the blueprints, and the different generation tests proving its capabilities. This will be delivered in the middle of the second semester March 12th, 2018.

A wind turbine will be operating by the end of the project. The turbine will stand at 110ft with a 4kW induction type motor. This will be delivered by the first part of second semester February 12th, 2018.

2. Specifications and Analysis

There are many methods of solving the problem of customers reducing energy costs to save money in the long term. The various solutions to this problem includes:

Our group has used the solution for the wind turbine to produce cheaper electricity. In this solution there are different methods for problems while building a wind turbine. The problems from choosing a wind turbine is knowing what type of generator to use, how to verify electricity won't be supplied to the power grid if the grid is undergoing maintenance, and different ways to maximize the power output supplied from the turbine.

Our team is using an induction generator based off the price point and how much power it supplies for what is needed for the customer's power consumption.

Our group is testing the induction generator with a secondary motor will be the easiest option. An additional motor is available through Iowa State University wind lab so cost will be negligible. Another reason this method was picked was that if the power from the grid is off either way the turbine will not be able to supply power so we wanted to use was physics has already provided to our team.

To improve the power output of the wind turbine there isn't one right solution and multiple solutions can be used at a time if our group finds that the solution is worth the costs.

Our team decided to focus on the tail vane of the turbine. This was due to the fact the wind turbine wouldn't be able to produce any power if it is not facing a direction where is catches the wind. The controller will also be built because it has a low cost and will help improve the lifespan of the wind turbine.

2.1 PROPOSED DESIGN

The design includes using a 4kW induction generator. The tower is 110 feet fall with three legs and triangle supports up the leg of the tower. Three turbine blades that are 10 feet tall. A tail vane pitching system has controller hooked up to a wind sensor that sends signals to the turbine telling what direction to go in. The design includes having blueprints of the entire turbine and grid layout as a package for anyone else interested in building a similar turbine.

A non-functional requirement includes a GUI to show the wind turbines power output along with the wind speed and direction.

2.2 DESIGN ANALYSIS

The turbine at 110 feet fall is built but not yet standing. The three-legged base will work for this application, in the future a four-legged based design would be preferred to add more stability.

The present tail vane pitching system as a very simple circuit, though doesn't allow for any fine tuning of the turbine. An upgraded circuit of the tail vane could be substituted to increase the power output of the turbine.

There are many methods of solving the problem of customers reducing energy costs to save money in the long term. The various solutions to this problem includes:

- Placing solar panels in a field or rooftop
  - Though this may be a viable solution in the future, currently the cost of solar isn't cheap and the initial cost wouldn't be made up for by the savings produced in the future.
  - This solution is still a valid idea to keep in mind, from the fact that cost of solar is decreasing rapidly and in the next five to ten the cost becomes more sustainable.
- Using less electricity
  - This idea would reduce electricity cost, but isn't the most practical. It compromising the customer's quality of living and in some cases isn't feasible if electricity is needed for working.
- Use bio renewables
  - This idea only works for customers who produce a large quantity of waste product, like a large restaurant or cattle farmers. The process isn't very efficient and the initial cost of making a converter to turn the waste into fuel has a decent startup cost.
  - Using this solution would also require a large amount of work constantly to supply electricity. The waste product would have to constantly be supplied to the converter for electricity.
- Rain based Hydro-Power
  - This solution would be fairly cheap to implement, but there isn't enough rainfall in Iowa that could produce enough power for a house.
- Create a wind turbine in a yard
  - This solution would produce enough energy to sustain a house and is cheap enough that the initial cost would eventually be covered by the saving in electricity.
  - A wind turbine is fairly larger so the only customers who could feasibly do this is if they own a large property. Famers and people who live outside large cities are more likely to use this solution.

Our group has used the solution for the wind turbine to produce cheaper electricity. In this solution there are different methods for problems while building a wind turbine. The problems from choosing a wind turbine is knowing what type of generator to use, how to verify electricity won't be supplied to the power grid if the grid is undergoing maintenance, and different ways to maximize the power output supplied from the turbine.

There's two main different type of generators that can be used in a wind turbine including a:

- Induction generator
  - Advantages

    - No additional Circuitry is required to run while hooked up with a three phase power supply. [3]
    - The generator changes speed slightly based of the torque supplied. This increases the life of the gearbox and the amount spent of maintenance. [3]
    - If power is cut of the generator will automatically turn off, protecting the power grid.
    - Fairly cost effective and can be bought for under a thousand dollars
  - Disadvantages
    - A small amount of power is constantly needed in order to produce power, making it not as efficient.
- Synchronous Permanent magnet generator.
  - Advantages
    - Produces a large amount of power from the extra flux added from the magnets.
    - A gearbox isn't needed to bring up the speed or the power output.
  - Disadvantages
    - Very expensive since the magnets used are rare earth metals. The cost is also driven up since the materials are mostly mined from Asia and there is a large tax export on this particular item.
    - Permanent magnets are very heavy, so a larger tower is need to support the weight.
    - There isn't any control of the rotor flux and only the wind speed can adjust the efficiently. [3]

Our team picked the induction generator based off the price point and how much power it supplies for what is needed for the customer's power consumption.

Verifying electricity won't back feed onto the power grid:

- Testing the generator with a secondary motor
  - Advantages
    - This method is already in use and proven to work. Induction motors need a small amount of reactive power in order to produce power, so if the power grid goes down the turbine will not be able to generator power without the reactive power supplied to it.
  - Disadvantages
    - A second motor is needed to verify the theory behind this, which adds to the cost of either purchases or renting another motor.
    - It takes time to collect all of the sample points to produce a curve showing the power needed to be supplied to the turbine.
- Create a sensor that cuts of the turbine when the power from the house is supplied
  - Advantages
    - Power wouldn't backflow onto the grid because it would never be supplied on the grid in the first place.
  - Disadvantages
    - This doesn't allow to sell back to the utility, which essentially lowers the amount of savings made by the wind turbine by not getting back the money from the power supplied by the turbine

        - Power consumption from the house changes daily, so if the sensor cuts off the turbine and the customer wants to bake some midnight cookies the turbine might be off during that time. An extra strategy would be needed to know how much the house is consuming at any given moment
- Have an extra battery that the turbine supplies power to
    - Advantages
        - Since wind velocity isn't constant, this would allow the customer to access power from the turbine even if the turbine isn't producing enough power for the current power consumption at that moment.
        - Power wouldn't backflow onto the grid because it would be supplied to the battery instead.
    - Disadvantages
        - Batteries are expensive and not efficient. Power loss would occur during this process to some extent.
        - There is a limited capacity on batteries, so if too much power is consumed by the turbine before it is used the power will be wasted.

Testing the induction generator with a secondary motor will be the easiest option. An additional motor is available through Iowa State University wind lab so cost will be negligible. Another reason this method was picked was that if the power from the grid is off either way the turbine will not be able to supply power so we wanted to use was physics has already provided to our team.

To improve the power output of the wind turbine there isn't one right solution and multiple solutions can be used at a time if our group finds that the solution is worth the costs.

- Changing the turbine blades angle
    - Advantages
        - Changing the pitch on the blades allows them to catch more wind, essentially bringing up the wind velocity. This is helpful due to the fact that wind speed increases the power output exponentially.
    - Disadvantages
        - Adding a pitching system increases the cost of a turbine.
        - Moving parts add to the maintenance required of the turbine, also increasing the cost.
        - The wind changes fairly often, meaning the pitch would change fairly frequently. This would increase noise pollution that the wind turbine already has.
- Changing the tail vane of the turbine
    - Advantages
        - Allows for the turbine to face the cardinal direction of the wind. Essentially bringing up the wind velocity from what could potentially be zero if facing the wrong direction. This is helpful due to the fact that wind speed increases the power output exponentially.
        - The cardinal direction typically stays in the same direction throughout the season, so it won't have to reposition constantly.
    - Disadvantages
        - Adding a tail vane increases the cost of a turbine.

        - Moving parts add to the maintenance required of the turbine, also increasing the cost.
- Increasing the height of the wind turbine
    - Advantages
        - The higher in the atmosphere, typically the faster the wind velocity is. Since wind velocity increase power exponentially this would be helpful.
    - Disadvantages
        - More material needed to build the tower.
        - If large enough, a larger crane would be needed to build the turbine.
- Controller
    - Advantages
        - Allows to turn the wind turbine on and off. This is useful to protect the wind turbine in high speeds and stop the blades from spinning too fast.
        - Keeps the turbine off during low speeds where little to no power is produce. This is helpful so the turbine doesn't have to spin as much which will in return improve the lifespan of the turbine.
    - Disadvantages
        - Current micro-controller uses propitiator computer programming language that will need to be learned.
        - Small cost added to the turbine.
        - Extra circuitry that will have to fit into the nacelle of the wind turbine.

3 Testing and Implementation

Structure

The structure has triangle base that is 110 feet tall. The nacelle which will house the induction generator and gearbox, with the tail vein attached to the back of the nacelle. The tower, gearbox and tail vein go up first. Once the generator and controls will be add after their testing is completed.

Generator

Two different types of tests will be run on the generator including a physical test of the generator and a virtual test of the generator using Simulink.

Testing the generator will have a separate motor that will spin the drive shaft on the generator that will simulate wind speed. The testing of the generator will give use functional test to see what the power outputs will be. The generator will be supplied with a constant reactive power. The outputs received will be speed vs. torque and torque vs. slip. The output should look something like the figure 1 below. The Simulink will be a double check and should have the same output as the physical testing of the generator.

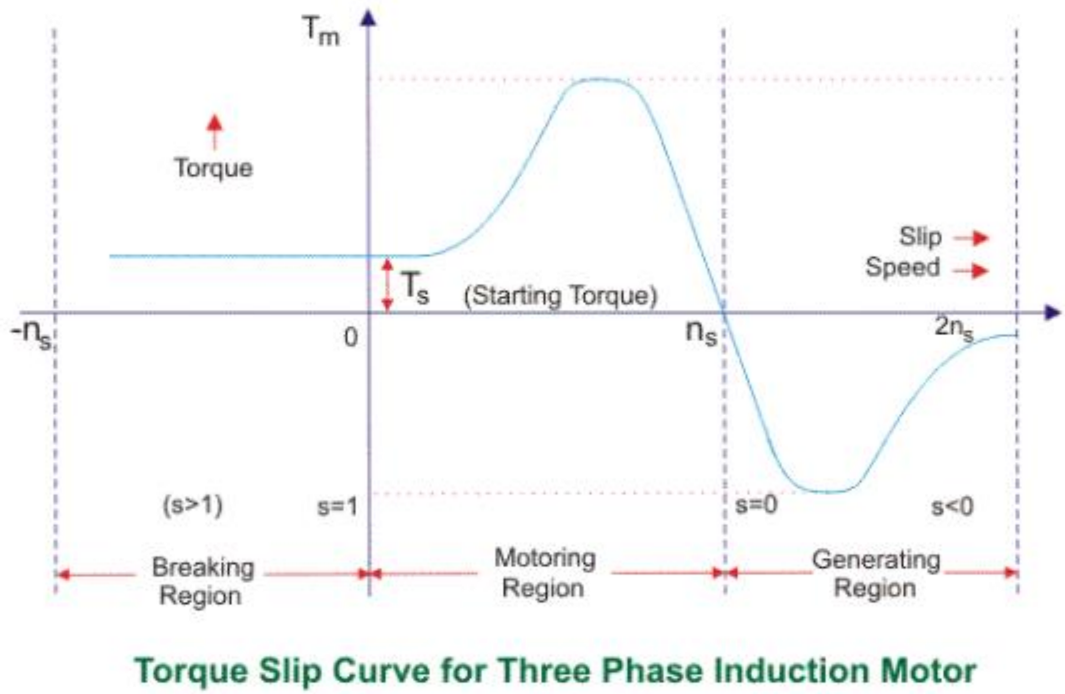

Figure 1-touque vs slip[4]

The Simulink model will be used as a non-functional test for outlining parameters for when generation should be activated to get optimal power outputs. Optimal power is when power to activate the generator is less than the power being output by the generator.

Controller

The controller is going to be based off an Arduino evaluation module. Control the power supply to the tail vane and the induction motor. The controller will take readings from an anemometer to determine if there is sufficient wind speeds.

For testing, the Arduino module will be given calculations in place of readings from the anemometer. The Arduino module programming will be evaluate the given data and determine if it is within the predetermined wind range. After this is done the anemometer will be hooked up to it and will be tested by first spinning the anemometer to ensure that the Arduino is receiving the proper values. Once this works it will be tested outside in the wind to verify the number ranges are accurate. The result should be the controller giving off a voltage once the values shown are in range, and the voltage is cut off when the wind speed is out of range.

Interface

A nonfunctional requirement will be a GUI connected to the controller. This will allow for a visual showing the power output for the client to use.

3.1 INTERFACE SPECIFICATIONS

Generator

Testing the generating will have a separate motor that spins the drive shaft of the generator that will simulate wind speed. A gear box will be connected to the shaft to make sure they are able to output enough power. A Simulink model will also be created to mimic the real model.

Controller

The micro-controller will determine if the anemometer readings are within the allotted wind speed range that will be most beneficial for operating the induction generator. Once the optimal wind speeds are obtained the micro-controller will close the relay circuit to allow the reactive power to flow to both the induction generator and the tail vane. The controller will not allow the reactive power to flow beyond the relays, which will prevent a constant use of main grid power.

3.2 HARDWARE AND SOFTWARE

Generator

These tests are needed to output wind vs. watt, to find optimal wind speed charts. This will allow us to get readings on how much speed is needed for production of the watts from the generator. To do this we will use a secondary motor for testing our induction motor. As a second method to verify what our output should be we will be using Simulink with the ASMG package in MATLAB.

Controller

The controller is finding the time and the wind speed that will be the most beneficial for operating the generator and tail vane. This is so power is not being drained or overproduction of watts. Our group is using an Arduino for the controller and a Digi Xbee for the hardware needed. The software that these programs use for coding is C.

3.3 PROCESS

Our functional testing includes the generator and controller, with the nonfunctional goal being the GUI.

Generator

While the second motor is moving the drive shaft of the generator, we will be taking measurements. The measurements taking will be the amount of reactive power being used by the generator and the amount of watts being produced.

Some challenges that we face is making sure that we get a correct output. Calculators for generations assume a lot of variables, so recreating those variables could be a problem, including a correct temperature and limited vibrations.

The testing will including an 'Anti-Islanding Test', 'Non-Export Test' and an 'In-Rush Current Test' these are the types of tests that various utility companies require to support more generator to connect to the grid.

Testing parameters include:

- Device ratings
    - kW
    - kV
    - Volts
    - Amps
- Maximum available fault current (A)
- In-Rush current (A)
- Trip points
    - Factory settings
    - Timing ranges
- Nominal power factor

Controller

This will be tested by the anemometer will need to be calibrated. This will be done with controlled speeds from a fan. Software will be created around the number of spins the anemometer makes in a set time. Then the controller will close the steady state relays allowing power to the generator and tail vane.

Some challenges for the controller is looking at the original controller and figuring out what the simple base model is doing and how it is done. After this is done we can modify this version to do what our group requires of it.

GUI

Testing the GUI will be mostly by trial and error. Our team does not have a lot of experience in coding and setting up a visual will be a learning process.

3.4 RESULTS

Generator

From the measurements gathered we should be able to find two limits. The first limit is when there are more watts outputted from the generator than the reactive power used. The second limit will be where the motor speed will start to overheat the generator. This will give a range of operation when the generator is safely producing more watts than the reactive power.

Controller

The results found should be that the controller will take in readings and then allow power flow to the generator and the tail vane. If time allows an extra output will be to have the controller send information to a user interface GUI.

4 Closing Material

4.1 CONCLUSION

The client Ron Zickefoose designed and is building a wind turbine on his property. That will not cause any islanding on the power grid. The wind turbine should be able to supply enough power for our client's needs, and enough to sell back to the utility. Documentation for the local utility will be provided showing the needed information to allow the wind turbine to be on the power grid. Proving that the wind turbine will not cause any islanding issues with the utility tests will be done on the induction motor used. There will be detailed research, analysis, description of the capabilities and the limitations of the induction motor provided. This research will allow for the wind turbine to be hooked up to the grid and supply power and income to our client.

4.2 REFERENCES

[1] https://en.wikipedia.org/wiki/Induction_motor

[2] https://en.wikipedia.org/wiki/Islanding

[3] http://www.alternative-energy-tutorials.com/wind-energy/induction-generator.html

[4] https://www.electrical4u.com/torque-slip-characteristics-of-induction-motor/

4.3 Appendices

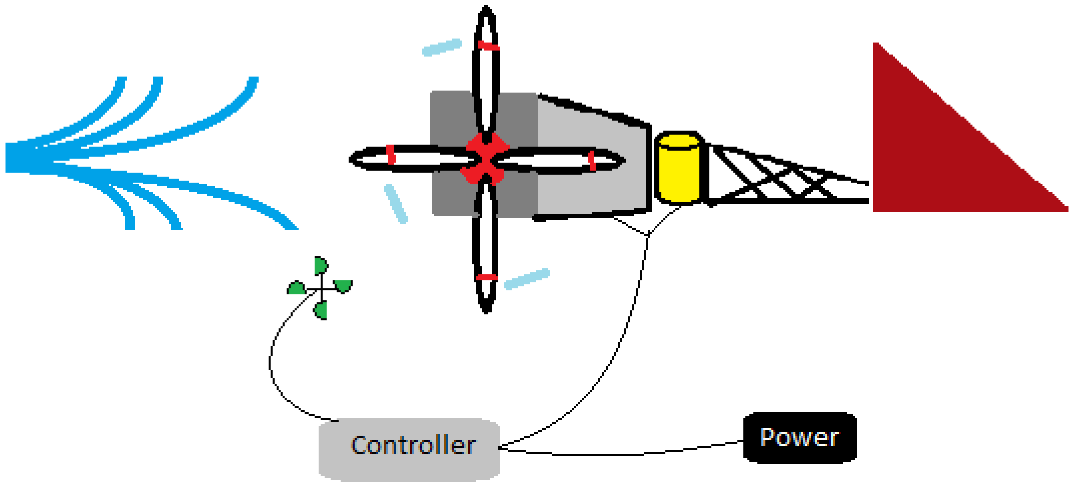

Figure 2 - Diagram showing connection between the wind turbine and the controller