

CWC Generator

Report 2

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DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

EXECUTIVE SUMMARY

This report presents the concept generation process behind the development of a novel generator design, guided by detailed analysis of two reference units: the MAD JENNY and the Melon Motor. These pre-existing generators were provided as case studies to reverse-engineer, test, and evaluate. The goal was to identify functional strengths and weaknesses in existing commercial or prototype systems in order to inform and inspire a refined generator concept that meets specific performance and design objectives.

The project began with a comprehensive teardown and characterization of each given generator. Mechanical disassembly allowed for a thorough understanding of component layout, manufacturing choices, and material selection. Electrical testing and electromagnetic simulation were conducted to quantify key performance parameters such as back EMF, torque, ripple, resistance, and thermal response under varying loads. The MAD JENNY, characterized by its compact construction and rugged build, offered insights into structural integration and magnetic circuit simplicity. In contrast, the Melon Motor showcased an emphasis on high-efficiency operation and smooth output characteristics, with a more intricate winding scheme and finer tolerances.

Findings from these analyses were used to establish a clear set of performance benchmarks and design criteria. These included optimizing electromagnetic efficiency, reducing mechanical complexity, improving thermal dissipation, and ensuring manufacturability within reasonable cost and material constraints. Leveraging simulation tools such as ANSYS Maxwell and Motor CAD, we created multiple parametric models to explore alternative topologies, magnet placements, stator designs, and coil configurations. Each iteration was evaluated not only for theoretical performance but also for practical considerations such as assembly feasibility and component accessibility.

The concept generation process culminated in the selection of a final design that synthesizes the most successful elements from both the MAD JENNY and Melon Motor, while introducing original innovations aimed at addressing their limitations. Our proposed generator concept maintains a balance between performance, durability, and scalability, making it well-suited for both prototyping and real-world application.

This report captures the full scope of our research and design journey, from the disassembly bench to the simulation environment, and provides a foundation for future prototyping, experimental validation, and refinements. The lessons learned from analyzing the MAD JENNY and Melon Motor not only shaped our final concept but also enriched our understanding of generator design as a multidisciplinary engineering challenge.

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1 BACKGROUND

In the background of the project, the project description, deliverables, and success metrics will be described. The project description explains what the project is about from the client proposal and meetings with the sponsor. The budget and fundraising targets will be discussed. Followed by why this project is important. The deliverables will describe the course, client, and competition specific deliverables that dictate the requirements listed later in Section 2. The success metrics, i.e., assessments, testing, calculations, and major design requirements, will be discussed.

1.1 Project Description

This project tasks us with creating and modifying 3-phase PMSG's to be used in the CWC by the Energy Club here at NAU. It is referred to as the 3D Printed CWC-scale Generators project, but the 3D printed portion is a bit of a misnomer. It means these generators are small scale to be used in the CWC. NAU has experimented with custom generators in the past but has commonly ended up using drone motors that were later modified for the CWC. These generators have performed poorly and lead to problems with lead times and designing around commercially available products rather than custom ones built for the sole purpose of wind competition. To solve these problems, we will first test existing generators with the Energy Club's dynamometer to characterize their performance. Then we will simulate the generators in Ansys Maxwell and MotorCAD, make modifications to current generator designs, and design our own generators to meet the specific design requirements.

The client of the project is NAU Professor David Willy who advises clubs like BAJA and the Energy Club and has over 20 years in the field of renewable energy. He is providing us with \$500 to complete this project, which will be divided amongst the future tasks of testing, modifying, and making generators. We are also tasked by the Capstone professor, Carson Pete, with fundraising at least \$300 to further fund our project. Through a combination of physical and monetary donations through family, friends, and a GoFundMe page, this \$300 goal has already been achieved. Further fundraising will continue to help our need for parts and sensors as the project progresses.

This project is important because it revolves around the renewable wind energy field. Wind energy is a fast-growing industry as it has over doubled the energy provided across the US from 4% in 2014 to 10% in 2023 [1]. The CWC helps students across the country get firsthand experience with this industry and the technology within it. Providing job experience and monetary support to continue succeeding in college and beyond. Producing the generators will help our NAU team perform better in the CWC, providing a greater chance of success in the competition. Helping the NAU team succeed helps NAU succeed. NAU's success will bring more opportunities to future engineering students, providing more resources and opportunities to help up and coming engineers in whatever field they pursue.

1.2 Deliverables

For this project we have deliverables for the class and specific deliverables given to us by our client. These deliverables are:

Week 5: Presentation One

Presentation one entails project description, initial research, customer requirements, engineering requirements, mathematical modeling, benchmarking, scheduling, and our budget.

Week 7: Initial research

Completing initial research for our client entails reading the Fundamentals of Electromagnetics and Brushless Permanent Magnet Motor Design. As well as doing research on the Maxwell equations, and machine design elements.

Week 8: Presentation Two

Presentation two entails engineering calculations, new project requirements, background on the dynamometer, sensors being used in the dynamometer, how those sensors will be included within the Arduino, as well as the new schedule and budget.

Week 8: Report One

Report one includes all of the work we have done to date. This includes all initial modeling, mathematical modeling, dynamometer modifications, schedule, and budget.

Week 8: Website check

This website check is to ensure our website is functional, professional, as well as have separate pages for the project description, Team/About Us, Gallery, and for Documents.

Week 10: Finish Dynamometer

To finish the dynamometer includes redoing the Arduino and making an electrical box to house the Arduino UNO. The Arduino board will have sensors so we can get outputs of rotations per minute (RPM), torque, voltage, and current.

Week 10: Analytical Analysis Memo

The Analytical Analysis Memo will include what topic each team member will be doing for the Individual Analysis assignment.

Week 11: Presentation 3

Presentation three will include the project description, design requirements, initial testing results, simulations, and concept generation.

Week 12: Finish Initial Testing

To Finishing initial testing, we will be testing the two generators we already have on the dynamometer and see how they compare to each other.

Week 12: Initial Simulations

Initial simulations will be done of the two generators we already have. We will be using ANSYS Maxwell as well as MotorCAD to model and test these designs.

Week 13: Modify existing design

Using ANSYS Maxwell or MotorCAD we will modify one of the preexisting generators, this will entail changing the number of magnetic pairings, number of turns in the coil, or the diameter of the wire used in the coil.

Week 14: Report 2

Report Two will include background on the project, customer requirements, engineering requirements, research done to date, mathematical modeling done to date, initial testing results, modified generator, and

concept generation.

Week 14: Individual Analysis

Each team member will take on one topic and justify its importance in reference to our project.

Week 15: Generate our own design

To generate our own design, we will use ANSYS or MotorCad to develop and model our design.

Week 15: Website Check 2

This website check will include all work done up to date. This entails simulations, prototypes, and mathematical modeling.

1.3 Success Metrics

The success of the CWC Generator project will be assessed through a combination of testing results, theoretical calculations, and adherence to major design requirements. Success will first be determined by the generator's ability to meet the core performance specifications established with the client, such as generating a maximum voltage of 48V, achieving a cut-in wind speed near 3 m/s, producing high magnetic flux density, and maintaining a low Kv rating around 150. Performance validation will involve experimental testing on the Energy Club's dynamometer, where outputs including voltage, current, torque, and efficiency will be measured and compared against simulation predictions from ANSYS Maxwell and MotorCAD. Success will also depend on the project's ability to stay within the \$500 provided budget and integrate modifications such as minimizing cogging torque and optimizing stator-magnet ratios, validated through parametric studies and harmonics analysis. Furthermore, meeting fabrication goals, including manufacturability within practical tolerances such as achieving a 0.5 mm air gap and a 0.1636 stator width ratio, will be critical to the project's evaluation. Overall, the project will be deemed successful if the final prototype generator matches or exceeds the modified benchmark standards set by the MAD JENNY and Melon Motor, maintains reliable performance during dynamometer testing, and demonstrates a substantial improvement over previous generator designs used in the CWC.

2 REQUIREMENTS

This section includes key concepts of customer and engineering requirements for designing and developing a generator. A list of requirements was formed after an initial meeting with the client. Using these requirements, the engineering specifications were obtained. The engineering specifications translate the given customer requirements into measurable design criteria.

2.1 *Customer Requirements (CRs)*

Our client is requiring us to make a generator that is:

- Low Voltage
- Small Size
- High power generation
- Under budget
- Ability to change easily
- Up to the CWC design standards
- 3 Phase AC generator

Required Process from Client:

- Analyze one generator from the Energy Club and one bought online
- Number of turns in the coil
- Diameter of wire used in the coil
- Number of magnetic pairings
- Model both existing generators in ANSYS
- Modify one of the existing generators
- Develop our own design in ANSYS
- Compare our design to the modified generator
- Build the generator that performs the best

2.2 *Engineering Requirements (ERs)*

The engineering requirements for this project are-

- Maximum 48 Volts
- 45 cm rotor diameter of the turbine
- Low total resistance torque (Nm)

- Low Kv rating
- High magnetic flux (Tesla)
- High turbine power output (W)
- Number of coils
- Tip speed ratio, between 7 and 8
- Diameter of the coil
- Cut out speed, 25 (m/s)
- Cut in speed, 3 (m/s)

2.3 House of Quality (HoQ)

Minimize or Maximize			Show Correlations here														
House Of Quality			Technical Specifications (How)												Competitive Assessment		
			Maximum 48 Volts	45 cm Roter Diameter of Turblli	Low Total Resistant Torque	Low Kv Rating	Magnetic Flux	Turbine Power	Generator Power	Number of Coils	Tip Speed Ratio	Diameter of coil	Cut Out Speed	Cut In Speed			
	Customer Requirements (What)	Importance	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
1	Low Voltage	96	9	3	9	9	9	9	9	9	3	9	9	9	1	9	3
2	Small Size	60	3	9	3	1	3	9	3	9	9	9	1	1	1	9	1
3	High Power Generation	100	9	1	9	9	9	9	9	9	9	9	9	9	9	3	1
4	Under Budget	28	1	3	1	1	1	3	3	3	3	3	3	3	1	3	9
5	Ability to change easy	60	1	3	3	9	3	3	9	9	9	9	1	1	3	3	1
6	Up to design standards for CWC	102	9	9	9	9	9	9	9	3	9	9	9	9	9	9	3
7	3 phase AC	34	3	3	3	3	3	1	3	9	1	3	1	1	3	9	9
Target			48 V	45 cm	2 N-m	150	1-3 T	100 kW	0.5-10 kW	6 coils	7 to 8	0.321-0.644 mm	25 m/s	3 m/s			
Importance			35	31	37	41	37	43	45	51	43	51	33	33			

Figure 1: House of Quality

3 Research Within Your Design Space

3.1 Benchmarking

3.1.1 MAD 5012 IPE V3.0 Brushless Motor [2]

The MAD 5012 was used in the Energy Club at NAU for the CWC and placed second. The MAD 5012 is SOTA as it was recently used in the CWC and is constantly reused in competitions due to its reliability and success. The MAD 5012 has a Kv rating of 160 and in Figure 1, the client wants a low Kv rating of 100 or below. With this information, the CWC generator team will consider this difference to ensure that the future design of the PMSG will be at least lower than MAD 5012's Kv rating or even lower than 100 Kv. The client also wants a high-power generator and with the MAD 5012, it produces a maximum of 882 W of power. This will be another item of an expected requirement for the PMSG so it can perform as well as the MAD 5012. Benchmarking with this motor is great for the future design of the PMSG as it was a winning generator in the CWC. These values are important as it will lead the CWC generator team to know what target values to reach as they create their own generator.

3.1.2 Air Breeze Wind Turbine Generator [3]

The Air Breeze is SOTA as it is being constantly used by many buyers for their own energy generation, competitions, and much more. The Air Breeze has a power output of 160 W. In Figure 1, the client wants a high-power output. However, seeing the MAD 5012 having a max power output of 882 W, it is obvious that there is a significant difference between the two. With this, we must provide a higher power output of 160 W due to the MAD 5012 producing a power output of 882 W. However, the Air Breeze has a cut-in speed of 3.1 m/s. This is a value that is significant for the PMSG design as the client wants a cut-in speed of 3 m/s. These values have a small difference and will be useful to compare when creating the PMSG design to ensure it gets at least below 3.1 m/s. In addition, the Air Breeze has a cut-out speed of 40.2 m/s. This is a high difference compared to the target value from the customer, which is 25 m/s. So, this will be considered in the design process to ensure we get a lower cut-out speed than the Air Breeze, which will then help the generator and turbine from further damage.

3.1.3 Avian 3536-1200 Kv Outrunner Brushless Motor [4]

The Avian 3536 is SOTA as it was released back in 2022 and is bought by many people for competitions. The Avian 3536 has a max power output of 310 W. This is a better upgrade than the Air Breeze, since the Air Breeze provided 160 W. However, it is still lower than the MAD 5012 and will be considered to make sure that the designs of the PMSG are comparable to the Avian 3536 and the MAD 5012. It is seen in the title of this section that it contains 1200 Kv, which is the highest out of the three systems that were seen. When benchmarking this motor, it is best for the CWC generator team to ensure that the Kv rating doesn't reach the Avian's Kv since it is too high for the client's requirements. Also, it is best to ensure that when creating the PMSG, it must be at least 310 W to provide sufficient efficiency.

3.2 Literature Review

3.2.1 Naomi Echo

Books

[5] Wind Energy Explained, Chapters 2 and 3

Chapter 2 will be used to reference basic characteristics and mathematical modeling. Chapter 3 will be referencing the aerodynamics of the turbine as well as the mathematical explanations.

[6] Performance comparison of electromagnetic generators based on different circular magnet arrangements

Reference for understanding how different magnetic pairings effect power generation.

Papers

[7] Preliminary Studies on Number of Coil Turns per Phase and Distance between the Magnet Pairs for AFPM Ironless Electricity Generator

Reference for understanding the relation between the number of turns within a coil and the power and torque output.

[8] Electric Generators Fitted to Wind Turbine Systems: An Up-to-Date Comparative Study

Reference for understanding how the generator will ingrate within the turbine system.

[9] Optimization and Comparison of Modern Offshore Wind Turbine Generators Using GeneratorSE 2.0

Reference for understanding where the current technology of wind turbines is currently.

Other

[10] How to Calculate Motor Kv & Motor Poles

Reference for understanding the direct correlation of Kv and number of turns in a coil.

[11] Basics of Armatures

Reference for understanding how armatures work and different ways they may be assembled.

3.2.2 Kaitlyn Redman

Books:

[12] Chapter 7: Shafts and Shaft Components - Shigley's Mechanical Engineering Design

This chapter is relevant because it goes into detail about equations used to design shafts.

[13] Chapter 11: Rolling-Contact Bearings – Shigley's Mechanical Engineering Design

This chapter is relevant because it goes into detail about equations used to design bearings.

Journals:

[14] Barings faults and limits in wind turbine generators

This journal is relevant because it goes into detail about the specific limits of wind turbine generators.

[15] Study of turbine-generator shaft parameters from the viewpoint of sub synchronous resonance

This journal is relevant because it goes into detail about shafts specifically in turbine generators.

[16] Optimal bearing configuration selection for power generation shaft-trains: A linear and nonlinear dynamics approach

This journal is relevant because it goes into detail about bearing configurations in power generated shaft-trains.

Website:

[17] Mechanical Engineering Design Unit 9 – Power Transmission: Shafts & Bearings

This website is relevant because it goes into detail about shafts and bearings.

[18] Types of bearings: Uses & Working Mechanisms explained

This website is relevant because it describes the different types of bearings we can use in our design.

3.2.3 Christian Brown

Books

[19] Fundamentals of Applied Electromagnetics

This textbook gave an overview of laws, equations, applications of electro and magnetostatics, and electromagnetics. These equations are fundamental to understanding how the magnets and the generator will act. It gave many different examples to apply to the generators in the future once the proper data has been acquired from them.

[20] A Student's Guide to Maxwell's Equations

This textbook went in-depth about 4 sets of equations from Maxwell and Ampere to understand the electromagnetics of electric generators. These 4 equations are all integrals explaining how magnetic and electric fields interact with one another. These help our understanding of the generator as it created electric currents due to magnetic fields.

[21] Brushless Permanent Magnet Motor Design Version 2 (Chapters 2, 7)

Chapters 2 and 7 from this textbook go into the workings of electromagnets and how they act. It also describes the different calculation strategies to figure out the flux, current, and impedance of electromagnets and the airgap within them. It helps our understanding by drawing similarities between the electromagnets and regular circuits. For example, as resistors are energy dissipaters to circuits, magnets are energy storages top circuits.

Papers

[22] Future research directions for the wind turbine generator system

This paper was a study of the aspects of modern-day wind generation systems and the benefits of PMSG's. It described the other different kinds of generators used in wind energy and how they compare. The different kinds of PMSG's were described in detail, comparing the cored versus coreless generators and their difference in structure and usage.

[23] Electric generators and motors: An overview

This study went into the development and evolution of electric generators over the years. From the first kinds of electric generators and their limited uses to the modern-day generators and the multiple applications they are used for. It described the evolution of our fundamental understanding of

electromagnets and how these were applied over the years.

[24] Mathematical Modelling of Wind Turbine in a Wind Energy Conversion System: Power Coefficient Analysis

This paper studied the fundamental equations that are used to model power output of turbines. This will be useful when testing our generators in the future to be able to compare power curves to see the similarities and differences between the different generators. The calculations will also be applicable when calculating these variables.

Online

[25] Electromagnetics in Power Engineering Maxwell 3D Simulations of a Residential Wind Generator

This is a tutorial for one of the modeling software's to be used to generate data on the electric generators. Ansys Maxwell and the different capabilities are gone into step by step with helpful diagrams and instructions to create the generator. The generator in the tutorial will be one we study in the future to see the different outputs compared to our other generators.

[26] 3d-printed Halbach Motor – Building Instructions

This YouTube video is a full tutorial on creating your own small-scale generator. It goes into depth about the magnets that were used and how they were measured. The coiling strategy to properly construct the coils around the stator. It even shows the different parts they 3D-printed and how they accomplished the correct dimensions in drawing them up.

3.2.4 Alonso Garcia

Books

[27] Magnetostatic Fields, in Fundamentals of Electromagnetics with MATLAB

This chapter talks about the important properties of time-independent static magnetic fields. It mentions related topics to our project like electrical currents, magnetic forces, magnetic circuits, and inductance. These specific topics are applied to the project because this is the basic understanding of how rotors and stators interact with each other and how it creates power based on these forces and currents.

[28] Time-Varying Electromagnetic Fields, in Fundamentals of Electromagnetics with MATLAB

This chapter talks about the application of static electricity and magnetic fields for time-varying cases. The most important topic of this chapter is Maxwell's Equations. These equations are important and applicable to this project because it will help relate the electromagnetic fields of our future design of a PMSG.

Papers

[29] Research on cogging torque optimization design of permanent magnet synchronous wind turbine

This paper talks about using the Taguchi algorithm optimization process for suppressing cogging torque. This algorithm works by looking over local parameters of the generator and seeing what can be changed to decrease the cogging torque. This paper is applicable since it provides data to lowering cogging torque and which approach is more efficient.

[30] Cogging Torque Reduction Based on a New Pre-Slot Technique for a Small Wind Generator

This paper talks about methods of reducing cogging torque. The main methods are Pre-Slot and Manufacturing Aspects, which helped approve lowering cogging torque. The Pre-Slot method would help our project by making pre-allocated slots between the stator poles which will help reduce torque. Additionally, manufacturing aspects will be applicable too because if the manufacturing of a part we make is almost perfect, then it'll help lower cogging torque.

[31] Cogging torque analysis in permanent magnet synchronous generators using finite element analysis

This paper talks about machine-based optimizations of minimizing cogging torque (fragmented magnet structure, opening notch magnet, and more). The fragmented magnetic structure, opening notch magnet, and many other methods are applicable to this project since each of these showed improvement of lowering cogging torque. Also, they showed the drawbacks of these methods. So, we can use this information to determine which is the better approach we can take without losing other important aspects of the PMSG.

Online

[32] Module 29: Permanent Magnet Rotor Design (SPM & IPM)

This video talked about the overview of designs of permanent synchronous rotors with figures to show benefits/drawbacks. This is applicable to our project since it shows many applications of applied designs for PMSG, which will help with our design process.

[33] Cogging torque of the turbine generator analysis with QuickField FEA software

This video works out the problem of finding cogging torque but explains with software to better understand why cogging torque exists. This is applicable to our project because we can use this to find results of our design, which in this case is finding cogging torque.

3.2.5 Javan Jake

Books

[34] Electric Motors and Drives: Fundamentals, Types and Applications: Fundamentals, Types and Applications

This book explains the physics behind how electrical energy is converted to mechanical energy (motors) and vice versa (generators).

[35] Design of Rotating Electrical Machines, 2nd Edition

Explains how electric machines convert energy, a fundamental concept in generator design. Since generators operate on the principle of electromagnetic induction, understanding these basics is essential.

Papers

[36] Systematically study on the static power-angle characteristics of a high voltage cable-wound generator prototype

Provides mathematical models and simulations to predict how the generator will behave under different conditions, which is essential for designing and optimizing generator performance.

[37] The effect of electromagnetic load on the basic dimensions of induction salient pole generators

Explores how electromagnetic load affects the magnetic leakage factor and basic dimensions of an induction generator with a salient pole rotor, providing essential information for optimizing generator efficiency.

[38] Operating the induction motor as a generator mode by supplying DC voltage and investigation of the end voltage depending on the excitation current and RPM

Experimental insights into how a three-phase wound-rotor induction motor can function as a generator by applying DC excitation to the rotor, making it useful for repurposing existing motors.

Other

[39] Understanding KV rating in brushless motors

Provides the different factors determining KV, the impact it has on motor performance, and selecting the appropriate rating for different applications.

[40] What does ‘Kv’ mean on brushes motors? Kv explained!

In-depth researching of the impacts of factor determining KV and specification application.

3.3 Mathematical Modeling

To support the design and evaluation of the proposed generator concept, mathematical modeling was used to predict electromagnetic behavior, mechanical performance, and thermal characteristics. These models were based on physical principles and informed by empirical data gathered from the MAD JENNY and Melon Motor reference units.

3.3.1 Tip Speed Ratio - Naomi Echo

$$\lambda = \frac{\text{Blade Tip Speed}}{\text{Wind Speed}} = \frac{\Omega \cdot R}{U}$$

$$\Omega = \text{Rotational Speed of the Turbine} \left[\frac{\text{rad}}{\text{s}} \right]$$

$$R = \text{Radius of Blade [m]}$$

$$U = \text{Wind Speed} \left[\frac{\text{m}}{\text{s}} \right]$$

The desired tip speed is 7-8, as this is industry standard [5]. Using a typical wind speed of 12 m/s we can find that the blade tip speed will need to be 84 m/s.

3.3.2 Thrust Force – Alonso Garcia

$$F_T = \frac{4\pi R^2 \rho U^2}{9}$$

F_T - Thrust force [N]

R – Radius of Turbine blade [m]

ρ - Density of air [kg/m³]

U – Air speed [m/s]

This equation finds the thrust force created as the turbine is rotated by the air. It also considers the turbine to be operating at Betz Limit to allow conservative calculations by setting its inference factor, a , as $1/3$. This is not listed above since this will allow an estimation for calculating this force.

3.3.3 Shaft Diameter – Alonso Garcia

$$d = \left\{ \frac{16n}{\pi} \left(\frac{2K_f M_a}{S_e} + \frac{1}{S_{ut}} [3(K_{fs} T_m)]^{\frac{1}{2}} \right) \right\}^{\frac{1}{3}}$$

d – Diameter of shaft [mm]

n – Safety factor

k_f - Fatigue stress concentration factor

M_a - Alternating moment [N-mm]

S_e - Endurance limit [MPa]

S_{ut} - Ultimate strength [MPa]

K_{fs} - Fatigue stress concentration factor

T_m - Mid-range torque [N-mm]

This equation is the distortion energy (DE) Goodman equation that helps determine the diameter of a shaft with a pre-defined material that considers torque and moments acting on the shaft. However, this equation has been simplified to due to the assumption that the shaft of the generator has constant torque and moments acting on the shaft [25].

3.3.4 Wire Diameter – Kaitlyn Redman

$$J = \frac{I}{A}$$

$$J = \text{Current Density} \left[\frac{A}{m^2} \right]$$

$$I = \text{Current} [A]$$

$$A = \text{Cross – Sectional Area} [m^2]$$

This equation is used to find the cross-sectional area of the wire so that it can be used to find the diameter.

$$d = \sqrt{\frac{4A}{\pi}}$$

$$d = \text{Diameter [m]}$$

$$A = \text{Cross – Sectional Area [m}^2\text{]}$$

This equation is used to find the diameter of the wire; it is then cross referenced with the American Wire Gauge chart to find the Gauge number needed.

$$R = \rho \frac{L}{A}$$

$$\rho = \text{Resistivity of Copper [\Omega m]}$$

$$L = \text{Total Length of Wire [m]}$$

$$A = \text{Cross – Sectional Area [m}^2\text{]}$$

$$R = \text{Resistance of Wire [\Omega]}$$

This equation is used to find the resistance so that it can be used to calculate power loss of the wire.

$$P_{\text{copper}} = I^2 R$$

$$P_{\text{copper}} = \text{Power Loss of Copper [A}^2\Omega\text{]}$$

$$R = \text{Resistance of Wire [\Omega]}$$

$$I = \text{Current [A]}$$

This equation is used to find the power loss of the copper, with the goal of minimizing it as much as possible

3.3.5 Magnetic Flux

$$B = \mu_0 \cdot \frac{N \cdot i}{g}$$

$$B = \text{Magnetic Flux Density [T]}$$

$$\mu_0 = \text{Permeability of air [H/m]}$$

$$N = \text{Number of turns}$$

$$I = \text{Current [A]}$$

$$g = \text{Air gap length [m]}$$

This equation is to show the simplify equation for Ansys. These equations demonstrate the Magnetic Flux density and Cogging Torque in 3D vector form

3.3.6 Cogging Torque

$$T_{\text{cog}} = -\frac{dW_c}{d\theta} = T_{\text{cog}}(\theta) = A_n \sin(n_1 \theta) + \dots$$

$$T_{\text{cog}} = \text{Cogging torque}$$

$$W_c = \text{Magnetic co-energy}$$

$\theta = \text{Rotor position}$

$A = \text{Amplitude}$

$n = \text{Harmonics Number}$

In this equation, this supports the way to model cogging torque ripples. Both papers you uploaded directly talk about using harmonic/Fourier series to model cogging torque (1). Real generators have multiple harmonics (28, 56, 84...).

4 Design Concepts

4.1 Functional Decomposition

The important function of this project is to ensure it meets the needs of the customer requirements. These specific requirements are to make sure that the generator outputs a high voltage, high power, low Kv rating, and be able to change the parameters within the generator for the NAU CWC team. These requirements are important to the project since these are the basic requirements for a general generator and the customer's needs are satisfied.

4.2 Concept Generation

Coils-

The coils of the generator wrap around the stator arms, and each generate electricity. The number of turns in a coil is one of the main components that determines the peak voltage and torque. These are the values that affect the Kv rating and power generation. From ANSYS simulation we were able to conclude that the high number of turns creates high voltage and torque. The main cons with high number of turns are that it will increase the difficulty of the manufacturing process as well as make the generator more difficult to spin because of the increased torque.

Air Gap-

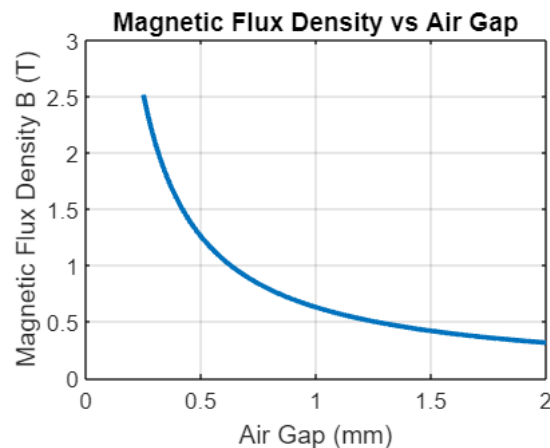


Figure 2: Magnetic Flux Density vs Air Gap

Figure 2 illustrates the effect of varying the air gap on magnetic flux density. As the air gap length

decreases, the magnetic flux density increases significantly. This behavior is expected because a smaller air gap reduces magnetic reluctance, allowing more concentrated magnetic flux between the rotor and stator. The graph supports the optimization choice of designing for a minimized air gap, showing that reducing the air gap size improves magnetic performance, which is critical for maximizing generator efficiency. Through systematic variation of the air gap and stator slot width ratio, we identified that a 0.5 mm air gap configuration provided the highest magnetic flux density, thereby optimizing electromagnetic performance while maintaining practical manufacturing tolerances.

Magnet and Slot Ratio-

The ratio of slots to magnets is important to consider when making any electrical motor or generator. It determines the performance of the generator and different ratios work better for different sizes and applications of generators. The two concepts being considered for this ratio are the same ratios in MAD JENNY and Melon Motor. MAD JENNY has a ratio of 24 slots to 28 magnets while Motor Melon has half of each, 12 slots and 14 magnets. The testing showed that each produces an even 3-phase distribution of magnetic flux and voltage, so further consideration is needed to determine which is better for our design constraints. The ratio of 24 slots and 28 magnets will be more difficult to manufacture than 12 and 14 due to increased complexity of the geometry and needing to fit more magnets into the same geometry. Though with more slots and magnets, there is less cogging frequency because the magnetic flux is distributed over more stator arms with smaller magnets. These will be important to consider when moving forward with the concept generation.

Shaft and Bearings-

```
Inputs
Generator
V - Voltage output from generator
P - Power output from generator
Kv - Constant voltage rating from generator

V = 48; % V
P = 10; % kW
Kv = 150; % Kv Rating

Turbine
D_b - Diameter of turbine blade
m_b - Total mass of blades and hub
h - Distance from centerline of shaft to thrust force

D_b = 45; % cm
m_b = 2; % lb (rough approx from Willy)
h = 7; % cm Distance for aerodynamic forces (thrust)

Shaft
L_lip - Length of thrust lip
L_b_b - Length of bearing to bearings from the outside part of them (Look in FBD)
L_hub - Length of hub
rho_al - Density of shaft material (Use aluminum)
Su - Material ultimate strength
K - Stress concentration factors

NOTE: Additional tables will be provided to help determine numbers for this estimation

L_lip = 3; % mm (subject to change)
L_b_b = 9; % mm (Length from end of bearing to other end of bearing)
L_hub = 3; % mm (Length where connection from blade will occur)
rho_al = 2830; % kg/m^3

Su = 324; % MPa (2011 Aluminum in Table A-22)
Kt = 1.7; % Assuming we're using a rounded fillet in Table 7-1
Kts = 1.5; % Assuming we're using a rounded fillet in Table 7-1
Kf = Kt; % Quick Conservative test
Kfs = Kts; % Quick Conservative test

a = 2.7; % Table 6-2
b = -0.265; % Table 6-2

Ka = a * Su^b; % Eq. 6-19
Kb = 0.9; % Guess
Kc = 1;
Kd = Kc;
Ke = Kd;

n = 3;
```

Figure 3: MatLab Code for Shaft and Bearing Bore Diameter

In Figure 3, it shows the inputs needed from the generator, shaft material, and turbine properties. These inputs are to be used for determining values like shear force, bending moment, torque, and diameter of shaft. After the code runs, it will display the shaft diameter needed based on the given inputs. With the current inputs in Figure 3, the shaft diameter was determined to be 4 mm for aluminum. With this shaft diameter, the bore diameter of the bearing can be chosen. This would be 4 mm as well.

Other concept generations within the shaft were bearings, thrust lip, and material. To start off, steel and aluminum were concepts for the shaft material. Steel is known for being a strong material and we want the shaft to withstand the forces applied from the turbine. However, steel is magnetic and can disrupt the magnetic field while the generator is spinning. So, aluminum was the final choice since it is not magnetic and reliable choice from many other PMSGs. Next, the bearing selection was either deep-grooved or cross roller bearings. Cross roller bearings are typically used within companies making rotors but are expensive compared to deep-grooved bearings. Deep-grooved bearings are the typical bearings seen anywhere in an engineering system and it would best fit this project due to its cost and availability. Lastly, the thrust lip was introduced into this concept generation because the shaft can cause the bearings to slip along it, which can make the generator fail. So, a thrust lip was added and the results from Figure 3 can determine the thrust lip diameter. Figure 3 shows the thrust lip of the shaft.

4.3 Selection Criteria

Coils-

The selection criteria for determining how many turns in a coil we will use only considering the number of turns that correlates to a wire gauge we are able to buy. As well as the voltage, torque, power, and Kv rating. An additional tool to analyze the voltage and torque in addition to the numerical values is analyzing the shape of the graphs. We are aiming for graphs that are consistent and symmetrical for voltage and current. To calculate the values Motor CAD was used to simulate the results of the voltage, current, and torque. These results were then inputted into a MATLAB code to calculate the Kv and Power. The table below displays all of the numerical results.

Table 1: Number of Turns in a Coil Results

Number of Turns	Gauge Size	Voltage (V)	Torque (N*m)	Current (amps)	Kv	Power (Watts)
30	21	10.36	.048	10	121.9	179.44
38	22	16.38	.06	10	77.11	263.7
49	23	28.6	.073	10	44.16	495.36

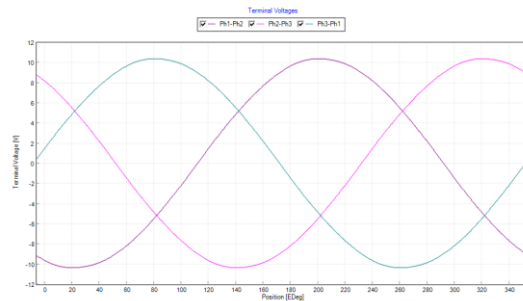


Figure 4: 30 Turn Voltage

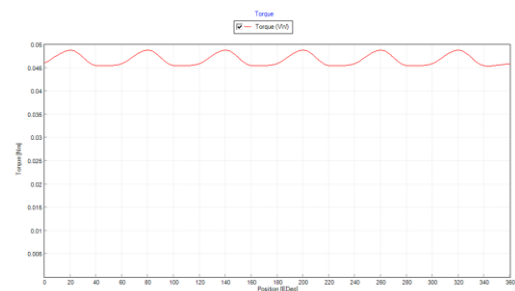


Figure 5: 30 Turn Torque

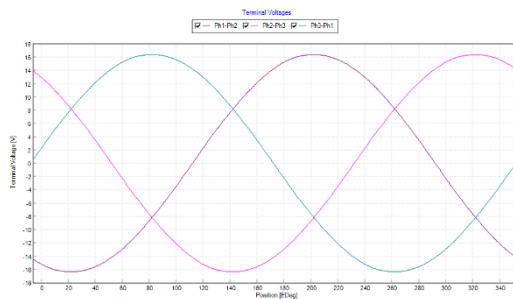


Figure 6: 38 Turn Voltage

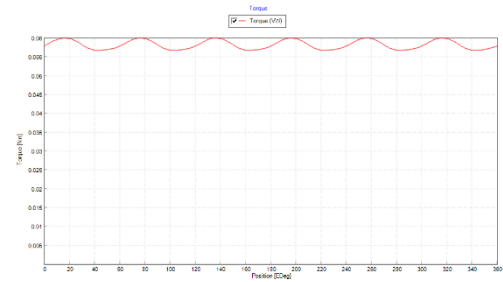


Figure 7: 38 Turn Torque

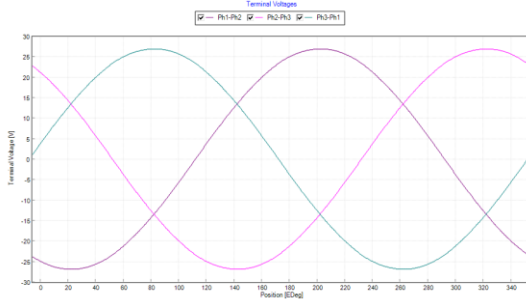


Figure 8: 49 Turn Voltage

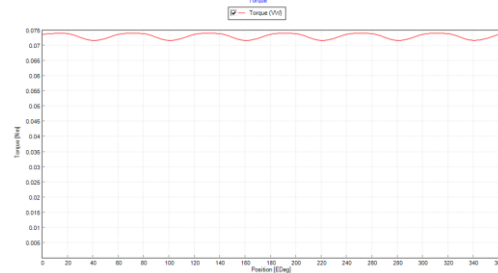


Figure 9: 49 Turn Torque

Magnet and Slot Ratio-

An online resource was used to help with the magnet and slot ratio concept generation and selection of the final concept, the equation and table below were utilized from this resource [41]. One parameter that helps reduce the concept generation to the most optimal ratios is the q factor. The inputs are the number of slots, magnets and phases.

$$q = \frac{N_s}{N_{ph} \cdot N_m} \quad (1)$$

Equation 1 shows q is the fraction of the slots per pole per phase of the generator. A q less than one denotes a concentrated winding generator, which is part of the 3-phase design. A q that is less than 0.25 is suboptimal as it means that the magnets are so small, multiple will go over the same stator arm at the same time. This produces conflicting magnetic fluxes as the magnets alternate between north and south around the rotor. A q greater than 0.5 is also suboptimal as it means a magnet will pass over multiple slots at the same time. This is no longer optimal for a concentrated winding and would be better applied to a distributed winding, where the coils wrap around the entire stator as opposed to a single stator arm. This combined with symmetry of magnets to slots and unbalanced ratios reduces the optimal concepts drastically.

Table 2: Cogging Frequency of Multiple Slot and Magnet Ratios

Ns	Nm	2	4	6	8	10	12	14	16	18	20	22	24	26	28
3	NoSym	NoSym	UnBal	q < 0.25	q < 0.25	UnBal	q < 0.25	q < 0.25	UnBal	q < 0.25	q < 0.25	UnBal	q < 0.25	q < 0.25	q < 0.25
6	q > 0.5	12	UnBal	24	q < 0.25	UnBal	q < 0.25	q < 0.25	UnBal	q < 0.25	q < 0.25	UnBal	q < 0.25	q < 0.25	q < 0.25
9	q > 0.5	q > 0.5	18	NoSym	NoSym	36	q < 0.25	q < 0.25	UnBal	q < 0.25	q < 0.25	q < 0.25	q < 0.25	q < 0.25	q < 0.25
12	q > 0.5	q > 0.5	UnBal	24	60	UnBal	84	48	UnBal	q < 0.25	q < 0.25	UnBal	q < 0.25	q < 0.25	q < 0.25
15	q > 0.5	q > 0.5	UnBal	q > 0.5	30	UnBal	NoSym	NoSym	UnBal	60	q < 0.25	UnBal	q < 0.25	q < 0.25	q < 0.25
18	q > 0.5	q > 0.5	q > 0.5	q > 0.5	q > 0.5	36	126	144	UnBal	180	198	72	q < 0.25	q < 0.25	q < 0.25
21	q > 0.5	q > 0.5	UnBal	q > 0.5	q > 0.5	UnBal	42	NoSym	UnBal	NoSym	NoSym	UnBal	NoSym	84	84
24	q > 0.5	q > 0.5	UnBal	q > 0.5	q > 0.5	UnBal	q > 0.5	48	UnBal	120	264	UnBal	312	168	168

Shown above in Table 2 is many different slot and magnet combinations from the absolute minimum of 2 magnets and 3 slots to the MAD JENNY ratio of 28 magnets and 24 slots. The ratios where q is in suboptimal range, the asymmetrical, and the unbalanced ratios are exempted from the calculation of the cogging frequency to narrow down the possible concepts. A higher cogging frequency is typically better when creating a generator. A higher cogging frequency correlates to a lower cogging torque at any single

instance. This is due to the amplitude of the cogging torque reducing as the frequency increases, creating what is closer to a line rather than a sine wave of varying torque. Looking at the two initial concepts of the MAD JENNY and Melon Motor ratios, the 24 slots and 28 magnets ratio appears more optimal having twice the cogging frequency than 12 slots and 14 magnets. The Pugh chart will help decide between the concepts with the selected parameters.

Air Gap-

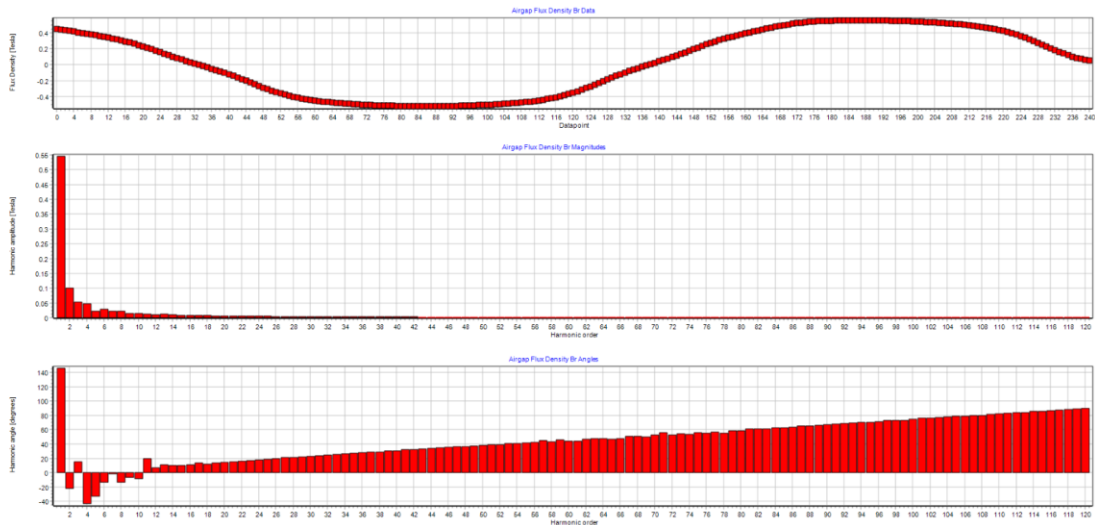


Figure 10: Flux Density with Air gap 2mm

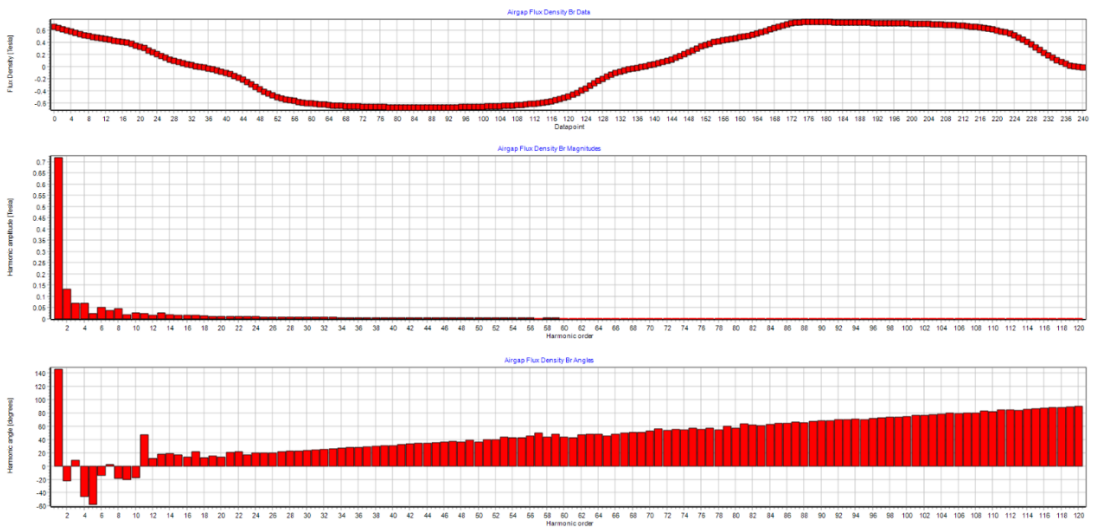


Figure 11: Flux Density with Air gap 1mm

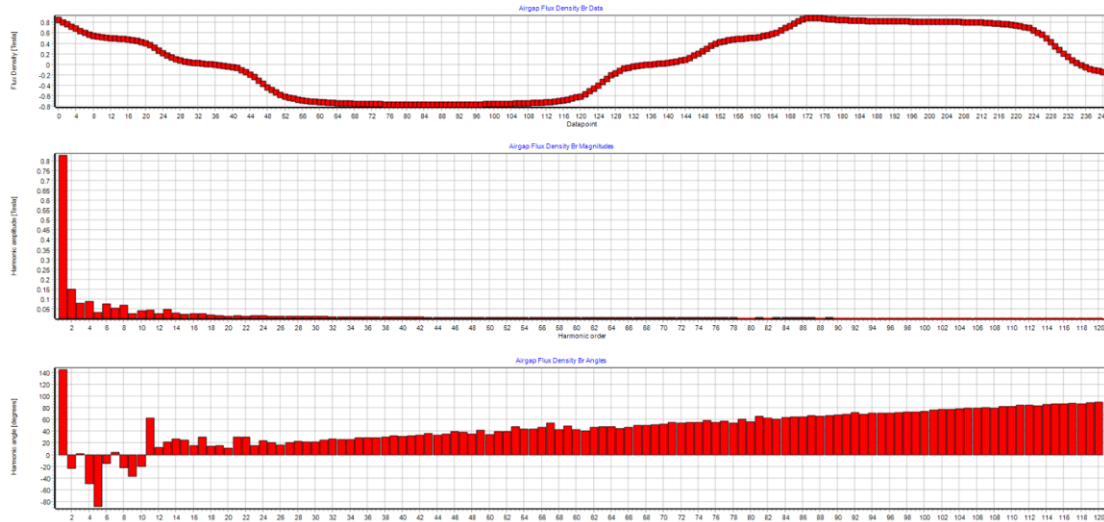


Figure 12: Flux Density with Air gap 0.5mm

From figures it shows the data from ANSYS which shows three different graphs.

Graph 1: Airgap Flux Density by Data (Top Graph)

This plot shows the variation of magnetic flux density (B) along the airgap of the generator or motor across different degrees of rotation (likely in electrical degrees or mechanical degrees). The x-axis represents position (or angular displacement), and the y-axis shows the flux density in Tesla (T). The wave-like shape indicates the periodic nature of the flux distribution across the airgap due to alternating poles of magnets. The smooth sinusoidal profile suggests good electromagnetic design with minimal distortion.

Graph 2: Airgap Flux Density by Magnitudes (Middle Graph)

This is a histogram of magnetic flux density magnitudes. It shows how frequently certain flux densities occur in the airgap. The majority of flux density values are concentrated around the lower end (left side of the graph), meaning that a large portion of the airgap experiences low-to-moderate flux. A few areas have high flux, corresponding to areas directly between stator and rotor poles.

Graph 3: Airgap Flux Density by Angles (Bottom Graph)

This histogram shows the flux density variation as a function of angle. It visualizes the harmonic content of the flux wave by indicating how different angular components contribute to the flux density. The sharp peaks and increase in height across angle indices suggest that harmonic distortion is present. Lower-order harmonics dominate, which is typical in practical machines.

In addition to air gap optimization, the stator slot design was refined by increasing the stator width to 9 mm, which resulted in a gap between stators of 1.47 mm and a corresponding slot width ratio of 0.16.

While literature recommends an ideal ratio between 0.13 and 0.15 for minimal cogging torque and optimal flux performance, manufacturing and machining limitations made achieving a 0.13 ratio impractical. Therefore, the selected configuration represents a balanced compromise between the best theoretical practices and realistic fabrication capabilities

Shaft and Bearings-

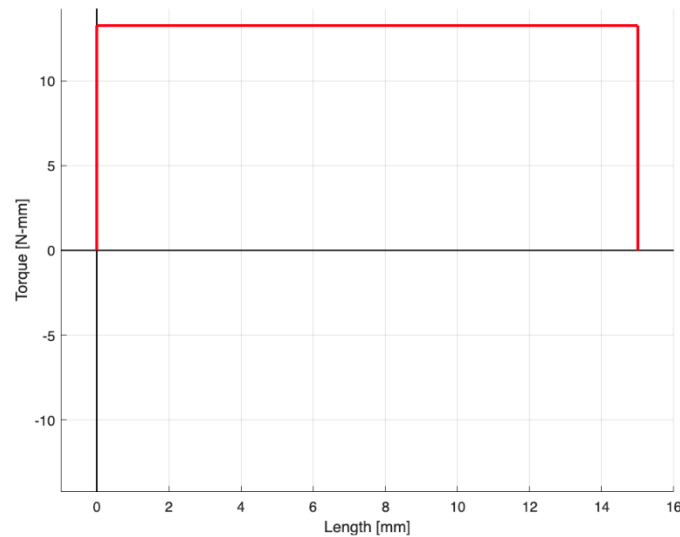


Figure 13: Torque Diagram Along Shaft

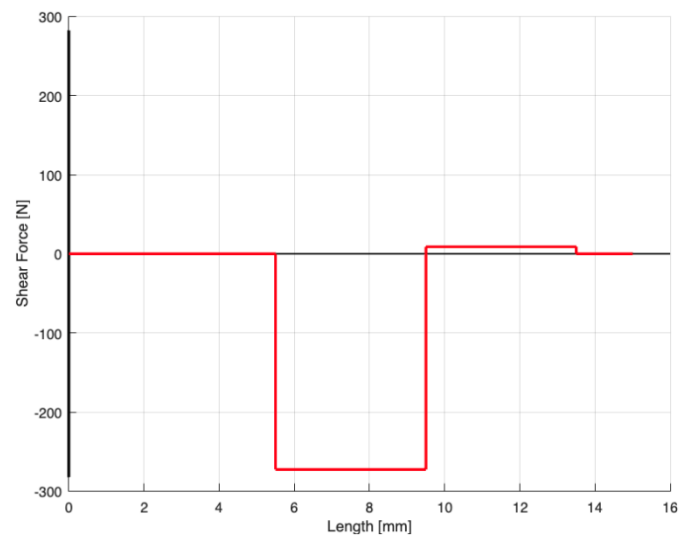


Figure 14: Shear Force Along Shaft

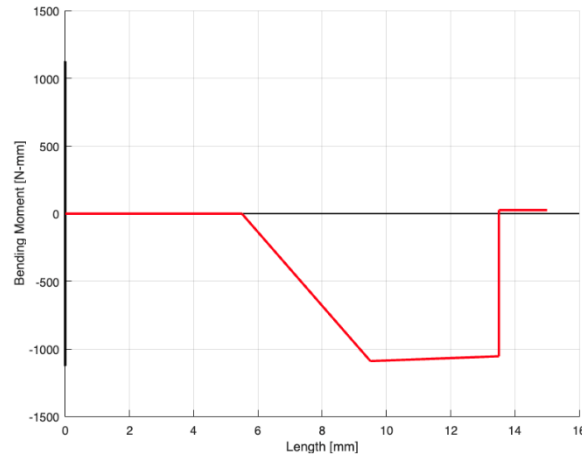


Figure 15: Bending Moment Along Shaft

In Figures 13, 14 and 15, these graphs are needed to find the absolute maximum value point of stress acting along the shaft. After finding this value, it will be used to apply the DE-Goodman equation to find the diameter of the shaft so it can withstand the stresses in it. The results previously mentioned was a 4 mm shaft for a 15 mm length shaft. This length can change during the design process but we saw it best fit to keep the length short so there isn't any increasing bending moment, which will then cause deformation to the shaft.

4.4 Concept Selection

Coils-

Table 3: Coils Pugh Chart

Characteristics	30 Turn	38 Turn	49 Turn
Voltage (Volts)	-	+	+
Current (amps)	0	0	0
Torque (N*m)	-	+	-
Kv	-	+	+
Power (Watts)	-	+	+
Manufacturing	+	+	-
Graph Shape	-	+	+
Total	1	6	4

This Pugh chart has calculated that the 38-turn generator performs the best, so this is what will be used in our design.

Magnet and Slot Ratio-

Table 4: Magnet and Slot Ratio Pugh Chart

Characteristics	12 Slots 14 Magnets	24 Slots 28 Magnets
Cogging Frequency	-	+
Complex Geometry	+	-
Number of Magnets	+	-
Total	2	1

Based on the Pugh chart and the different parameters to consider mentioned in the concept generation section, the 12 slots and 14 magnets ratio is the concept that will be implemented into the final design.

Air Gap-

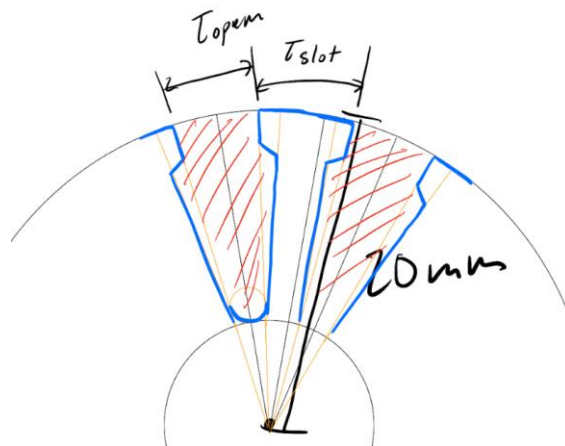


Figure 16: Diagram of Stator

In Figure 16 shows where the T_{open} and T_{slot} are on the stator for reducing the cogging torque. This value will be the result of the stator ratio width in Table 5.

Table 5: Stator Ratio Width

Stator Width (mm)	Width Between Stators (mm)	Ratio Width
8	2.4720	0.3090
8.2500	2.2220	0.2693
8.5000	1.9720	0.2320
8.7500	1.7220	0.1968
9	1.4720	0.1636
9.2500	1.2220	0.1321

9.5000	0.9720	0.1023
9.7500	0.7220	0.0740

Table 5 presents a comparison of different stator slot width ratios, defined as the ratio of the open slot width to the total slot pitch. This ratio plays a critical role in determining the magnetic flux distribution and cogging torque behavior of the generator. The slot width ratio influences the airgap flux linkage, and the harmonic distortion present in the system.

Shaft and Bearings-

Table 6 - Material of shaft Pugh Chart

<i>Characteristics</i>	Steel	Aluminum
Strength	+	-
Cost	-	+
Non-Magnetic	-	+
Total	1	2

Table 7 - Bearings Pugh Chart

<i>Characteristics</i>	Deep-Grooved	Cross Roller
Strength	+	+
Cost	+	-
Total	2	1

In Tables 6 and 8, the chosen material and bearings for the shaft are aluminum and deep-grooved, respectively. These were chosen to withstand the forces that the shaft will encounter. Aluminum was chosen since the shaft can't interfere with the magnetism within the generator as it can cause the generator to lose its efficiency. The deep-grooved bearing was chosen due to its cost and availability.

5 Schedule and Budget

5.1 Schedule

Initiation					Testing				
Define goals	Everyone	100%	1/23/25	1/24/25	Learn ANSYS	C.B./K.R.	100%	2/22/25	3/6/25
Develop team charter	Everyone	100%	1/24/25	1/26/25	Learn MotorCAD	J.J./N.E.	100%	2/22/25	3/6/25
Do tutorials on SolidWorks	Everyone	100%	1/24/25	1/26/25	Build generator in ANSYS	Cristian Brown	100%	3/7/25	3/29/25
Meet with Dr. Willy	Everyone	100%	1/27/25	1/31/25	Build generator in ANSYS	Kaitlyn Redman	100%	3/7/25	3/29/25
Initiator website	Alonso Garcia	100%	1/29/25	2/3/25	Build generator in MotorCAD	Naomi Echo	100%	3/17/25	3/29/25
Meet with Kevin Brown	Everyone	100%	1/31/25	2/4/25	Build generator in MotorCAD	Javan Jake	100%	3/17/25	3/29/25
Research cogging torque	Alonso Garcia	100%	1/31/25	2/19/25	Build new gen in ANSYS	Kaitlyn Redman	10%	4/16/25	4/20/25
Research Kv	Javan Jake	100%	1/31/25	3/19/25	Expoxy vs super glue	Naomi Echo	100%	4/9/25	4/20/25
Research tip speed ratio	Naomi Echo	100%	1/31/25	2/19/25	flux leakage al vs steel	Naomi Echo	100%	4/15/25	4/20/25
Research shaft & bearings	Kaitlyn Redman	100%	1/31/25	2/19/25	Test exsiting generator	C.B./J.J.	95%	3/10/25	4/4/25
Research air gap size	Christian Brown	100%	1/31/25	2/19/25	Test Modify generator	Naomi Echo	100%	4/4/25	4/11/25
Complete/revise presentation	Everyone	100%	1/31/25	3/19/25	Test new generator	C.B./J.J.	0%	4/18/25	4/22/25
Take apart generator and alternator	Everyone	100%	2/4/25	2/13/25	Evaluation/Deliverables				
Planning and design					Compare current generators	Everyone	100%	3/12/25	4/5/25
Create schedule	Naomi Echo	100%	2/5/25	2/9/25	Magnetic Flux analysis, maxwell	Christian Brown	10 0%	3/24/25	4/3/25
Identify deliverables	Naomi Echo	100%	2/7/25	2/13/25	Magnetic fluz analysis, motorcad	Javan Jake	100%	3/24/25	4/3/25
Develop Budget	Javan Jake	100%	2/12/25	3/19/25	Coil analysis, motorcad	Naomi Echo	100%	3/24/25	4/3/25
Finish dyno	Alonso, Naomi	95%	2/12/25	3/19/25	Coil analysis, maxwell	Kaitlyn Redman	100%	3/24/25	4/3/25
Solder dyno	Naomi Echo	100%	2/14/25	3/19/25	Modified vs New gen.	Everyone	0%	4/23/25	5/5/25
Replace Dyno Screen	N.E.	100%	2/19/25	2/21/25	Report 1	Everyone	100%	2/12/25	3/3/25
Electrical box for dyno	Naomi and Alonso	100%	2/14/25	3/19/25	Report 2	Everyone	20%	3/30/25	4/25/25
4 min Adapter to test gen.	Kaitlyn Redman	100%	2/14/25	2/24/25	Presentation 1	Everyone	100%	1/31/25	2/9/25
Temperature Sensor	Naomi Echo	100%	2/21/25	2/25/25	Presentation 2	Everyone	100%	3/10/25	3/14/25
Voltage Sensor	Javan Jake	100%	2/21/25	2/25/25	Presentation 3	Everyone	100%	3/24/25	3/30/25
Current Sensor	Kaitlyn Redman	100%	2/21/25	2/25/25	Prototype 2- super glue vs epoxy	Naomi Echo	100%	4/18/25	4/25/25
Temp Sensor	Christian Brown	100%	2/21/25	2/25/25	Prototype 2- negative stator with lam C.B.		75%	4/18/25	4/25/25
Arduino Code	Alonso Garcia	100%	2/21/25	3/25/25	Stator Cad	Christian Brown	100%	4/14/25	4/17/25
Make Arduino Schematic	Alonso Garcia	100%	2/24/25	3/1/25	Negative Stator Cad	Christian Brown	100%	4/15/25	4/22/25
Build Arduino Board	Naomi, Alonso	100%	3/10/25	3/14/25	Case Cad	Javan Jake	0%	4/7/25	4/22/25
Ch. 1.6, 10	Naomi Echo	100%	2/17/25	3/1/25	Website Check 1	Alonso Garcia	100%	3/3/25	3/9/25
Ch. 1.2, 7, 10	Christian Brown	100%	2/17/25	3/1/25	Website Check 2	Alonso Garcia	20%	3/18/25	5/5/25
Ch. 1.6, 10	Alonso Garcia	50%	2/17/25	4/2/25					
Ch. 1.3, 8, 10	Javan Jake	100%	2/17/25	3/1/25					
Ch. 1.6, 10	Kaitlyn Redman	100%	2/17/25	3/1/25					
make tachometer adapter	Naomi Echo	100%	3/24/25	3/31/25					
make L bracket for generator	Alonso Garcia	100%	3/26/25	4/5/25					
Make pags for Arduino (possibly?)	Alonso Garcia	90%	4/1/25	4/2/25					
make stand for the electrocukle	Alonso, Naomi	0%	3/30/25	4/2/25					
concept gen for our own design	Naomi Echo	100%	4/3/25	4/19/25					
concept gen for our own design	Alonso Garcia	100%	4/3/25	4/19/25					
concept gen for our own design	Javan Jake	50%	4/3/25	4/19/25					
concept gen for our own design	Kaitlyn Redman	100%	4/3/25	4/19/25					
concept gen for our own design	Christian Brown	100%	4/3/25	4/19/25					
Plan for manufacturing	Naomi Echo	100%	4/9/25	4/19/25					
Modify generator	Naomi Echo	100%	3/6/25	4/5/25					
Design new generator	Everyone	100%	4/1/25	4/19/25					

Figure 17: Gantt Chart Spring 2025

Initiation				
Update Dr. Willy on any progress during the summer	Everyone	0%	8/25/25	8/29/25
Modify existing generators	Everyone	0%	8/25/25	9/22/25
UGRADS Registration	Everyone	0%	10/20/25	10/26/25
TBA	TBA			
Planning and design				
Build our own generators	Everyone	0%	9/22/25	10/27/25
33+% Build	Everyone	0%	8/25/25	9/22/25
67+% Build	Everyone	0%	9/23/25	10/13/25
Draft of Poster	Everyone	0%	10/27/25	11/2/25
100+% Build	Everyone	0%	10/14/25	11/3/25
Final Poster	Everyone	0%	11/10/25	11/30/25
Initial Testing Results Video	Everyone	0%	11/4/25	11/17/25
Product Demo	Everyone	0%	11/18/25	11/24/25
Final Testing Results Video	Everyone	0%	11/18/25	11/24/25
Practice Presentation	Everyone	0%	12/1/25	12/7/25
TBA	TBA	0%		
Testing				
Test all built generators	Everyone	0%	10/27/25	11/24/25
TBA	TBA			
Evaluation/Deliverables				
HW 00	Everyone (Individual)	0%	8/25/25	8/31/25
Project Management	Everyone	0%	8/25/25	8/31/25
Engineering Calculations	Everyone	0%	9/1/25	9/7/25
Self-Learning or Individual Analysis	Everyone (Individual)	0%	9/1/25	9/14/25
Peer Evaluations 1	Everyone (Individual)	0%	9/22/25	9/28/25
Website Check #1	AG	0%	10/6/25	10/12/25
Testing Plan	Everyone	0%	10/13/25	11/2/25
Peer Evaluations 2	Everyone (Individual)	0%	10/20/25	10/26/25
Peer Evaluations 3	Everyone (Individual)	0%	11/10/25	11/16/25
Final CAD Packet	Everyone	0%	11/17/25	11/23/25
Final Report	Everyone	0%	11/24/25	11/30/25
Final Website Check	AG	0%	11/24/25	11/30/25
Peer Evaluations 4	Everyone (Individual)	0%	12/8/25	12/14/25
Client Handoff	Everyone	0%	12/8/25	12/14/25

Figure 18: Gantt Chart Fall 2025

As this semester comes to an end, the deliverables for ME 476C will be the main things to be worked on. This includes finishing CAD for the system of the generator, modifying previous generators, and cleaning up any extra work for the Dyno. As for ME 486C, the main deliverables to start working would be building the actual generator as the next semester comes to an end. However, the client will be reached out to attain more work to do that can be done over the summer.

5.2 Budget

Budget & Fundrasing			
Find No.	Company:	Description:	Amount:
1	Gofundme	Online donation for capstone team. Can be shared through friends, family, and social media.	\$120.00
2	Team	Cash Donation	\$ 80.00
3	Materials & tools	Tools and Materials that were donations throughout the course	\$ 95.95
4	Northern Arizona Uni	Capstone budget	\$500.00
		Total:	\$795.95

Figure 19: Budget and Fundraising

The budget for the capstone is shown in Figure 19 of \$700 and the rest is donations from third parties. These third parties given materials and tools to help with the project.

Dynamometer	Prototype 1	Prototype 2	Final Product
14%	21%	25%	40%

Figure 20: Future Expense

Figure 20 is for the future expenses for our prototypes where 14% already went to developing the dynamometer and the rest is for next semester's product.

5.3 Bill of Materials (BoM)

Bill of Material				
Find No.	Company:	Description:	Cost	Purchase/Not Purchase
1	Amazon	IR Infrared Obstacle Avoidance Sensor IR transmitting Arduino	\$ 9.99	Purchase
2	Amazon	5pcs 30A range current Sensor Module Arduino	\$ 11.99	Purchase
3	Amazon	Electric Motor	\$ 9.99	Purchase
4	Amazon	LCD Screen Display Module Blue Backlight X 2	\$ 39.96	Purchase
5	Amazon	ElectroCookie Solerale Breadboard	\$ 8.49	Purchase
6	Amazon	LeMotech Electrical Box 5.9"x3.9"x2.8"	\$ 15.99	Purchase
7	The Home Depot	Black Rubber Cord	\$ 2.64	Purchase
8	Harbor Feight	3pc Poxxy Glue	\$ 9.14	Purchase
9	Amazon	Ball Bearings Bore 4mm OD 10mm ID 5mm	\$7.64	Purchase
		Total:	\$108.19	

Figure 21: Up to Date Bill of Materials

The majority of the expenses are updated for the course which was for the dynamometer. More materials will be considered next semester for the future products of the generators.

6 Design Validation and Initial Prototyping

6.1 Failure Modes and Effects Analysis (FMEA)

Potential failures of this design is the shaft experiencing much more effects that were not considered in the analysis. In short, the analysis used a high safety factor to consider the effects that were not included in the analysis.

6.2 Initial Prototyping

Super Glue vs Epoxy:

Super glue or epoxy will be used to adhere the magnets to the rotor. The strength of each material was tested as well as its ease of use. Knowing the capabilities of each material will greatly impact our design because it affects the durability of the generator, manufacturing process, as well as the design of the air gap. 919 super glue and ET5441 epoxy were used in this testing. The results below clearly show that the super glue was much stronger than the epoxy used.

Table 6: Epoxy Force Testing Results

Trial	Force Applied Until Failure (lbs)
1	72.2
2	81.3
3	91.1
4	81.1
5	55.4

Table 7: Super Glue Force Testing Results

Trial	Force Applied Until Failure (lbs)
1	126.1
2	133.4
3	167.3
4	187.2
5	143.3

The next aspect that was assessed was how easy it was to use. To activate the epoxy both components had to be mixed and then painted onto the steel being used in testing. This was very messy and time consuming, the epoxy also took a full twenty-four hours to fully cure. The super glue was much easier to use; I was able to apply a small dot of glue on to the area straight from the tube. The super glue cured almost immediately and was very easy to use. From our findings that the super glue was very quick and easy to use as well and was able to withstand a much larger force than the epoxy, we will be using it in

our design to adhere the magnets to the rotor.

6.3 *Future Testing Potential (Kaitlyn)*

Our future testing includes using ANSYS Maxwell and the Dynamometer to simulate real-world conditions on the following model:

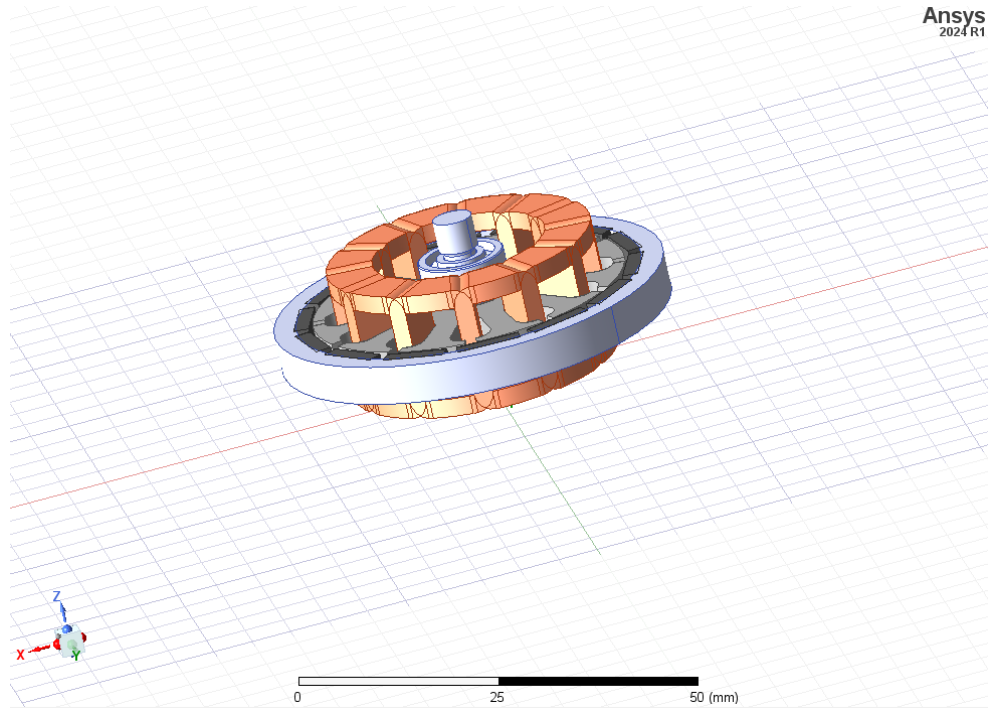


Figure 22: Final CAD Generator

7 CONCLUSION

This report has documented the full process of developing a custom generator design tailored for low-speed, high-torque wind turbine applications. Beginning with a thorough teardown and analysis of two reference generators we identified key design strengths, performance trade-offs, and common failure points. These insights informed the development of our own concept, which was evaluated through iterative modeling, simulation, and engineering analysis. Parametric modeling in ANSYS Maxwell and Motor CAD, combined with analytical tools, enabled us to optimize electromagnetic performance, thermal behavior, and manufacturability. Key design decisions, including stator geometry, magnet arrangement, and wire gauge selection, were supported by mathematical justification and simulation results. Wire diameter analysis ensured that our design maintains electrical reliability and thermal safety under expected operating conditions. Our final generator concept combines proven strategies from the reference designs with original improvements to efficiency, robustness, and ease of assembly. This design is now ready to move into the prototyping and testing phase, where real-world validation will further refine its performance. This project demonstrates structures and data-driven approach to generator design, highlighting the value of reverse engineering, simulation tools, and collaborative problem-solving in developing practical energy solutions.

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