

CWC-scale Generators

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Project Description

- CWC Team typically buys generator for competition
- Goal: Create a generator to be modified by CWC Team
- Sponsored by Professor David Willy
- Solves multiple problems
 - Design around commercially available vs custom parts
 - Availability and lead times of commercial products
 - Modularity to match aerodynamic requirements

Required Process

- Analyze two generators from The Energy Club
 - Number of turns in the coils
 - Number of magnetic pairs
- Modify one generator from the Energy Club
- Develop our own design and compare it to the modified generator
- Build the generator that preformed the best in the simulations

Benchmarking

- Winning generator given by Kevin Bruns, MAD5012
- Air Breeze Wind Turbine Generator, 160W
- Avian 3536-1200Kv Outrunner Brushless Motor



Figure 1: Energy Club Generator



Figure 2: Air Breeze Wind Turbine



Figure 3: Avian Outrunner Brushless Motor

QFD

Minimize or Maximize																		
House Of Quality			Technical Specifications (How)												Competitive Assessment			
			Maximum 48 Volts	45 cm Roter Diameter of Turbine	Low Total Resistant Torque (Nm)	Low Kv Rating	Magnetic Flux(Tesla)	Turbine Power(W)	Generator Power(W)	Number of Coil	Tip Speed Ratio	Diemeter of coil(mm)	Cut Out Speed(m/s)	Cut In Speed(m/s)				
	Customer Requirements (What)	Importance	1	2	3	4	5	6	7	8	9	10	11	12		1	2	
1	Low Voltage	2	9	3	9	9	9	9	9	9	3	9	9	9		1	9	
2	Small Size	3	3	9	3	1	3	9	3	9	9	9	1	1		1	9	
3	High Power Generation	4	9	1	9	9	9	9	9	9	9	9	9	9		9	3	
4	Under Budget	2	1	3	1	1	1	3	3	3	3	3	3	3		1	3	
5	Ability to change easy	3	1	3	3	9	3	3	9	9	9	9	1	1		3	3	
6	Up to design standards	5	9	9	9	9	9	9	9	3	9	9	9	9		9	9	
7	3 phase AC	4	3	3	3	3	3	1	3	9	1	3	1	1		3	9	
Target			48 V	45 cm	2 Nm	TBD	TBD	TBD	TBD	TBD	7 to 8	TBD	25 m/s	3 m/s				
Importance			35	31	37	41	37	43	45	51	43	51	33	33				

Literature Review

Books

[1] 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.

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

Reference for understanding how different magnetic pairings effect power generation

Papers

[3] 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

[4] 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

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

Reference for understanding where the current technology of wind turbines are currently

Other

[6] How to Calculate Motor Kv & Motor Poles

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

[7] Basics of Armatures

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

Literature Review

Books

[8] 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.

[9] 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

[10] Bearings faults and limits in wind turbine generators

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

[11] 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

[12] 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.

Websites

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

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

[14] 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.

Literature Review

Books

[15] Fundamentals of Applied Electromagnetics

Overview of laws, equations, applications of electro and magnetostatics, and electromagnetics.

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

Four sets of equations from Maxwell and Ampere to understand the electromagnetics of electric generators.

Papers

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

Aspects about the modern-day wind generation system and benefits of synchronous generators, PMSG.

[18] Electric generators and motors: An overview

Development and evolution of electric generators.

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

Fundamental equations used to model power output of turbines.

Online

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

A tutorial on one of the modeling software's to be used to generate data on the electric generators.

[21] 3d-printed Halbach Motor – Building Instructions

A tutorial on developing, constructing, coiling, and benchmarking magnets.

Literature Review

Books

[22] Magnetostatic Fields, in *Fundamentals of Electromagnetics with MATLAB*

The important properties of time-independent static magnetic fields

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

Application of static electricity and magnetic fields for time-varying cases (mainly Maxwell's Equations)

Papers

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

Taguchi algorithm optimization process for suppressing cogging torque

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

Methods of reducing cogging torque (Pre-Slot Method & Manufacturing Aspects)

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

Machine based optimizations of minimizing cogging torque (fragmented magnet structure, opening notch magnet, and more)

Online

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

Overview of designs of permanent synchronous rotors with figures to show benefits/drawbacks

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

Worked out problem of finding cogging torque but explains with software to better understand why cogging torque exists

Literature Review

Books

[29] 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).

[30] *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

[31] 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.

[32] 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.

[33] 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

[34] Understanding KV rating in brushless motors

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

[35] What does 'Kv' mean on brushes motors? Kv explained!

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

Cogging Torque

$$T_{cog} = -\frac{1}{2} \Phi_m^2 \frac{dR}{d\theta}$$

T_{cog} - Cogging Torque

Φ_m - Flux due to the Magnets
Crossing the Air Gap

R - Reluctance Viewed by the
Magnetomotive force

θ - Angular Position of the Rotor

- An "almost constant value R for any rotor position" will allow a low cogging torque [25]

Constant Voltage (KV)

$$KV = \frac{rpm}{V} = \frac{\text{Revolutions per minute}}{\text{Volts}}$$

Max Voltage: 48V

KV Range: 100-200

$$rpm = KV \times V$$

$$rpm = 100 \times 48 = 4800$$

$$rpm = 200 \times 48 = 9600$$

Measure of number of revolutions per minute that motor turns when 1V is applied with no load [35]

Tip Speed Ratio

$$\lambda = \frac{\text{Blade tip speed}}{\text{Wind speed}} = \frac{\Omega R}{U}$$

U = Wind Speed

R = Radius

Ω = Rotational Speed of Turbine

- Maximizes power output[1]
- Rotational speed needs to be fast enough, so the wind is utilized efficiently[1]
- Desired tip speed ratio is 7-8

Shafts and Bearings

Torsional Shear Stress: $t = Tr/J$,
where,

- T is torque
- r is the distance from the neutral axis
- J is the polar moment of inertia

Power: $P = T\omega$, where,

- T is torque
- ω is angular velocity

Bending Stress: $\sigma = My/I$, where,

- M is moment
- y is distance to center
- I is moment of inertia

Optimum Air Gap Size

μ_0 = air permeability

H = external magnetic field strength

m = magnetic moment

B_m = max flux density in air-gap

g = thickness of magnet

δ = air-gap length

B_r = remanence (residual magnetism)

H_c = coercivity of magnet (resistance to external field w/o demagnetizing)

$$\mu_0 = 4\pi \cdot 10^{-7} \frac{H}{m}$$

$$B_m = \frac{2g\mu_0 B_r H_c}{B_r \delta + 2g\mu_0 H_c}$$

Budget

Initial budget: \$500

Plan to raise the money:

- GoFundMe donation
- Raised: \$150

Anticipated expense: \$300

Actual Expense to date: \$0

Schedule

Planning and design				
Create schedule	Everyone	50%	2/5/25	2/9/25
Identify deliverables	Naomi Echo	50%	2/7/25	2/12/25
Develop budget	Javan Jake	70%	2/12/25	2/15/25
Finish dyno	Everyone	0%	2/12/25	3/1/25
Modify generator	Everyone	0%	3/8/25	3/27/25
Design new generator	Everyone	0%	4/1/25	4/15/25
Testing				
Learn ANSYS	N.E./C.B./K.R.	0%	2/7/25	2/19/25
Learn MotorCAD	A.G./J.J.	0%	2/7/25	2/19/25
Build generator in ANSYS	N.E./C.B./K.R.	0%	2/20/25	2/24/25
Build generator in MotorCA	A.G./J.J.	0%	2/20/25	2/24/25
Test exsiling generator	Everyone	0%	3/2/25	3/7/25
Test Modify generator	Everyone	0%	3/28/25	4/9/25
Test new generator	Everyone	0%	4/16/25	4/20/25
Evaluation/Deliverables				
Compare current generator	Everyone	0%	3/4/25	3/7/25
Modified vs New gen.	Everyone	0%	4/21/25	5/3/25
Report 1	Everyone	0%	2/12/25	3/3/25
Report 2	Everyone	0%	3/30/25	4/14/25
Presentation 1	Everyone	100%	1/31/25	2/9/25
Presentation 2	Everyone	0%	3/10/25	4/14/25
Website Check 1	Alonso Garcia	50%	2/23/25	3/17/25
Website Check 2	Alonso Garcia	0%	3/18/25	5/5/25

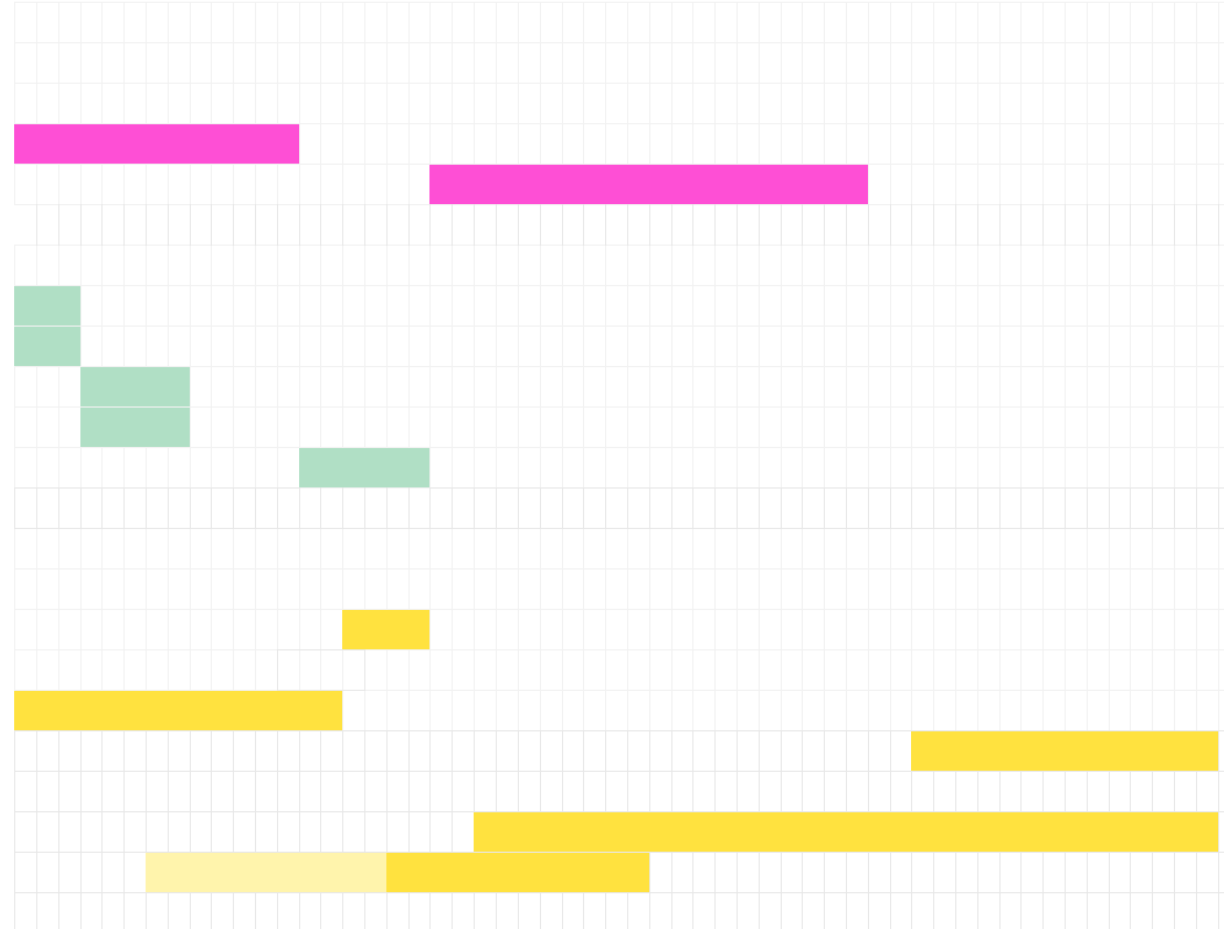


Figure 4: Gantt Chart

Moving Forward

- Take apart the Energy Clubs generator as well as an alternator
- Finish building dynamometer
- Use ANSYS and MotorCAD to simulate the generators



Figure5: Alternator

Thank you

Any Questions?

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