Sustainable Energy Group Design Project 3
Group 5

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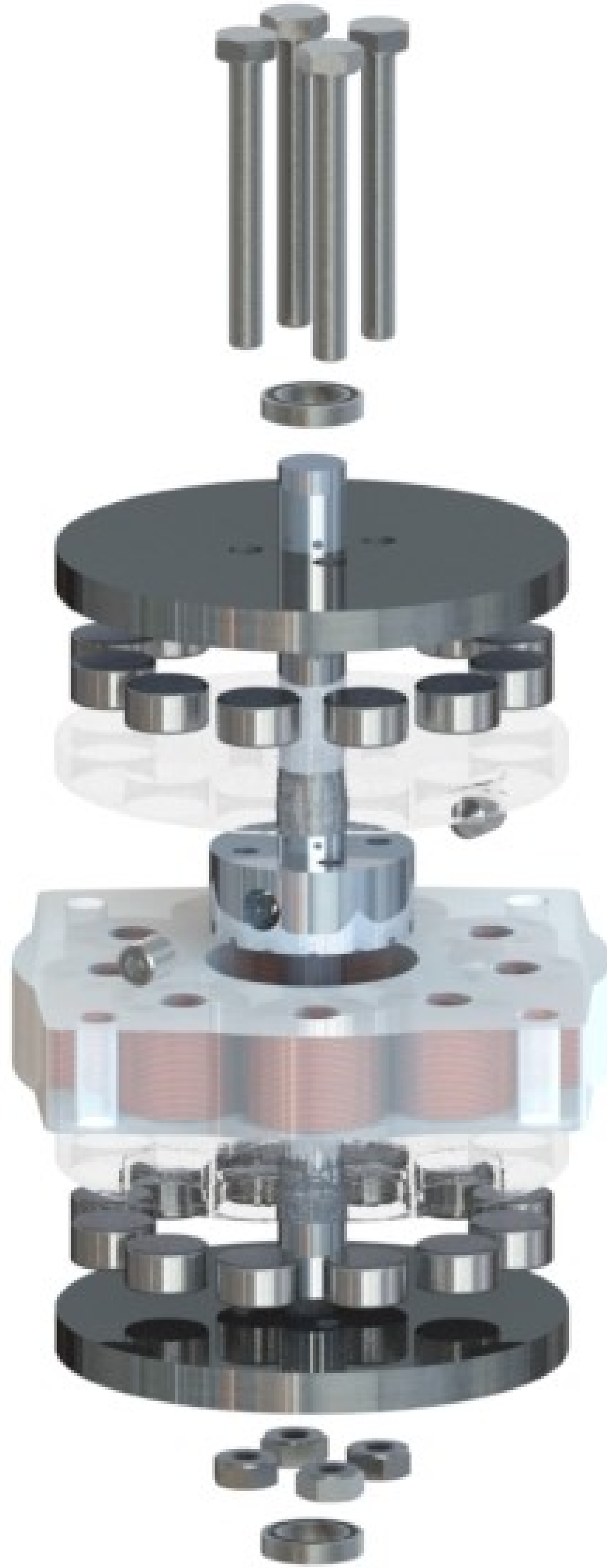
Contents

1. List of symbols

ai	pole arc to pole pitch ratio
Bmg	magnetic flux density on magnet surface (T)
Br	remanent magnetic flux density (T)
dc	copper diameter (mm)
Din	generator inner diameter (mm)
Dout	generator outer diameter (mm)
Ef	electro-magnetic force (V)
fnom	generator nominal frequency (Hz)
g	mechanical clearance gap (mm)
Hc	coercive field strength (A/m)
Iacmax	maximum AC current (A)
Jmax	maximum current density (A/mm2)
kd	inner to outer radius ratio kf coil fill factor
ksat	saturation factor
n	generator RPM
Nc	number of turns per coil
nnom	nominal RPM
Nphase	number of turns per phase
Pnom	generator nominal power (W)
pcu	copper density (kg/m3)
Q	total number of coils
sc	copper crosection (mm2)
tw	stator axial thickness (m)
vw	wind speed (m/s)
wc	coil side width (m)
wm	permanent magnet radial width (m)
la	permanent magnet axial width (m)
η	generator efficiency
λopt	optimum tip speed ratio
μrrec	recoil permeability
Φmax	maximum magnetic flux (Wb)
C	capacitance of a smoothing capacitor (F)
$\triangle$t	half-period (ms)
$\triangle$U	ripple voltage (V)
I	charge current in (mA)



2. Introduction

The whole design project was split within my team into roles and corresponding parts where I was responsible for electronics and design. Hence, my part was to design and manufacture a generator and required electronics to achieve given for the wind turbine requirements. To accomplish my task, I have researched different types of generators, their manufacturing technologies and applications. Proceeding from a chosen generator and an available microcontroller (Arduino Uno) my next step was to focus on a suitable and efficient design of an electrical circuit with the required components being available from provided suppliers.

The given design is mainly based on the lectures made by Dr Uwe Stein of The University of Edinburgh and on Wind Engineering Volume 36, pages 411 to 442, by K.C. Latoufis[2]. Based on the book the Block Diagram (Figure 1.1) of the whole wind turbine system was drawn. The decision on the type of the generator to be used is relying on the information and a comparative Table 1 (page 119) made by Olver Probst in the paper Small Wind Turbine Technology[4]. Hence, considering the pros and cons of each type of generator, it was decided to use an axial flux permanent magnet synchronous generator which is very popular and well-documented design for a smallscale wind turbine. Therefore, for the calculations, I have used the theory form the already stated book and Axial Flux Permanent Magnet Generator, by N Bannon[1]. My manufacturing process which I have not fully completed I have relied on A wind turbine recipe book, by Hugh Piggott[3]. Electrical design was only based on stated lectures.

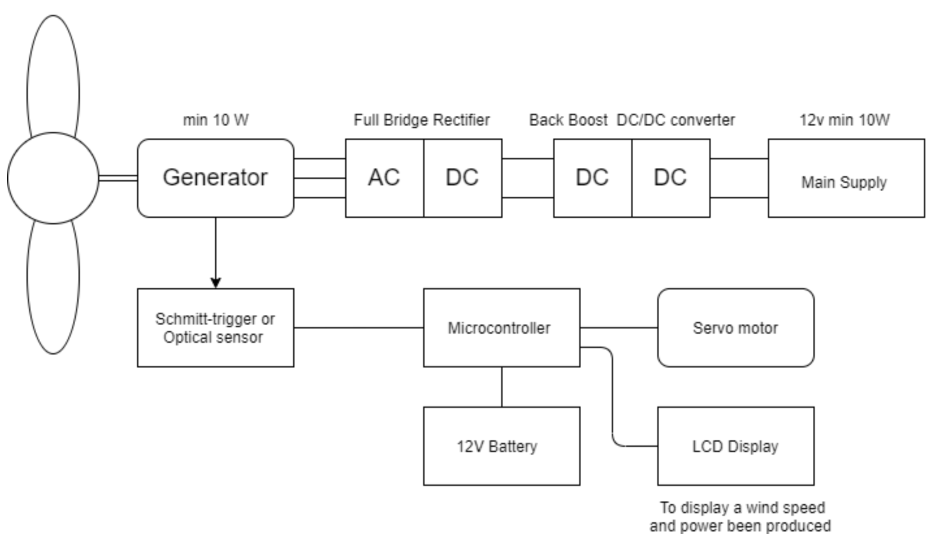


Figure 2.1: Block Diagram of the whole system

3. Final Design

3.1 Generator Design

For a generator the decision was made to use a dual rotor, single stator axial flux permanent magnet synchronous generator (PMSG), due to relatively simple manufacture and having an advantage of a modular design, which is conceptually attractive for small-scale wind turbines. Also, this design has a negligible starting torque. To decrease copper losses N52 magnets were chosen which require less current to be produced for the same power output. The output voltage frequency is not relevant as it is immediately converted to a DC voltage, but it should be below 500 Hz. By considering the rotor and magnet size it was decided to use six pole pairs giving 127Hz at 2540 rpm, where rotation speed was made optimal for a wind speed of 12m/s with a tip speed ratio of 3 and radius of 13.5cm. For coils a star connection is used, enable us to get a higher voltage to a speed ratio in comparison to delta connection.

$$fnom = \frac{n \times p}{120} = 127Hz$$

$$Q = \frac{3 \times p}{4} = 9coils$$

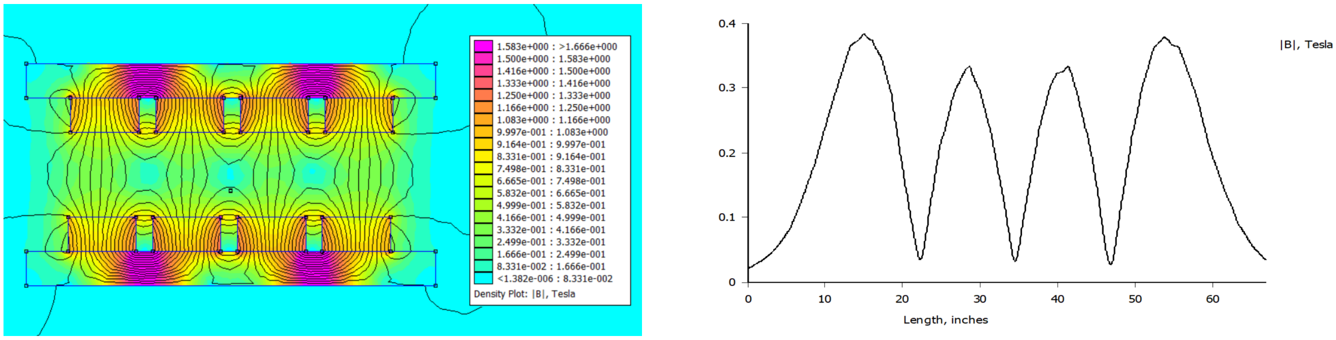
A generator dimensions were calculated relying on recommended values and equations from Wind engineering[2]. In which it was recommended to use back-iron disks with the same thickness as magnets(5mm) and a maximum current density of 6A/mm2. For a magnetic flux density (Bmg), the simulation in Finite Element Method Magnetics software (Femm 4.2) was made and it predicted a flux to be 0.35 Tesla for the worst-case scenario, where the coils are furthest away from both rotors. Substituting those numbers in the formulas below the size of a stator, the number of coils and diameter of copper could be calculated, which in theory are 12.3cm, 158turns and 0.43mm. However, due to manufacturing constraints, some values have been adjusted and the final values have been stated in Table 3.1.

$$\mu_{\mathrm{rrec}} = \frac{Br}{\mu_0 \times H_{\mathrm{c}}}$$

$$B_{\mathrm{mg}} = \frac{B_{\mathrm{r}}}{1 + \mu_{\mathrm{rrec}} \times \frac{(g+0.5t_{\mathrm{w}})}{h_{\mathrm{m}}} \times k_{\mathrm{sat}}} \quad \Longrightarrow t_{\mathrm{w}} = 12.3cm$$

$$\Phi_{\max} = B_{\mathrm{mg}} \times \omega_{\mathrm{m}} \times l_{\mathrm{a}} = 7.7 \times 10^{-5} Wb$$

Figure 3.1: Finite Element Method Magnetics software (Femm 4.2)



(a) Flux generated by magnets

(b) Flux at the worst-case scenario

$$N_{\mathrm{c}} = \frac{\sqrt{2}E_{\mathrm{f}} \times 120}{q \times 2\pi \times k_{\mathrm{w}} \times \Phi_{\mathrm{max}} \times n \times p} = 158 turns$$

$$I = \frac{1.1 \times P_{turbine}}{3 \times V_{EMF} \times \eta_{gen}} = \frac{1.1 \times 20}{3 \times 12 \times 0.7} = 0.87A$$

$$J_{max} = \frac{I_{acmax}}{} = 6A/mm^2 \Rightarrow s_c = 0.145mm$$

$$d_c = \sqrt{\frac{4 \times s_c}{\pi}} = 0.43mm \Rightarrow \text{Copper wire with a diameter of 0.511mm was used}$$

Table 3.1: Generator dimensions

Generator Characteristics		**Rotor**		**Stator**	
Nominal Power	20W	Iron Disks Thickness:	5mm	Coils Axial thickness	12.5mm
Nominal Frequency	127Hz	Inner Rotor Diameter	8mm	Coil leg width	3.5mm
Pole Pairs	6	Outer Diameter	60mm	Turns per Coil	161
Coil Number	9	Magnets Axial Thickness	5mm	Copper diameter	0.511mm
		Diameter of a magnet	10mm		

3.2 Electronics

In electronics my part was to design a full bridge rectifier with a DC-DC Boost Buck converter. Where the rectifier to decrease a voltage drop was built from Schottky diodes and as a converter, a Step Up, Step Down Converter (XL6009) was used, with input range 3.8V - 32V. To smoothen induced voltage a 0.4mF was fitted in parallel to a rectifier. For protection, a solid stay relay, a 1.5A fuse and 14V Zener diode were implemented, which can physically disconnect the load from the generator in case of emergency. The relay is controlled by Arduino Uno, which needs to be programmed.

$$C = I \times \frac{\triangle t}{\triangle U} = 333\mu F \;\Rightarrow \text{0.4mF was used in a design}$$

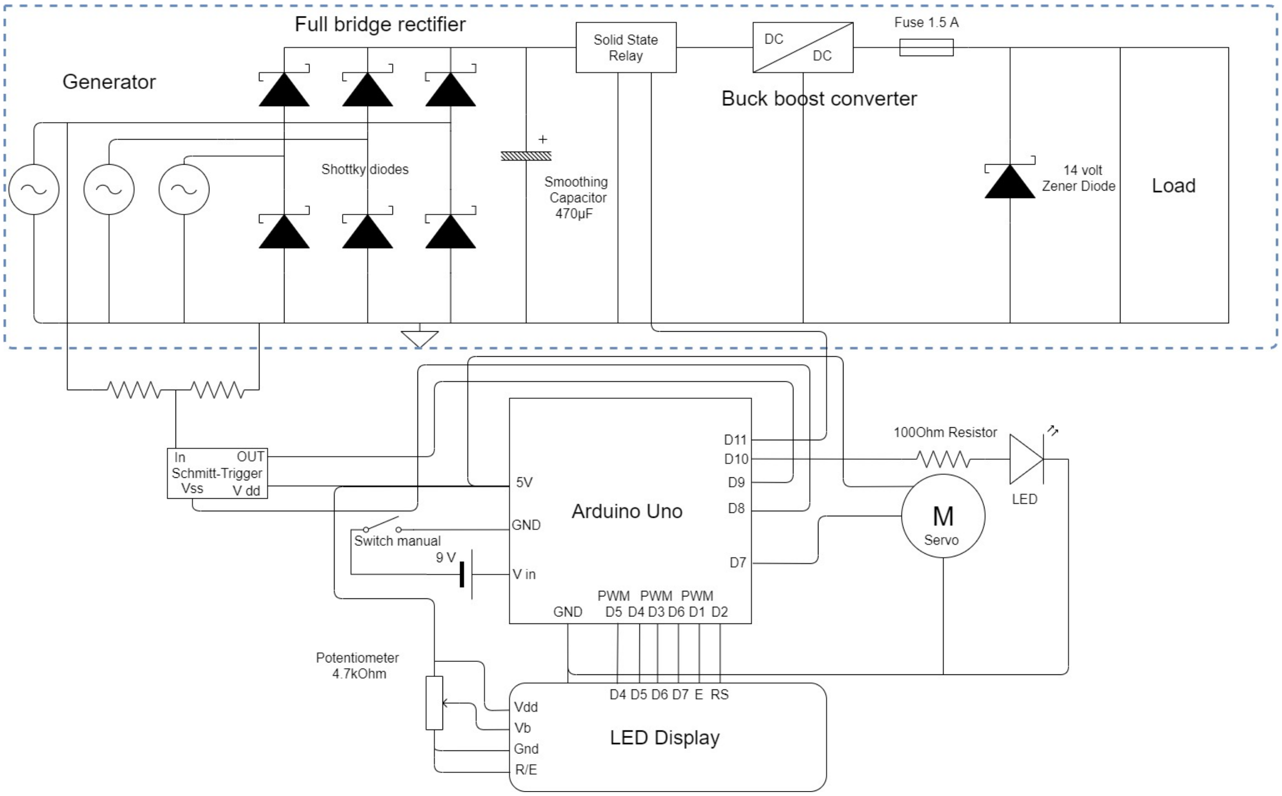
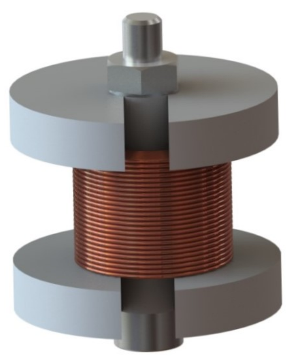


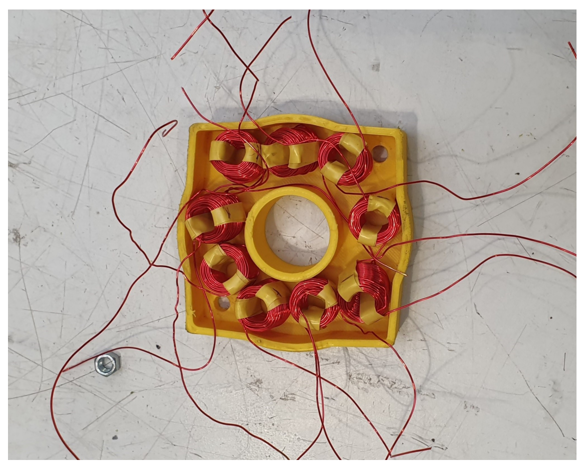
Figure 3.2: Electrical schematic/circuit. My part is a blue area.

4. Manufacturing

The generator was built-in steps. First, back iron disks were designed in CAD and laser cut. Besides, magnets and electronics components were ordered. Due to manufacturing constraints, holes were not perfect and were improved by drilling. Secondly, using 4mm of an acrylic, parts were laser cut which was holding magnets on top of back-iron disks. Then magnets, as well as those parts, were glued to iron disks. Thirdly, I have 3D printed parts (Figure a) for a coil winding and using a drill have winded 9 coils clockwise. The final step which was completed was to 3D print a casing for casting a rotor using a provided epoxy (Figure b). For an electrical circuit, I have only made a full bridge rectifier which was consist of provided in a laboratory Schottky diodes and by using a digital oscilloscope and signal generators I have looked at the output curves. As one of the conclusions for the stated test is that signal generators in an electrical lab can be out of calibration and each probe for a digital oscilloscope must be calibrated before attaching to pins.



(a) Wiring tool



(b) Casing for casting

To complete generator manufacturing my team would need to finish a stator and make a rotor connector to a shaft. For a stator, all coils must be soldered to produce a 3 phase star connection. To avoid any further frustrations all coils must be checked for continuity using a multimeter and be arranged clockwise with a heat shrink being placed on one of its ends before soldering. The Next step would be casting for which the casing would be needed to be covered in cellophane, otherwise epoxy will stick the casing and the stator together. At the same time, rotor to a shaft connector would need to be 3D printed, which would be attached to a shaft via socket set screw cone points. Therefore, bolts which connect rotors would also pass through the connector making a rigid connection between two rotors. Hence, the air gap of a 1mm could be more feasible to maintain. After the generator is constructed and tested the electrical components would be needed to be adjusted and soldered onto a stripboard.

5. Impact of the Covid-19

The lockdown due to the Covid-19 has cancelled all the labs since the 22nd of March and later all kinds of public places including libraries, making everyone isolate themselves at their homes. For me, it is resulted in losing motivation to continue to do the project at the same pace and getting more antisocial to everyone and my group. The whole design has been made before the lockdown. Therefore, nothing has changed since then.

Regarding a group work, for me, it was my first student group project, where I have needed to work with people with different level of motivation, mentality and interpersonal skills. I have faced with communication problems, management work and by looking at results I cannot say I did well. Unfortunately, the effort I have made did not promote collaboration or team building. Hence, making me be a concern on my team working and management skills. In addition to this, I have realised the importance of having a good manager and the effect of a manager on the group. In conclusion, I can highlight that each member of a team needs to spend some of his working time towards team collaboration and that any team is as effective as the less effective member. Thus, helping that member will result in better team performance.

Bibliography

[1] Nick Bannon, Jimmy Davis, and Erin Clement. Axial flux permanent magnet generator. *University of Washington*, 2013. Accessed: 2020-04-30.

[2] Kostas Latoufis, Georgios Messinis, Panos Kotsampopoulos, and Nikos Hatziargyriou. Axial flux permanent magnet generator design for low cost manufacturing of small wind turbines. *Wind Engineering*, 36, 12 2012. Accessed: 2020-04-30.

[3] Hugh Piggott and John Blow. *How to build a WIND TURBINE*. 2003. Accessed: 2020-04-30.

[4] Oliver Probst, Jaime Martinez, Jorge Elizondo, and Oswaldo Monroy. *Small Wind Turbine Technology*. 04 2011. Accessed: 2020-04-30.

Appendix A: Additional material

Table 5.1: Bill of materials

	Dimension	**Material**	**Total price**
Generator			
Iron disc	60*5*60 mm(WHL)		
Shaft	8mm		0.8
Magnet holder		Acrylic	0.144
Connector		PLA	0.5
Socket set screw cone point	M4	Steel	4.87
Coils	24 AWG	Copper	0.23
Nuts	M4	Steel	0.23
Bolts	M4 35mm	Steel	
Epoxy			
Magnets	5*10mm (HD)	N52	20.95
		Total	**27.72**
Electronics			
Shottky diodes			0.93
DC/DC converter			4.68
Zenner diode 14V			0.41
Solid state relay			1.18
Smoothing capacitor			0.09
Fuse 1.5A			0.13
		Total	**7.42**