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To: Dr. Armin Eilaghi
From: CWC GEN
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Re: Finalized Testing Plan

I. Design Requirements Summary

The following Tables entail the Customer and Engineering Requirements (CR & ER), respectively, as well as descriptions of each.

Table 1. Customer requirements and descriptions

Customer Requirements		Description
CR1	Low Voltage	Client set safety standard
CR2	Small Size	Intended for a small-scale wind turbine
CR3	High power	To perform well in the CWC
CR4	Under Budget	Limited to funds and donations
CR5	Adaptable Kv and power	For future guideline changes and improvements, tip speed ratio and power curve required
CR6	Up to CWC design standards	Eligible to be used in competition
CR7	3 phase AC Generator	Standard efficient small scale generator design
CR8	Tip speed ratio of 7	Efficient ratio for small scale wind turbines

Table 2. Engineering requirements and descriptions

Engineering Requirements		Description
ER1	Maximum 48 Volts	CWC guidelines and safety purposes
ER2	45 cm rotor diameter	CWC guidelines for turbines
ER3	Low total resistance torque (Nm) (cogging torque)	Higher efficiency at lower wind speeds
ER4	Low Kv rating	Below 150 is desired for our design, this increases voltage
ER5	High turbine power output (W)	Based on max wind speed
ER6	Number of coils	Determined by stator geometry and fill ratio
ER7	Diameter of the coil	The gauge to be used in the coil
ER8	Cut out speed	Based on peak rpm that generates 48 V
ER9	Cut in speed	CWC guidelines and higher efficiency
ER10	RPM	Range based on Tip Speed Ratio
ER11	Current	From Power Calcs
ER12	Generator Torque	Power & RPM from Kv rating
ER13	Stator Skew	Based on Calcs of range
ER14	Small Scale	Diameter, Thickness, etc.

II. Top Level Testing Summary

Table 3. Test summary table

Experiment #	What is Tested	Relevant DRs
1	No load dynamometer sweep	CR1, CR5, ER1, ER3, ER4
2	Constant resistance dynamometer sweep	CR1, CR3, CR5, ER1, ER3, ER4
3	Constant current dynamometer sweep	CR1, CR3, CR5, ER1, ER3, ER4

III. Detailed Testing Plans

A. Experiment 1: No load dynamometer sweep

1) Summary

This experiment determines how much voltage the generator produces (CR1, ER1), how the Kv and power adapt with speed (CR5), how much resistive torque exists (ER3), and the Kv rating of the 3-phase PMSG (ER4). This experiment will require an Arduino Uno R3, three-phase AC-to-DC rectifier with voltage divider, infrared (IR) sensor, torque transducer, multimeter, and dynamometer. With these equipment, voltage, rotational speed, and torque will be measured to help quantify Kv rating from voltage and rotational speed, and resistive torque from the torque data over time.

2) Procedure

1. Mount the generator securely and connect its shaft to the dynamometer motor through the coupler (see Figure 1).
2. Connect the generator's three-phase output wires to a 3-phase AC-to-DC rectifier to convert AC voltage to DC voltage.
3. Wire the DC voltage output to the data acquisition (DAQ) system (see Figure 2).
4. Integrate the torque transducer, infrared (IR) sensor, and voltage divider with the DAQ system to measure torque, rotational speed, and voltage, respectively.
5. Connect an external power supply to the dynamometer motor (see Figure 3).
6. Verify all electrical and mechanical connections before testing.
7. Run the dynamometer motor and sweep the power supply input quasi-statically, collecting data points at each power step.
8. After reaching the maximum throttle input, stop the dynamometer.
9. Process the collected data to determine the Kv curve and calculate the resistive torque for the generator.

3) Results

This test will produce a linear relationship between rotational speed and voltage. The slope of this relationship determines the generator's Kv rating, given by

$$Kv = \frac{\omega}{V} \tag{1}$$

where ω is the rotational speed (RPM), and V is the voltage output of the generator (V).

Based on the design requirements, the expected K_v rating is below 150. Given the dynamometer's maximum speed of 5700 RPM, the expected K_v range is 117–150 RPM/V, corresponding to an output voltage of approximately 38–48 V according to (1).

Torque results will be analyzed to determine the resistive torque by viewing the amount of torque required to overcome internal friction and magnetic resistance before the generator begins to rotate. Because resistive torque can only be obtained experimentally, the results will report a measured range based on the torque data collected during the test.

4) Conclusion

The results from the no load sweeps will confirm whether the generator meets the design requirements for low Kv rating, maximum voltage, and minimal resistive torque.

B. Exp 2 & 3: Constant resistance and constant current dynamometer sweep

1) Summary

The loaded dynamometer sweeps follow the same procedure as the no-load test but include electrical loading to measure additional performance characteristics. These tests determine the Kv rating, peak voltage, resistive torque, electrical power, and mechanical power. The results will verify whether the generator achieves a low Kv rating (CR5, ER4), maximum voltage (CR1, ER1), low resistive torque (ER4), and high-power output (CR3). The setup includes an external motor to drive the generator, a torque transducer to measure torque, an infrared (IR) sensor to measure rotational speed, a Hall-effect current sensor to measure current, a 3-phase AC-to-DC rectifier to convert the generator output to DC, and a voltage divider to safely send voltage signals to the data acquisition (DAQ) system. Voltage and rotational speed data will be used to plot the loaded Kv curve. Torque and rotational speed will determine mechanical power, while voltage and current will determine electrical power.

2) Procedure

1. Mount the generator securely and connect its shaft to the dynamometer motor through the coupler (see Figure 1).
2. Connect the generator's three-phase output to a 3-phase AC-to-DC rectifier to convert AC voltage to DC voltage.
3. Wire the DC voltage output to the DAQ system (see Figure 2).
4. Integrate the torque transducer, IR sensor, current sensor, and voltage divider with the DAQ system to measure torque, rotational speed, current, and voltage, respectively.
5. Connect an external power supply to the dynamometer motor (see Figure 3).
6. Verify all mechanical and electrical connections before operation.
7. Sweep the power supply input quasi-statically, recording data at each power step.
8. After reaching maximum throttle, stop the dynamometer.
9. Process the collected data to generate the Kv curve, resistive torque curve, and mechanical and electrical power curves.

3) Results

The results will show a nonlinear relationship between rotational speed and voltage, from which the Kv rating can be determined using (1).

Torque data will reveal the resistive torque, indicating how much torque is required before the generator begins to rotate.

Mechanical power will be calculated from torque and rotational speed using

$$P_m = T\omega \tag{2}$$

where P_m is the mechanical power (W), T is the torque (N-m), and ω is the rotational speed (rad/s).

Electrical power will be determined from voltage and current using

$$P_e = VI \tag{3}$$

where P_e is the electrical power (W), V is voltage (V), and I is current (A).

4) Conclusion

The results from the constant resistance and constant current sweeps will confirm whether the generator meets the design requirements for low Kv rating, maximum voltage, minimal resistive torque, and high-power output.

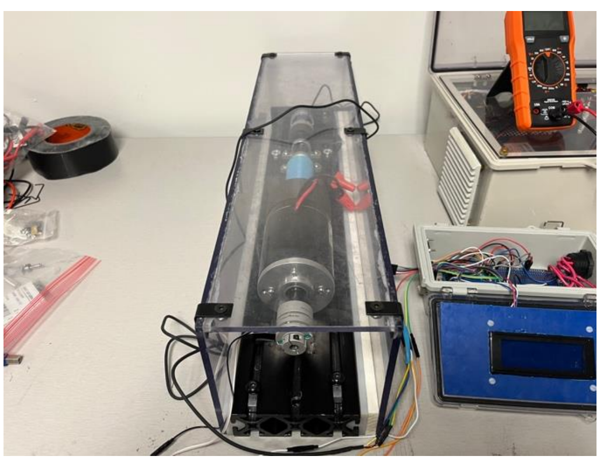

Figure 1: Dynamometer Setup

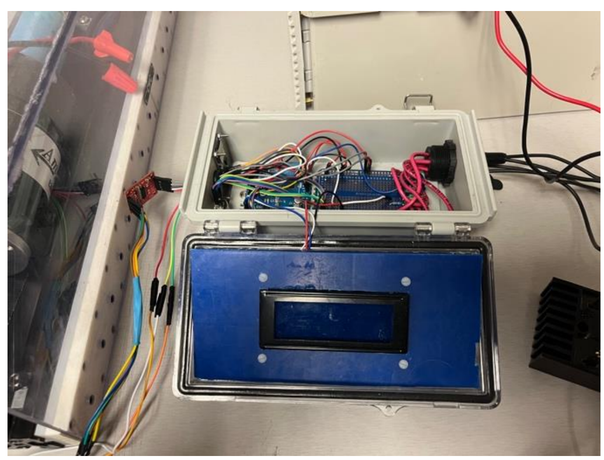

Figure 2: Data Acquisition system

Figure 3: The power supply to the dynamometer motor

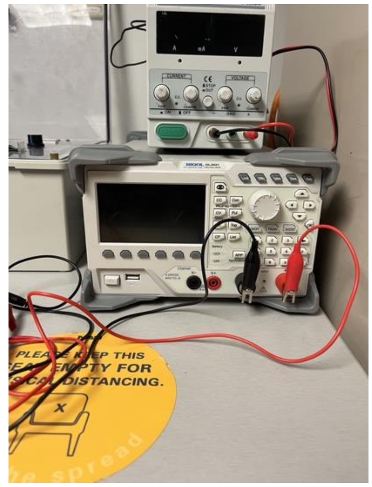

Figure 4: Programmable load

IV. Specification Sheet Preparations

Table 4. CR summary table

Customer Requirement	CR met? (Y/N)	Client Acceptable (Y/N)
CR1 – Low voltage		
CR2 – Small size		
CR3 – High power		
CR4 – Under budget		
CR5 – Ability to change Kv and power		
CR6 – Up to CWC design standards		
CR7 – 3 phase AC generator		
CR8 – Tip speed ratio of 7		

Table 5. ER summary table

Engineering Requirement	Target	Tolerance	Measured/Calculated Value	ER met? (Y/N)	Client Acceptable (Y/N)
ER1 – Maximum 48 volts	48 V	+/- 2 V			
ER2 – 45 cm rotor diameter	45 cm	+/- 1 cm			
ER3 – Low total resistance torque (Nm) (cogging torque)	20 N-mm	+/- 5 N-mm			
ER4 – Low Kv rating	125	+/-25			

ER5 – High turbine power output (W)	100 kW	+/- 25kW			
ER6 – Number of coils	6	+/- 2			
ER7 – Diameter of the coil	.483 mm	+/- .150 mm			
ER8 – Cut out speed	25 m/s	+/- 1 m/s			
ER9 – Cut in speed	3 m/s	+/- 1 m/s			
ER10 – RPM	5600 RPM	+/-100 RPM			
ER11 – Current	10 A	+/- 2 A			
ER12 – Generator torque	100 N-mm	+/- 20 N-mm			
ER13 – Stator skew	2 degrees	+/- 1 degree			
ER14 – Small scale	5in x 5in	- 2in x 2in			

V. QFD

Figure 6 is the Quality Function Deployment used in this testing process. The tested ERs will link to the CRs of low voltage, high power, and adaptable Kv. These CRs are linked since the tested ERs relate to obtaining voltage, acquiring the PMSG’s Kv rating, calculating the PMSG’s electrical and mechanical power.

House Of Quality			Technical Specifications (How)																
			Maximum 48 Volts	45 cm Rotor Diameter	Low Cogging Torque [Nm]	Low Kv Rating	High Power Output [W]	Number of Coils	Wire Gauge	Cut Out Speed	Cut In Speed	RPM	Current	Generator Torque	Stator Skew	Small Scale	Competitive Assessment		
	Customer Requirements (What)	Importance	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3
1	Low Voltage	100	9	3	9	9	9	9	9	9	9	9	9	3	3	1	1	9	3
2	Small Size	74	3	9	9	1	9	9	9	1	1	1	3	1	9	9	1	9	1
3	High Power	100	9	1	9	9	9	9	9	9	9	9	9	3	3	3	9	3	1
4	Under Budget	34	1	3	1	1	3	3	3	3	3	1	1	1	1	9	1	3	9
5	Adaptable Kv and Power	52	1	3	3	9	3	9	9	1	1	3	3	3	3	1	3	3	1
6	Up to CWC Standards	100	9	9	9	9	9	3	9	9	9	9	3	3	1	9	9	9	3
7	3 phase AC	48	3	3	3	3	1	9	3	1	1	3	9	3	3	3	3	9	9
8	70 m/s Tip Speed Ratio	62	3	9	1	3	3	1	1	9	9	9	1	3	1	9	9	9	9
		Target	48 V	45 cm	2 N-m	<150	100 kW	15 coils	23 AWG	25 m/s	3 m/s	5760-7200 RPM	23 A	2 Nm	2 degrees	1.18 in Diameter			
		Importance	38	40	44	44	46	52	52	42	42	44	38	20	24	44			

Figure 6: Quality Function Deployment