REPORT

Permanent Magnet Generator Performance Testing

This document was prepared by Advanced Energy.

January 23, 2014

advanced energy

Introduction

Permanent magnet (PM) motor technology is receiving increased attention due to promising performance features of the technology. A PM generator prototype invented by Joe Shepard of Franklin-Thomas Company (FTC) was delivered to Advanced Energy for testing. The goal of the test program is to determine the efficiency and performance features of the generator. This report presents findings of the test program.

Test Procedure

Test Setup

The generator (pictured below in Figure 1) is a polyphase permanent magnet generator with embedded rectifiers on one of the end rings. Therefore the output of the generator is DC. The machine was tested as a generator.

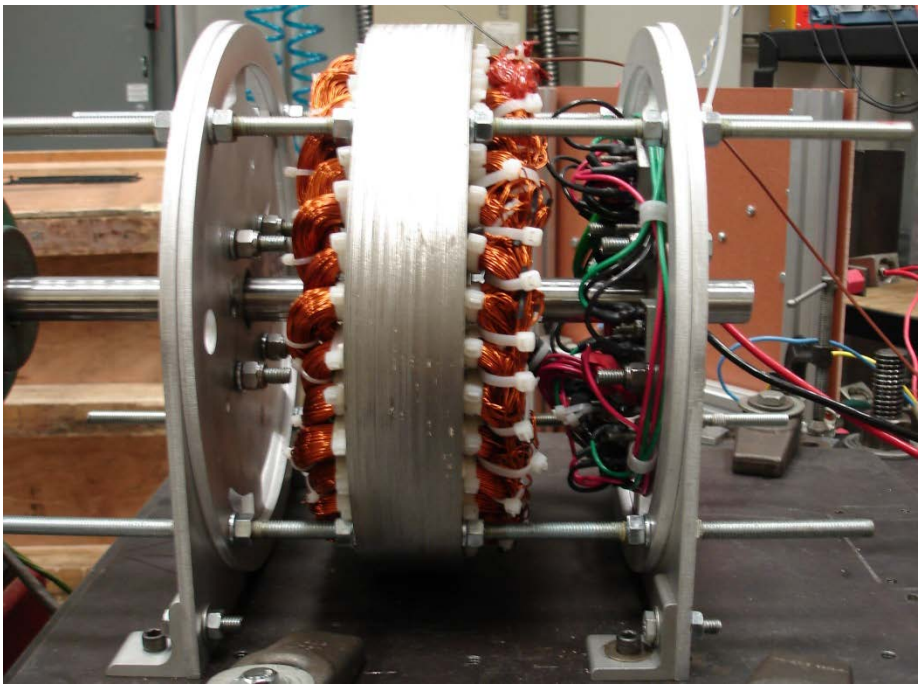

Figure 1: Permanent Magnet generator

Advanced Energy used an electric motor driven by a Variable Frequency Drive to control the generator. The output of the generator was connected to a Load Bank to dissipate the power generated by the machine. Torque and speed were measured at the shaft of the generator and considered the input power. Voltage and current were measured at the output of the generator and considered the output power. The efficiency of the generator was calculated by dividing the output power by the input power.

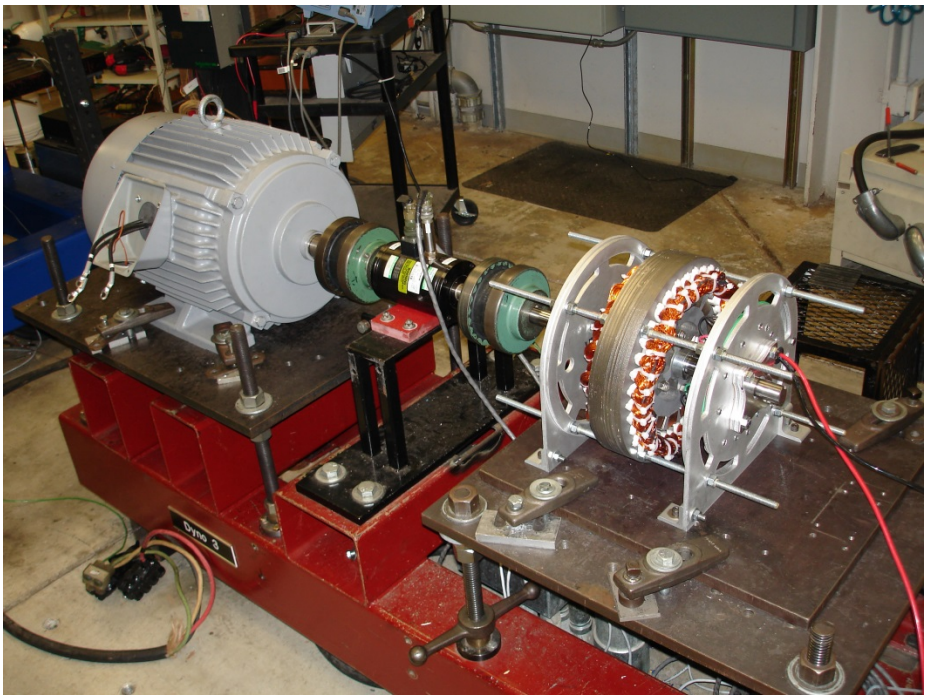

Figure 2: Permanent Magnet generator on dynamometer

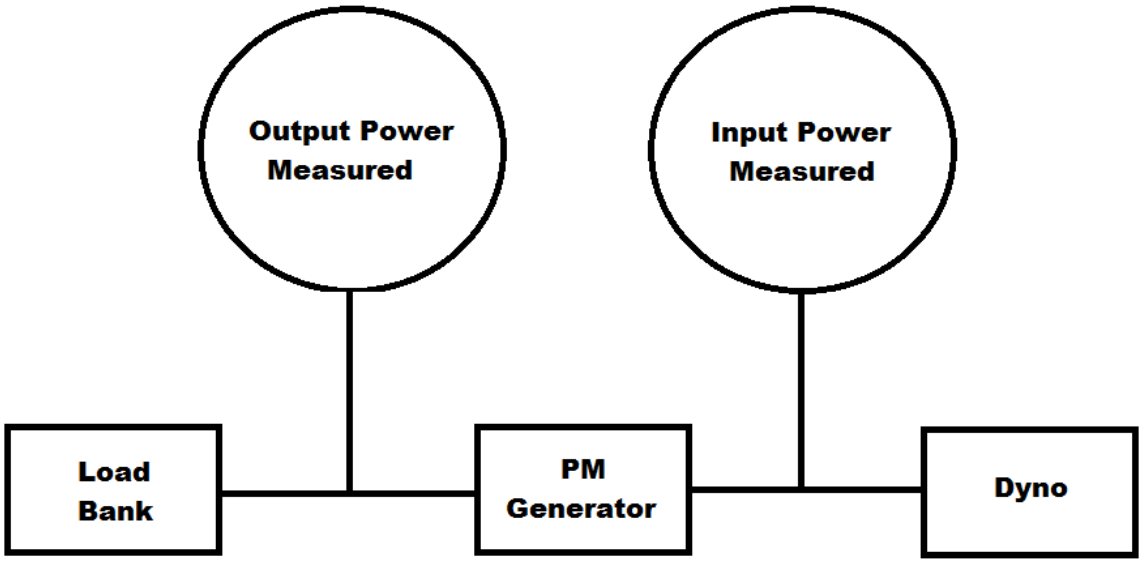

Figure 3: Schematic of the test setup

Open Circuit Test

The generator was initially spun with the output leads unconnected to load. The result is presented in the Figure 4.

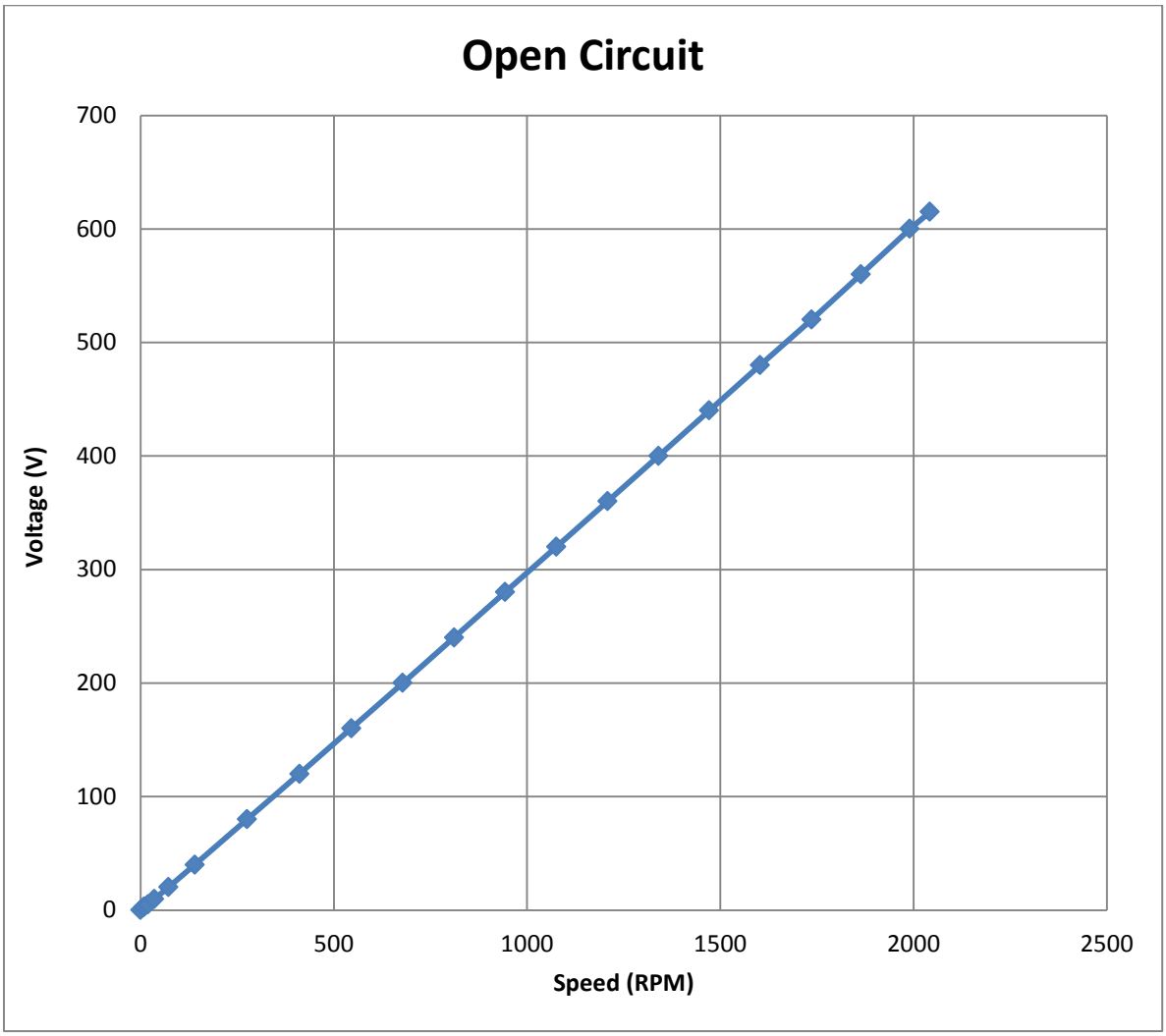

Figure 4: Voltage-speed characteristics at open circuit

Load Test

The generator was tested at a number of load and speed points. The exact rating and capability of the generator was not known prior to the test. However the inventor had proposed a maximum current of 66A and a test voltage not to exceed 600Vdc. A number of data points were taken within the specified voltage and current values. The data from the test is shown below in Tables 1-2 and plotted in Figs 5-8. The generator efficiency was calculated as output power divided by input power.

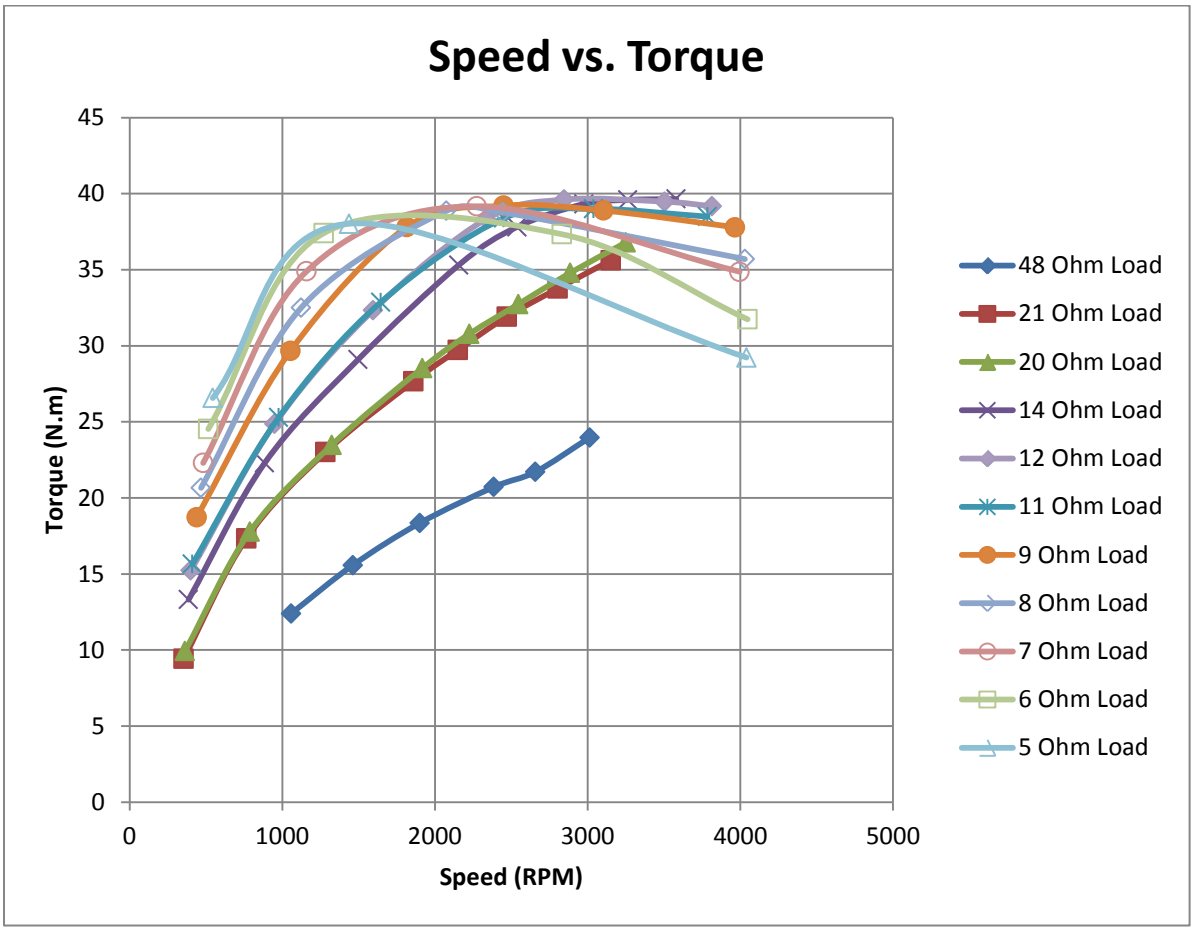

Figure 5: Speed vs. Torque at various Loads

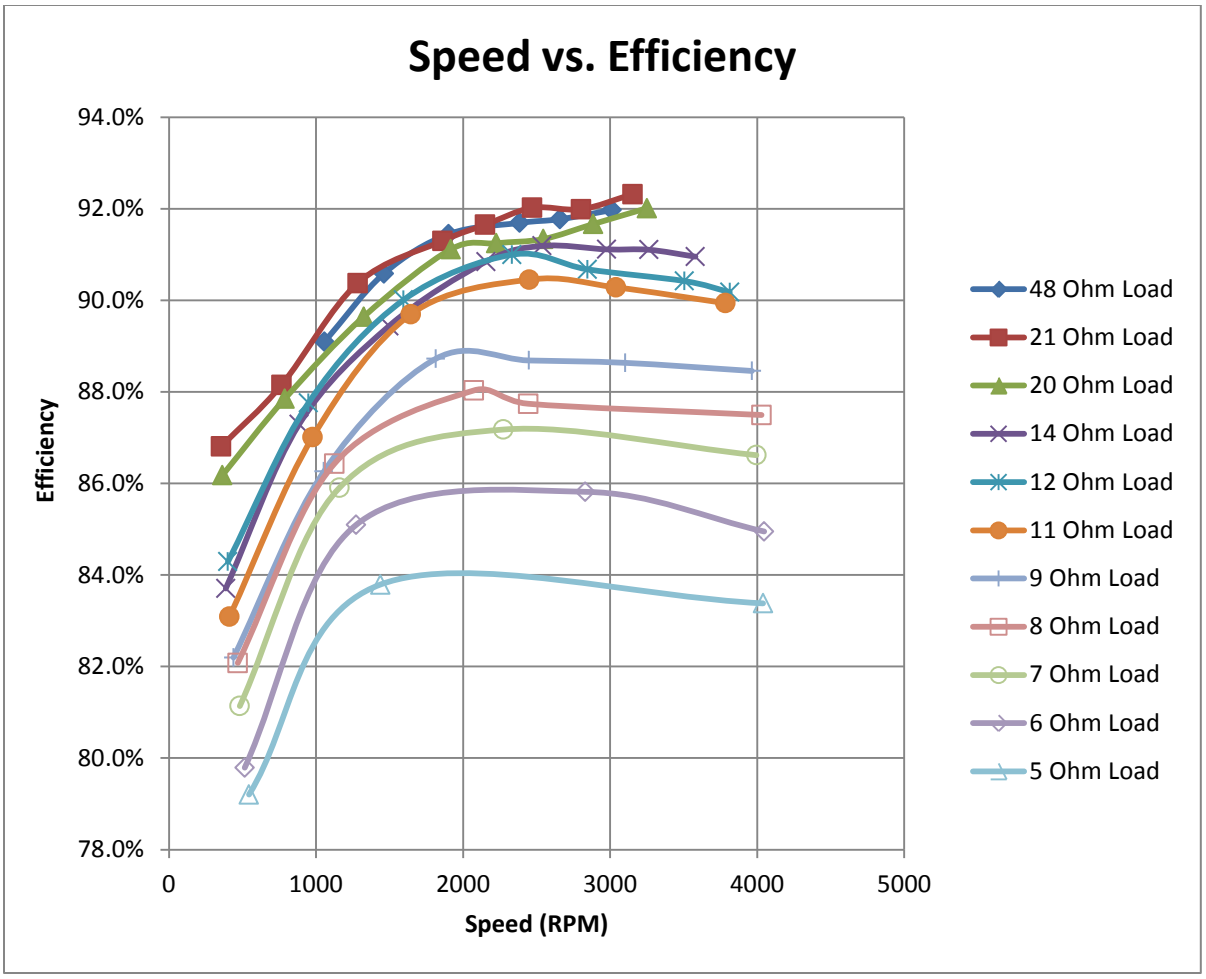

Figure 6: Speed vs. Efficiency at various Loads

From Figure 5, the maximum torque developed by the motor over the load range tested was about 40Nm. Also the maximum efficiency achieved within the tested load points is 92.3% as shown in Figure 6. At lower values of resistive load, the motor heated up more rapidly than at the higher values of load resistance.

Figure 8 shows the temperature rise (stator winding temperature minus ambient temperature) of the motor during the test program. The stator winding temperature measured by a thermocouple placed on the winding and the measured values are shown in the Tables 1-2.

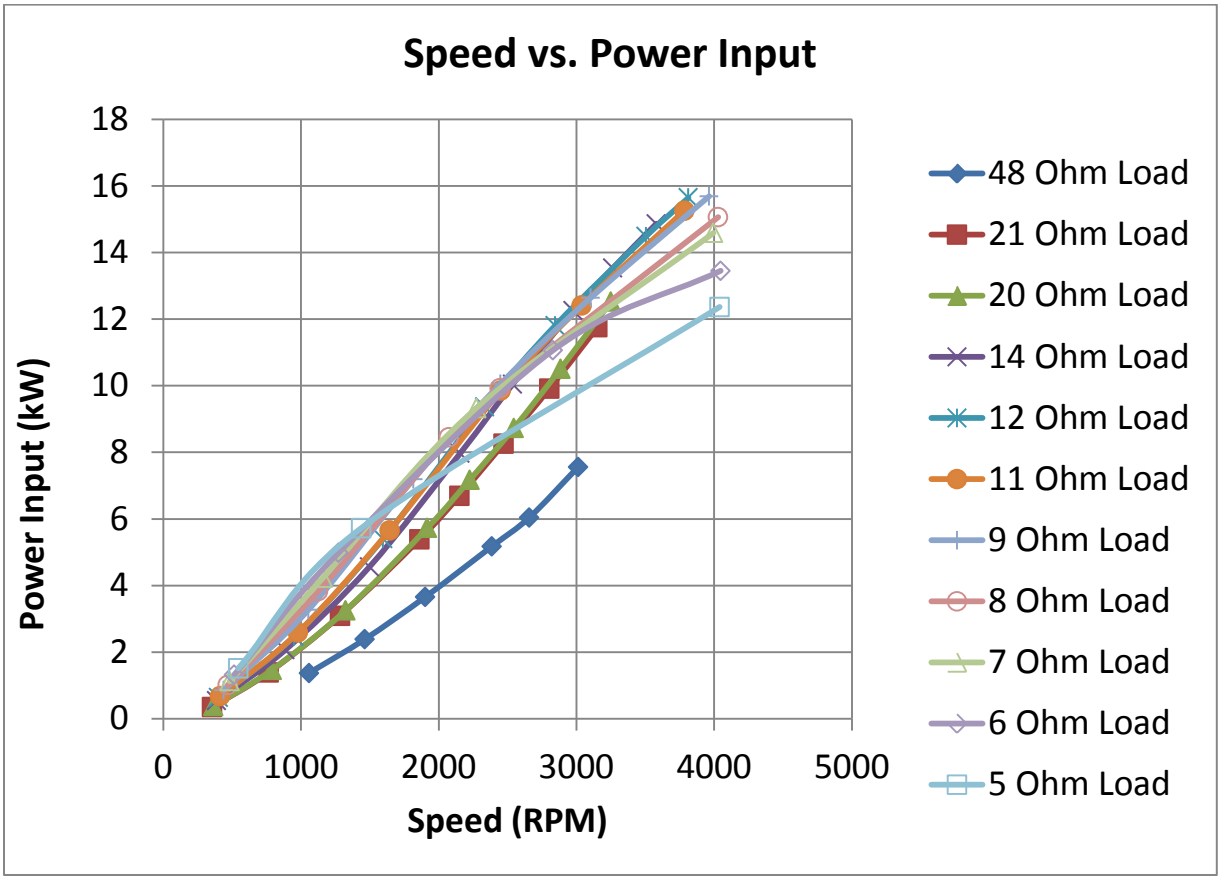

Figure 7: Speed vs. Power input at various Loads

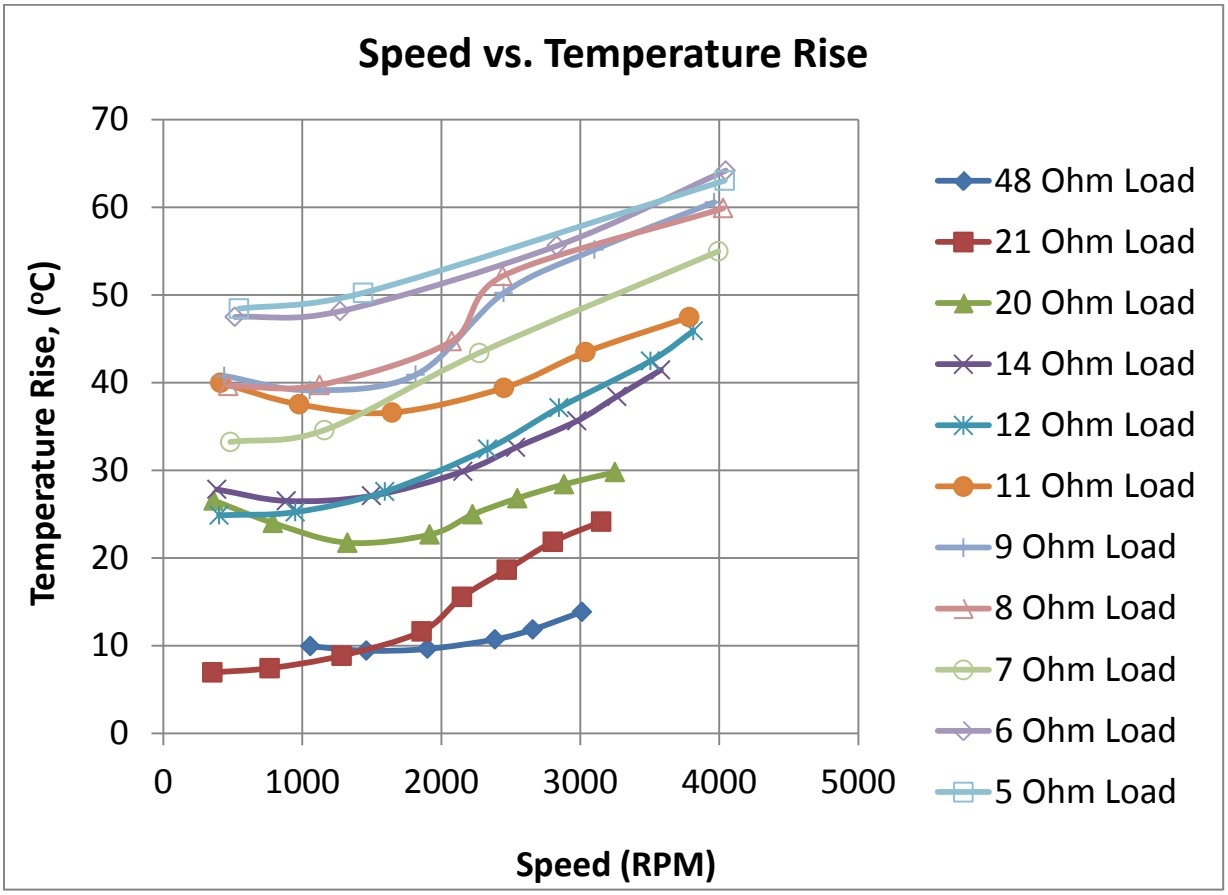

Figure 8: Speed vs. temperature rise over ambient at various Loads

Table 1: Test Data at resistive load range of 14 to 48 ohms

Load (Ω)	Speed (RPM)	Torque (N-m)	Power In (W)	Current (A)	Voltage (V)	Power Out (W)	Efficiency (%)	Ambient (°C)	Stator (°C)
48	1057	12.4	1371.8	5.1	239.9	1222.2	89.1%	23.7	33.7
	1462	15.6	2384.6	6.8	319.9	2160.1	90.6%	23.9	33.3
	1901	18.4	3654.3	8.3	400.2	3341.7	91.4%	23.9	33.5
	2386	20.7	5175.3	9.9	479.9	4745.3	91.7%	23.7	34.4
	2658	21.7	6042.9	10.7	519.9	5545.6	91.8%	24.1	36.0
	3012	24.0	7558.8	12.5	557.0	6952.0	92.0%	24.1	37.9
21	354	9.4	349.1	3.8	80.0	303.0	86.8%	22.6	29.5
	765	17.3	1389.0	7.6	160.0	1224.4	88.1%	22.9	30.4
	1283	23.0	3091.0	11.6	240.1	2793.5	90.4%	23.9	32.8
	1860	27.7	5387.1	15.4	319.9	4918.2	91.3%	24.3	35.9
	2150	29.7	6694.1	17.0	359.6	6135.2	91.7%	23.8	39.4
	2471	31.9	8256.7	19.0	399.6	7597.9	92.0%	23.9	42.5
	2803	33.8	9910.2	20.7	439.8	9116.4	92.0%	24.0	45.8
	3152	35.6	11755.5	22.6	479.5	10852.4	92.3%	24.2	48.4
20	363	9.9	377.1	4.1	79.9	325.0	86.2%	23.5	50.0
	788	17.8	1467.5	8.0	160.3	1289.2	87.9%	23.6	47.6
	1324	23.5	3255.0	12.2	239.7	2917.8	89.6%	24.8	46.5
	1917	28.5	5727.5	16.3	319.9	5218.6	91.1%	24.6	47.2
	2226	30.8	7175.9	18.2	359.9	6547.8	91.2%	23.8	48.8
	2547	32.7	8733.0	19.9	399.9	7976.6	91.3%	23.8	50.6
	2885	34.8	10510.2	21.9	439.5	9634.2	91.7%	24.0	52.4
	3250	36.8	12521.1	24.0	479.6	11520.9	92.0%	24.1	53.9
14	386	13.3	538.4	5.6	80.2	450.7	83.7%	22.6	50.4
	885	22.3	2067.1	11.3	159.7	1804.4	87.3%	22.9	49.4
	1497	29.1	4561.8	17.0	239.9	4080.0	89.4%	23.6	50.7
	2155	35.3	7967.7	22.6	319.8	7238.2	90.8%	23.5	53.3
	2537	37.8	10046.5	25.4	360.5	9161.3	91.2%	23.5	56.1
	2976	39.3	12256.9	28.0	399.0	11167.5	91.1%	23.8	59.5
	3263	39.6	13529.7	29.4	419.5	12326.1	91.1%	24.1	62.5
	3580	39.7	14864.2	30.8	439.2	13519.4	91.0%	24.1	65.5

Table 2: Test Data at resistive load range of 5 to 12 ohms

Load (Ω)	Speed (RPM)	Torque (N-m)	Power In (W)	Current (A)	Voltage (V)	Power Out (W)	Efficiency (%)	Ambient (ºC)	Stator (ºC)
12	401	15.2	639.2	6.7	79.9	538.8	84.3%	21.9	46.8
	949	24.9	2471.7	13.5	160.0	2169.2	87.8%	22.7	47.9
	1595	32.3	5400.1	20.3	239.9	4860.6	90.0%	23.7	51.3
	2333	38.3	9366.5	26.6	319.8	8523.3	91.0%	23.1	55.6
	2846	39.6	11806.2	29.7	359.9	10705.5	90.7%	23.6	60.7
	3505	39.5	14487.2	32.8	399.4	13099.5	90.4%	24.0	66.5
	3813	39.2	15644.2	34.0	414.8	14107.8	90.2%	24.0	69.9
11	411	15.6	674.1	7.0	80.0	560.1	83.1%	22.2	62.1
	977	25.3	2587.6	14.1	160.0	2251.5	87.0%	22.4	59.9
	1644	32.9	5657.6	21.1	240.0	5074.6	89.7%	23.5	60.0
	2450	38.4	9850.2	27.9	319.8	8909.7	90.5%	23.3	62.7
	3039	39.0	12411.3	31.2	359.6	11205.3	90.3%	23.6	67.1
	3784	38.5	15252.7	34.3	399.3	13717.9	89.9%	24.1	71.6
9	439	18.7	860.9	8.8	80.0	707.6	82.2%	21.9	62.6
	1054	29.7	3274.8	17.7	159.8	2824.9	86.3%	22.8	62.0
	1816	37.8	7188.6	26.5	240.2	6378.1	88.7%	23.5	64.4
	2449	39.2	10056.2	31.3	284.7	8918.4	88.7%	23.6	73.8
	3103	38.9	12637.4	35.1	319.4	11201.0	88.6%	23.7	78.9
	3964	37.8	15689.2	39.0	356.1	13878.1	88.5%	24.0	84.6
8	468	20.7	1012.3	10.4	80.2	830.9	82.1%	22.1	61.7
	1124	32.5	3826.4	20.7	159.9	3307.1	86.4%	23.4	63.1
	2075	38.9	8446.6	31.0	240.0	7435.8	88.0%	23.6	68.3
	2443	38.8	9917.6	33.5	259.9	8701.7	87.7%	23.5	75.7
	4029	35.7	15062.7	41.1	320.5	13179.1	87.5%	23.7	83.6
7	482	22.3	1124.6	11.4	80.1	912.5	81.1%	21.5	54.7
	1159	34.9	4235.4	22.7	160.0	3638.4	85.9%	23.1	57.7
	2273	39.2	9325.0	33.9	239.7	8129.2	87.2%	23.1	66.5
	3994	34.9	14586.5	42.1	299.8	12634.4	86.6%	23.9	78.8
6	515	24.5	1323.4	13.2	80.0	1055.9	79.8%	22.2	69.7
	1273	37.4	4986.4	26.5	159.9	4243.2	85.1%	23.2	71.3
	2830	37.3	11064.8	39.5	240.1	9495.4	85.8%	23.5	79.1
	4047	31.7	13452.2	43.3	263.8	11427.6	85.0%	24.4	88.5
5	544	26.6	1514.2	15.0	79.9	1199.3	79.2%	21.8	70.2
	1438	38.0	5725.6	30.0	159.7	4797.5	83.8%	23.3	73.5
	4040	29.2	12365.3	44.0	234.5	10310.2	83.4%	24.0	87.0

Cogging Torque

The cogging torque of the generator was measured at zero excitation to determine cogging characteristics. The generator was rotated at low rpm (about 3-rpm) to measure the dynamic characteristics, acquired through a high speed data acquisition system. This measurement was compared to another measurement of cogging taken by hand spinning the rotor while the torque was recorded. The dc offset about was 0.2Nm. The cogging torque characteristic is presented below in Figure 9. The rotor was not held in position, therefore the plot references measured data points rather than rotor position.

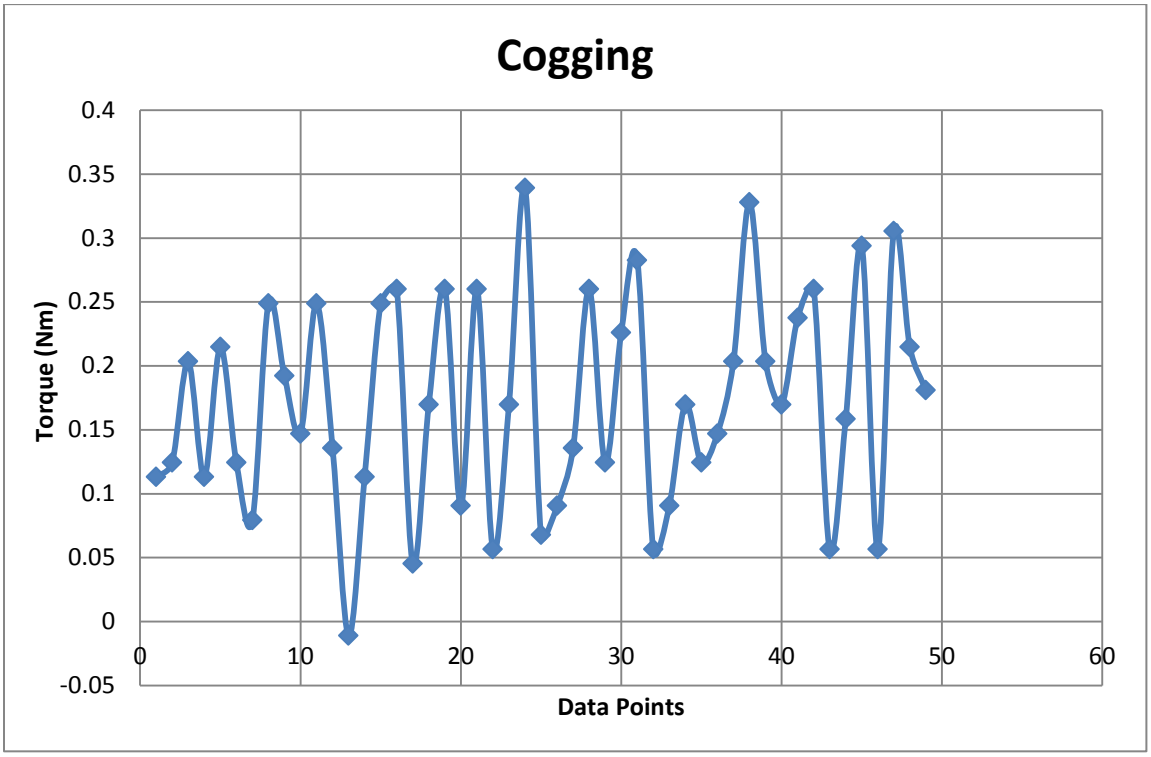

Figure 9: Cogging torque measurement

Conclusion

A permanent magnet generator prototype invented by Joe Shepard of Franklin-Thomas Company (FTC) was delivered to Advanced Energy for testing, to determine the efficiency and performance features of the generator. The generator has embedded rectifiers and therefore its output is DC. The machine was tested as a generator and no test in the motoring regime was carried out. The output of the generator was connected to a Load Bank and measurements were performed at varying resistive loads from 5-ohm to 48-ohm.

The maximum torque developed by the motor over the load range tested was about 40Nm and the maximum efficiency developed within the range is 92.3%.