Confirmation of Electrical Power Production

Using Johnson Fresnel Lens in the Field Coupled to a Sterling Engine

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Background

The quest to replace perishable fossil fuels with renewable energy sources has long been understood as critically important for the short and long-term survival of human family. Work in this area has been undertaken in the development of many different technologies, from hydro energy, to wind and solar.

In the solar branch of the renewable energy family, there are two sections, solar process heat systems and photovoltaic (PV). Solar process heat systems either trap sunlight directly, as in a greenhouse with a heat sink, or the systems concentrate solar energy to a higher temperature and use that heat energy to do work such as heat water for washing or cooking, or to heat water into steam to heat buildings or to drive mechanical systems. Many of these systems use other fluids beside water to extract work at lower or higher temperatures. Solar hot water heaters are some of the most common solar process heat technology machines currently in use and have a history reaching back more than half a century. Solar concentrators have also been around for a very long time. Generation of electricity from either gas turbine, steam engine, sterling engine, or photovoltaic systems have also successfully been used with solar concentrators in the solar process heat branch of the renewable energy family.

Solar concentrators creating solar process heat, typically fall in two major groups, reflectors and lenses. Reflectors typically use mirrors or reflective surfaces often set up with a parabolic curve, to focus the sunlight to a target. The target will then receive as much light as several suns shining directly on the target. In larger systems, the equivalent of a hundred suns or more can be achieved, and that heat can then be used to do some work, whether that is heating water or other fluids or ultimately producing electricity.

The second type of solar concentrator uses lenses. In the case of lenses, the light passes through the lens and is focused on a smaller area. The lens can again create many to even a hundred suns worth of solar process heat energy in one small location. This difference in temperature can then be engaged to do work.

There are a couple of types of lenses that have been successfully used for concentrating sunlight. Full convex lenses are circular and can focus all of the light passing through them to a single point. In the 1750's Joseph Priestly, a scientist, chemist, and writer, used sunlight and a moderately sized convex lens to decompose mercury oxides to isolate pure oxygen, among many other concentrated sunlight experiments. A vivid demonstration of this type of solar lens effectiveness is shown in science videos from the 1970s showing an 8" steel I beam being cut by the sunlight as it is swung through the focal point of a 4-foot diameter convex lens. It melts instantaneously as if hit with a very large cutting torch.

The problem with this type of lens is that large versions of it are very heavy and very expensive to make. A second type of convex lens, that can be built from a relatively thin sheet of glass or plastic is called a Fresnel lens. This type of lens is built by creating rings in the sheet, each ring has a slightly different pitch, again designed to focus the light to a center point.

Fresnel lenses have been successfully used in solar research projects just like full convex lenses. Up until recently, they were also expensive to make although much lighter than full convex lenses.

This current study falls under the solar process heat branch of the renewable energy family dealing specifically with Fresnel lenses. The lenses used in this study were developed and patented by Mr. Neldon Johnson, and show significant promise in reducing the cost of solar process heat by lens concentration.

Design Objectives

Convex lenses, while very effective, are not often used to capture solar process heat energy. This is due to cost and weight issues. Even Fresnel lenses can be very expensive. Mr. Johnson has succeeded in developing a Fresnel lens which is much less expensive and lighter weight. The objective of lower cost, and lower weight, means that capital investment in these heat systems is less and therefor a critical technology to consider in the development of solar process heat systems.

The design objectives for the Johnson Fresnel lens are:

Mass producible

Low cost

Breakaway in high wind to prevent tower damage

Effective in concentration of sunlight

Have adjustable focal point and pattern depending on desired target shape and temperature

Solar Process Heat

The Johnson Fresnel lens can be used to generate solar process heat and have undergone preliminary testing on the following:

Hot water

Water has been pumped through copper coil targets producing live steam.

Liquid Salt

The lenses have been used to melt salt to a molten state for use in heat storage systems.

High Temperature Oil

The lenses have been used to heat high temperature oil to 700°C. The high temperature oil can then be used to boil water in a heat exchanger.

Dilute Sulfuric Acid

The Johnson lens has been used to boil water out of dilute sulfuric acid. This system allows the storage of heat indefinitely. (When water is added to the sulfuric acid, an exothermic reaction occurs producing heat when needed. This system can be used to keep hydroponic plant systems warm during winter months with energy gathered in summer months, eliminating the need for natural gas or coal heating).

Electrical Generation

Beside the use of solar process heat for heating or cooling buildings directly, another use is the creation of electricity. There are many ways of creating electricity from solar process heat, this including:

Steam Engine

The very first public power station was the Pearl Street Station in New York City, where Thomas Edison first created electricity using a steam engine coupled with a generator and his invention, the light bulb, to light a city block of tenements. The solar process heat from the Johnson Fresnel lens can be used to drive a small steam engine and alternator as well, even on a similar size to the first stage commercial power generation, the Pearl Street Station.

Steam Turbine

Solar process heat can also be used to drive steam turbines. The steam turbine is currently the work horse in producing electricity worldwide.

Concentrated PV

While photovoltaic cells are the most common of all renewable energy electricity producers, they are relatively inefficient. In other words, the surface area required to produce a given amount of electricity is large compared to the actual sun energy delivered to the space. It takes a lot of area for a small amount of power production. They are also relatively expensive.

Concentrated PV uses lenses or reflectors to deliver more sun light to a given PV cell. If the cell has cooling, this system allows the cell to produce larger amounts of current and at the same time allows the capture of solar process heat in the coolant allowing the hybrid system to improve total energy capture significantly over PV alone. The Johnson Fresnel lens has been used to drive some preliminary concentrated PV tests with cells.

Sterling Engine

The Sterling engine is a Rankine Cycle engine that uses heat to expand a gas driving a piston, rather than an internal combustion explosion to drive the gas expansion and piston. These engines have been around for more than 100 years and have become more efficient and effective in the last 30 years. They are currently used as replacements for diesel engines in remote generation sites as they require no maintenance for 25 or more years. They are effective at simply converting solar heat directly into electricity.

This study used a Sterling Engine, built by Inifinia. The model, “Colorado”, was designed to specifically work with a solar collection system called “Power Dish” a reflective lens system. In this study, Johnson’s team used the Johnson Fresnel lens to concentrate the light, rather than reflective mirrors.

Study Objective

The objective of this study is to show that the Johnson Fresnel lens system can be used to generate enough process heat to generate electricity using a Sterling Engine system.

Study Set Up

The Johnson Fresnel lenses were mounted on their tower. Each lens is roughly triangularly shaped, like a pizza slice and when combined with other pieces makes a full circle.

For this test each individual piece captured about 18.5 square feet of area.

15.5 individual pieces were assembled to complete the entire circle. The combined pieces have the following coverage:

18.5	Sq. ft
15.5	Lens Units
286.75	Sq. ft
26.6	Sq. meters

The circle of lenses were mounted to the Johnson Lens Tower, which allowed the lenses to be turned to face the incoming sunlight. The "Colorado" Sterling engine was mounted to the target receiver holder and a small parabolic reflector added as a collar around the head of the sterling engine.

The "Colorado" was hooked up to its controller and the load was wired to an Onics 35 Ohm, 6 kW resistor to act as the load for the test.

Figure 1: Name Plate of Load Resistor

Study Data Acquisition

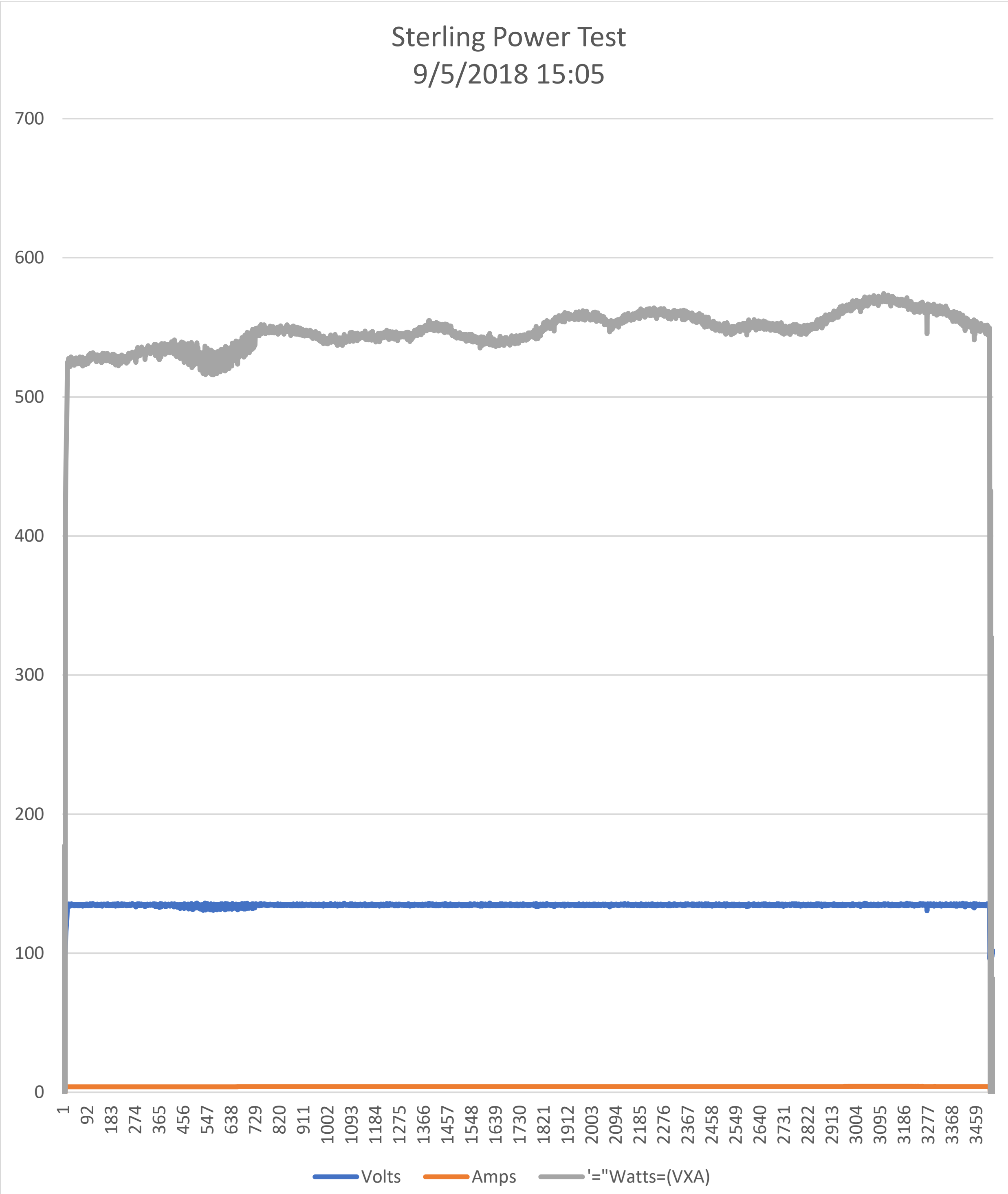
The manufacturer, Infinia, built sensors into the "Colorado" to allow the controller to monitor performance. These sensors reported to a controller and data was recorded for review. Various data points include generator volts, amps, whether the system is running and producing power, an algorithm of head temperature, and various operational data points, such as cooling pump information, etc.

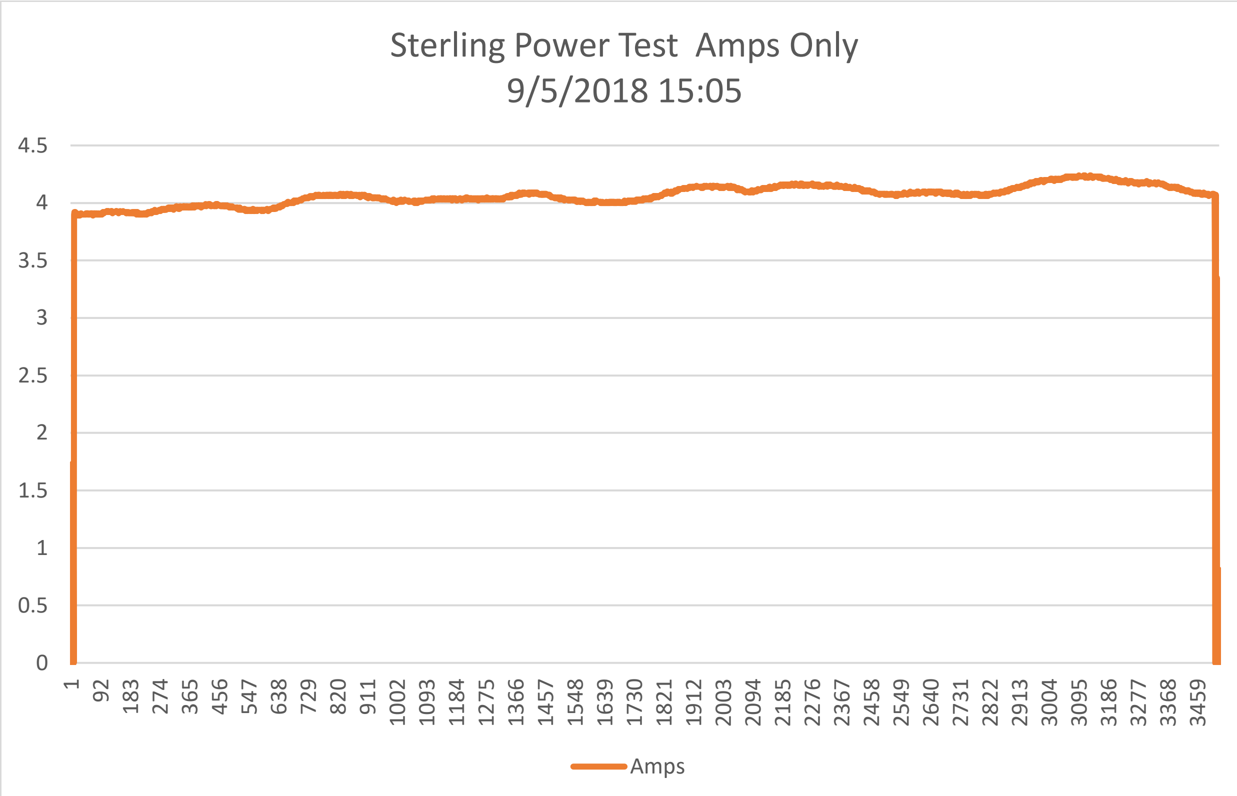
Statements from Sterling Engine Manufacturer

The Infinia assets were purchased by the company Qnergy which continues to build Sterling Engines for remote power systems. Infinia and Qnergy have been building Sterling Engine Generators for more than 30 years. Engineers familiar with the "Colorado" solar model were available for questions and informed the researchers that the volt and amp sensors were accurate to within about 2%, certainly closer than 5%. The Infinia engineers also informed this research team that the watts as reported in the data was a calculation, not from the sensors, and was based on variables and constants not sensors. They also explained that the "Colorado" can be tuned to the actual temperature conditions by adjusting the gas pressure and adjusting variables in the control system to optimize the efficiency and performance of the machine. This particular unit, used in this study, was not tuned to the available solar heat conditions and currently running in a "safe" mode. Additional tuning of the "Colorado" or using Qnergy's new current production model, the QE 80, may allow the system to capture more of the available solar energy in ongoing development.

Data

See Appendix A for data output. The charts in this section show watts produced based on Volts * Amps.





Electrical Definitions and Background Calculations

Basic Electrical Definitions

Amps Volts and Ohms

In the early 1800's chemists and early electrical engineers began to develop definitions that are still used today to describe electrical properties and characteristics. For this study the following definitions are noted as they are used in the calculations and data:

Amps

Amps is basically the amount of current that is flowing. When thinking of electricity moving in a wire one can use the analogy of water moving in a garden hose. Amps represents the gallons per minute moving in the hose.

Volts

Volts is electron pressure. In the garden hose analogy, volts is similar to water pressure or PSI, (pounds per square inch).

*V=I*R or Ohm's Law*

This formula notes that Voltage = Amps x Resistance.

Definition of Power or Work

For electricity to do useful work, either one needs a high voltage and at least a little electrical flow, amps, or we need a lot of flow and at least some pressure, volts. When one has both pressure and flow, or volts and amps, work can be done. This relationship is described in the following foundational formula.

*Volts*Amps=Watts*

The larger the watts number, the more work that can be done.

1000 watts is called 1 Kilowatt. 1 Kilowatt by definition = 1.34 Horse Power = 3,415 British Thermal Units (BTU) produced in 1 hour. This is enough heat to boil 3.54 lbs. of water or about 1/3 gallon of water in 1 hour.[1]

Back Ground Calculations

The following calculations look at potential solar process heat available to the system as well as expected and actual performance.

[1] Machinery Handbook 23, Industrial Press Inc. NY, pg. 2440

1	Lenses			
1.1	On the Test the lenses are:	18.5	sq ft	
1.2		15.5	units	
1.3		286.75	sq ft	
1.4		0.0929	meter/sq ft	
1.5		26.6	sq meters	
2	Average Energy Capture Available at			
2.1		7.2	kWh/m^2/day	Based on Solar Data for Delta
2.2	Average Sun Hour per Day.			
2.3	Sunrise	7:09	AM	
2.4	Sunset	7:45	PM	
2.5	Total Sun Span	12.5	hours	
2.6	Hours of Significant Contribution	10		80% of the hours create most of the contribution
2.7	Average Per Hour	0.72	kWh/m^2/hr	
3	Potential Energy Capture			
3.1	Per Set of Lenses	19.18	kwatts	This is if the lenses were 100% efficient
3.2	Lens Capture Efficiency	50%		
3.3	Energy Available at Lens Efficency	9.59	kwatts	
4	"Colorado" Sterling Engine Efficiency	28%		Based on Designers Statement
4.1	Efficieny Untuned in Lower Curve Portior	6%		"Colorado" while available is not the perfect size match.
4.2	Potential Electrical Output from "Colorado"	0.537061	Kwatts	
5	Equivalent BTU Capture in Water			
5.1	Energy Available	9.59	kwatts	
5.2	Time to Boil Away 1 Gallon of water			
5.3	at 1 kwatt	3.54	lbs H2O Evap/Hour	
5.4	With Available Energy	33.94993	lbs H2O Evap/Hour	
5.5		8.34	lbs H2O/Gallon	
5.6	Total Water Boiled off in 1 hour	4.070735	5 Gallons	

The following calculations look at the reasonableness of the data. Using the formula, Volts = Amps * Ohms, to confirm that the data and the resistor make sense.

	Volts	Amps	Watts Calc		
9/5/2018 15:58	134.81	4.24	571.5944		
	Volts at Generator			134.81	Volts
	Amps at Generator			4.24	Amps
	Load Resistance			35	Ohms
	Forumula Definition				
		V=I*R		148.4	Volts
		Controler Loss		9%	
So based on losses through the controler, it is resonsnable.					

Thus, the data check shows that voltage, amps, and resistance are balanced within 9%. From this one can concluded that data points are realistic, and it therefore follows that the watts calculation makes sense.

Conclusion

Clearly, by the most basic definitions of electrical power, the Johnson Fresnel lens system produces enough solar process heat to run a Sterling engine and produce electricity. Selecting a Sterling engine sized for this application and tuning the engine - generator will likely improve performance.

Researchers

Johnny Kraczek MET

Johnny Kraczek is a 30 year senior engineer and technologist with extensive experience in mechanical, manufacturing, automation, process and renewable energy engineering projects. He has worked on renewable energy missions internationally and has lead extensive research directed toward solving the energy problems of islands in the Pacific and Caribbean. As a speaker on renewable energy and sustainable energy systems, he has presented at US energy gatherings, and spoken at conferences in India and presented to 33 central and south American Nations delegates at a Central America Conference sponsored by the United Nations in the Dominican Republic.

Jeffery Jorgenson EE PE

Jeff Jorgensen has over 34 years of experience in the design and operation of electrical distribution systems, instrumentation and process control systems. He possesses a high level of knowledge in electrical power engineering with strengths in electrical studies including load flow, voltage drop, short circuit, protective device coordination and arc flash.

Kerm Jackson ME PE

Kerm Jackson, a Senior Mechanical Engineer has nearly 40 years of mechanical engineering experience working on both renewable energy projects, industrial and complex DOD cleanup projects.

Paul Freeman MFET

Paul Freeman is a Manufacturing Engineer and Technical Writer with significant experience in cutting edge renewable energy technology and it's manufacturing process.

Appendix A

Test Data Notation

The test data is delivered from the controller in a Comma Delimited File with the following headings of interest (and more):

Date/Time	Drive Voltage (VDC)	Current (A_rms)	Power (W) – (Algorithm)	Heater Head Temp (degC)	Heater Head Temp Setpoint (degC)	Generator Voltage (ADC Counts)	DC Voltage (VDC)	Hall Sensor Counter	Generator State	Pump Set Speed	Pump Actual Speed

For this study, the columns of interest are:

Date/Time – Recording the moment the data was sampled

Drive Voltage – This is the voltage coming off of the "Colorado" Sterling generator

Current (A_rms) – This Amperage pushed out by the generator

Power Watts – Algorithm – This number is not the watts generated by the Sterling Engine, but power calculated from the head temperature algorithms. The "Colorado" Engineers note that this number as well as the head temperature is based on variables and constants set up during the Infinia Power Dish use, so they are specific to a different application. Therefore this number not used in this study.

Generator Voltage (ADC Counts) – Is actually not a voltage but a number representing cycles and it is not used.

DC Voltage (VDC) – This number represents the voltage coming out of the controller on its way to the resistor.

Generator State – This column of data tells declares when the engine is not running, warming up, or running.

"None" means the motor is not yet exposed to sun heat. As the lenses are brought into alignment with the sun, the sterling starts to receive some process heat and begins "BUMPING". Once the heat reaches a level that the unit can produce power the status changes to "RUNNING".

The remaining columns in the data are extraneous to this study.